www.amegroups.com

AME Publishing Company

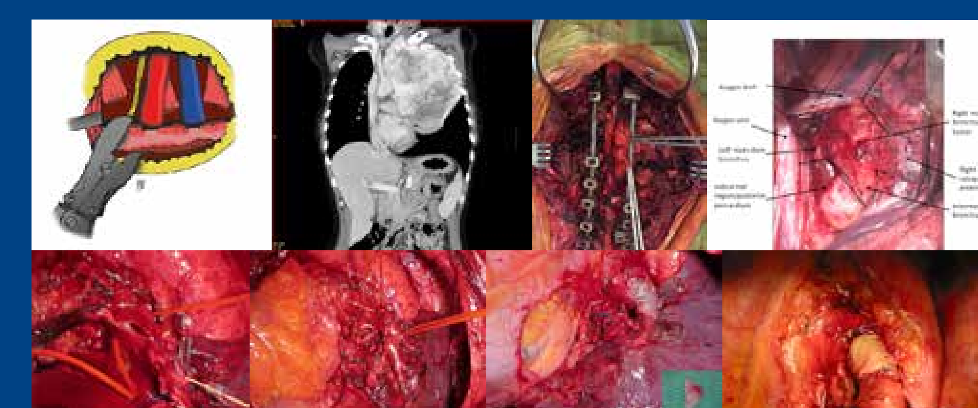
1A032

OPEN THORACIC SURGERY

Marco Scarci,
Alan D. L. Sihoe,
Benedetta Bedetti

OPEN THORACIC SURGERY

Marco Scarci, Alan D. L. Sihoe, Benedetta Bedetti



AME Publishing Company

Open Thoracic Surgery

Marco Scarci, Alan D. L. Sihoe, Benedetta Bedetti

AME
Publishing Company

AME Publishing Company

Room C 16F, Kings Wing Plaza 1, NO. 3 on Kwan Street, Shatin, NT, Hong Kong

Information on this title: http://book.amegroups.com
For more information, contact books@amegroups.com

First published in 2017
Printed in China by AME Publishing Company

Marco Scarci, Alan D. L. Sihoe, Benedetta Bedetti

Open Thoracic Surgery (Hard Cover)

ISBN: 978-988-77840-5-0

Open Thoracic Surgery
(FIRST EDITION)

EDITORS

Marco Scarci
Department of Thoracic Surgery, University College London Hospital, London, UK

Alan D. L. Sihoe
MBBChir, MA(Cantab), FRCSEd(CTh), FCSHK, FHKAM, FCCP Clinical Associate Professor, Department of Surgery, The University of Hong Kong, Chief of Thoracic Surgery, The University of Hong Kong Shenzhen Hospital, Shenzhen, China; Guest Professor, Department of Thoracic Surgery, Tongji University, Shanghai Pulmonary Hospital, Shanghai, China; Honorary Consultant, Department of Surgery, Queen Mary Hospital, Hong Kong

Benedetta Bedetti
Department of Thoracic Surgery, Malteser Hospital, Von-Hompesch-Str. 1, 53123 Bonn, Germany

AUTHORS

John Agzarian
Division of Thoracic Surgery, Department of Surgery, Faculty of Health Sciences, McMaster University, St. Joseph's Healthcare Hamilton, Hamilton, Canada

Marco Alifano
Thoracic Department, Paris Center University Hospital, Paris, France

Mazen Rasmi Alomari
Group Florence Nightingale Hospitals, Istanbul, Turkey

Elena Arnaiz-Garcia
Service of Cardiovascular Surgery, Salamanca University Hospital, Salamanca, Spain

Diego Avella Patino
Department of Surgery, The University of Chicago, Chicago, IL 60637, USA

Benedetta Bedetti
Department of Thoracic Surgery, Malteser Hospital, Bonn, Germany

Luca Bertolaccini
Department of Thoracic Surgery, AUSL Romagna - Forlì Teaching Hospital, Forlì, Italy

Andrea Bille
Head and Neck and Thoracic Surgery Units, Guy's and St Thomas' NHS Foundation Trust, London, UK

Marc Boada
General Thoracic Surgery Department, Hospital Clínic de Barcelona, Spain

Antonio Bobbio
Thoracic Department, Paris Center University Hospital, Paris, France

Korkut Bostanci
Department of Thoracic Surgery, Marmara University Faculty of Medicine, Istanbul, Turkey

Jury Brandolini
Department of Thoracic Surgery, AUSL Romagna - Ravenna Teaching Hospital, Ravenna, Italy

Roberto Crisci
Thoracic Surgery Unit, University of L'Aquila, "G. Mazzini" Hospital, Piazza Italia 1, Teramo, Italy

Antonio D'Andrilli
Department of Thoracic Surgery, University of Rome Sapienza, Rome, Italy

Guilherme Dal Agnol
Department of Thoracic Surgery, Americas Medical Center, Rio de Janeiro, Brazil

Francesco Damarco
Thoracic Surgery and Lung Transplant Unit, Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, University of Milan, Milan, Italy

Jean-Paul P. M. de Vries
Department of Vascular Surgery, St. Antonius Hospital, Nieuwegein, the Netherlands

Mariano Di Martino
Barts Thorax Centre, Barts Health NHS Trust, London, UK

Duilio Divisi
Thoracic Surgery Unit, University of L'Aquila, "G. Mazzini" Hospital, Piazza Italia 1, Teramo, Italy

Mark K. Ferguson
Department of Surgery, The University of Chicago, Chicago, IL 60637, USA

Anna E. Frick
Department of Thoracic Surgery, University Hospitals Leuven, Leuven, Belgium

Marta G. Fuentes-Gago
Service of Thoracic Surgery, Salamanca University Hospital, Salamanca, Spain

Domenico Galetta
Division of Thoracic Surgery, European Institute of Oncology, Milan, Italy

José M. Gonzalez-Santos
Service of Cardiovascular Surgery, Salamanca University Hospital, Salamanca, Spain

Erkan Kaba
Department of Thoracic Surgery, Istanbul Bilim University Medical Faculty, Istanbul, Turkey

Nikolaos Kostoulas
Department of Thoracic Surgery, St. James's University Hospital, Leeds, UK

David Lawrence
Thoracic Surgery Department, University College London Hospitals (UCLH), London, UK

Sarah Majercik
Trauma and Surgical Critical Care, Intermountain Medical Center, Salt Lake City, Utah, USA

Antonio E. Martin-Ucar
Thoracic Surgery Units of University Hospitals Coventry and Warwickshire NHS Trust, Coventry, UK

Laureano Molins
General Thoracic Surgery Department, Hospital Clínic de Barcelona, Spain

Francisco Javier Moradiellos
Thoracic Surgery Department, Hospital Universitario Quirónsalud Madrid, Madrid, Spain

Kenneth Muscat
Head and Neck and Thoracic Surgery Units, Guy's and St Thomas' NHS Foundation Trust, London, UK

Mario Nosotti
Thoracic Surgery and Lung Transplant Unit, Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, University of Milan, Milan, Italy

Ricardo Oliveira
Department of Thoracic Surgery, Research Centre, Institut universitaire de cardiologie et de pneumologie de Québec, Université Laval, (IUCPQ-UL), Chemin Sainte-Foy, Quebec City, Canada

Nikolaos Panagiotopoulos
Thoracic Surgery Department, University College London Hospitals (UCLH), London, UK

Kostas Papagiannopoulos
Department of Thoracic Surgery, St. James's University Hospital, Leeds, UK

Alessandro Pardolesi
Department of Thoracic Surgery, AUSL Romagna Teaching Hospital, Forlì, Italy

Davide Patrini
Thoracic Surgery Department, University College London Hospitals (UCLH), London, UK

Camilla Poggi
Department of Thoracic Surgery, University of Rome Sapienza, Rome, Italy

Federico Raveglia
Department of thoracic Surgery, San Paolo Hospital, Milan, Italy

Erino A. Rendina
Department of Thoracic Surgery, University of Rome Sapienza, Rome, Italy

Ilaria Righi
Thoracic Surgery and Lung Transplant Unit, Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, University of Milan, Milan, Italy

Gaetano Rocco
National Cancer Institute, Pascale Foundation, Naples, Italy

Lorenzo Rosso
Thoracic Surgery and Lung Transplant Unit, Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, University of Milan, Milan, Italy

Michele Salati
Unit of Thoracic Surgery, AOU Ospedali Riuniti di Ancona, Ancona, Italy

David Sánchez-Lorente,
General Thoracic Surgery Department, Hospital Clínic de Barcelona, Spain

Marco Scarci
Thoracic Surgery Department, University College London Hospitals (UCLH), London, UK

Joachim Schmidt
Department of Thoracic Surgery, Malteser Hospital, Bonn, Germany

Philipp Schnorr
Department of Thoracic Surgery, Malteser Hospital, Bonn, Germany

Christopher W. Seder
Department of Cardiovascular and Thoracic Surgery, Rush University Medical Center, Chicago, IL, USA

Yaron Shargall
Division of Thoracic Surgery, Department of Surgery, Faculty of Health Sciences, McMaster University, St. Joseph's Healthcare Hamilton, Hamilton, Canada

Ricard Simo
Head and Neck and Thoracic Surgery Units, Guy's and St Thomas' NHS Foundation Trust, London, UK

Laura Socci
Sheffield Teaching Hospitals NHS Trust, Shef eld, UK

Piergiorgio Solli
Department of Thoracic Surgery, Maggiore and Bellaria Hospitals, Bologna, Italy

Lorenzo Spaggiari
Division of Thoracic Surgery, European Institute of Oncology, Milan, Italy; Department of Oncology and Hematology-Oncology-DIPO, University of Milan, Milan, Italy

Davor Stamenovic
Department of Thoracic Surgery, St. Vincentius Kliniken, Karlsruhe, Germany

Salvatore Strano
Thoracic Department, Paris Center University Hospital, Paris, France

Ricardo Mingarini Terra
Division of Thoracic Surgery, Hospital das Clinicas, University of Sao Paulo Medical School, Sao Paulo, Brazil

Alper Toker
Group Florence Nightingale Hospitals, Istanbul, Turkey

Paula Antonia Ugalde Figueroa
Department of Thoracic Surgery, Research Centre, Institut universitaire de cardiologie et de pneumologie de Québec, Université Laval, (IUCPQ-UL), Chemin Sainte-Foy, Quebec City, Canada

Çağdaş Ünlü
Department of Surgery, Northwest Clinics, Alkmaar, the Netherlands

Rob H. W. van de Mortel
Department of Vascular Surgery, St. Antonius Hospital, Nieuwegein, the Netherlands

Dirk Van Raemdonck
Department of Thoracic Surgery, University Hospitals Leuven, Leuven, Belgium; Department of Clinical and Experimental Medicine, KU Leuven University, Leuven, Belgium

Gonzalo Varela
Service of Thoracic Surgery, Salamanca University Hospital, Salamanca, Spain

Federico Venuta
Department of Thoracic Surgery, University of Rome Sapienza, Rome, Italy

Arthur Vieira
Department of Thoracic Surgery, Research Centre, Institut universitaire de cardiologie et de pneumologie de Québec, Université Laval, (IUCPQ-UL), Chemin Sainte-Foy, Quebec City, Canada

Cornelis G. Vos
Department of Surgery, Northwest Clinics, Alkmaar, the Netherlands

Michiel T. Voûte
Department of Surgery, Erasmus University Medical Center, Rotterdam, the Netherlands

David A. Waller
Barts Thorax Centre, Barts Health NHS Trust, London, UK

Thomas W. White
Trauma and Surgical Critical Care, Intermountain Medical Center, Salt Lake City, Utah, USA

Preface

Recent years have seen a strong emphasis on minimally invasive thoracic surgery. That has reflected in training programs across the world with the results that younger surgeons have somewhat lost the necessary skills needed to treat more complex cases.

Open thoracic surgery aims to fill this gap in knowledge and is intended for the younger practicing thoracic and cardiothoracic surgeons. Expert operators will also find a wealth of tricks and tips to improve their procedures.

It is written by leaders in the field, with proven experience in advanced open resections.

With this book, we aimed to deliver in a concise yet comprehensive package a full synopsis of the entire spectrum of conditions that can be treated by thoracic surgeons.

It focusses on the technical aspects of the technique with in-depth explanation to reproduce the procedure. A unique aspect of this handbook is its systematic approach to open techniques and also all the standard incisions.

Chapters 1 and 2 are about thoracic incisions and tracheostomy.

Chapters 3 to 19 covers in details all aspects of lung resections, with detailed descriptions, tips and tricks for advanced resections (Pancoast, resection on bypass and airway resections).

The rest of the book covers surgery for mesothelioma (both pleurectomy decortication and expleural pneumonectomy) and a wide array of chest wall conditions (pectus deformities, resections for cancer and traumas).

We hope that the simple format of the book will help the reader to consolidate his or her understanding of clinical concepts and technical procedures. At the same time, we hope that it will provide an overview of the essentials of best peri-operative care.

Marco Scarci
Department of Thoracic Surgery, University College London Hospital, London, UK.
(Email: marco.scarci@mac.com)

Preface

History is full of “disruptive technologies” that promise to revolutionize the way we live. And yet, history then goes on to demonstrate that these rarely–if ever–do that.

As I fly from one continent to the next to lecture and teach, I often marvel at the wonder of modern air travel. The advent of commercial flight was meant to replace transportation by land and sea, and yet today the bulk of intercontinental logistics is still done by rail and by ships. Whenever I shop, I can choose to pay a range of cards, or a variety of electronic ‘cashless’ payment systems - yet how many people have given up carrying cold hard cash in their pockets? Similarly, mp3 has not fully replaced vinyl records, nor email the postman.

Thoracic surgery has similarly faced the push of technology throughout its history. When video-assisted thoracic surgery (VATS) arrived on the scene in the 1990s, many were already predicting that open thoracotomy would follow the dinosaurs into extinction. Why would anyone want a large painful wound when the same operation could be done using a minimally invasive approach? However, the reality is that today the majority of chest operations around the world are still being done using traditional open approaches.

There are several potential reasons for this. Centres around the world have variously described: lack of resources to develop VATS; lack of opportunities to train in VATS; lack of any financial, academic, career incentives to develop VATS; lack of patients perceived to be amenable to VATS; and so on.

There are many arguments why these ‘reasons’ may not actually be valid, and why they can be overcome. But whatever the reason, open surgery has persisted as the most commonly used thoracic surgical approach. As such, the field of open thoracic surgery has been constantly evolved and improved upon by its many practitioners around the globe. It would be facile to dismiss open surgery as ‘backward’ or ‘out of date’. Advances in surgical technology and techniques are not limited to VATS, and many developments have advanced the practice of open surgery just as well.

The book therefore comes at a most pertinent time. For years, the focus in thoracic surgery has been so skewed towards minimally invasive approaches that open approaches have been relatively neglected. This book provides a timely review of the latest knowledge and insights into open chest surgery. It covers all major operations and describes the classic techniques with the latest updates and modifications. Chapters have been written by experts in the field and represent the state of the art.

For surgeons practising open thoracic surgery, this book is an invaluable resource and the most up-to-date reference currently available. For proponents of VATS, this book is similarly indispensable as a manual of what can and should be done when thoracoscopic approaches are not feasible or conversion is necessary. For all thoracic surgeons, this book is a most relevant reconfirmation that the best basic principles of thoracic surgery will always remain regardless of new-fangled technologies and revolutions.

Alan D. L. Sihoe
MBBChir, MA(Cantab), FRCSEd(CTh), FCSHK, FHKAM, FCCP
Clinical Associate Professor, Department of Surgery,
The University of Hong Kong,
Chief of Thoracic Surgery, The University of Hong Kong Shenzhen Hospital, Shenzhen, China;
Guest Professor, Department of Thoracic Surgery, Tongji University,
Shanghai Pulmonary Hospital, Shanghai, China;
Honorary Consultant, Department of Surgery, Queen Mary Hospital, Hong Kong.
(Email: adls1@lycos.com)

In the modern world of minimally invasive thoracic surgery (VATS), the open approach has moved to the background. Even though the VATS approach is nowadays the gold standard for many procedures and its technical development allows to perform advanced surgeries through VATS, there are situations where the open approach is still the best and, often, the only solution.

This book covers the whole spectrum of thoracic surgery and it is written by leaders in the field from different countries. Surgery for lung cancer, chest wall resection and reconstruction, treatment of empyema are all among the subjects discussed and described in this book. Along the standard techniques, also advanced procedures like carinal and sleeve resections and the use of cardiopulmonary bypass in thoracic surgery are described in graphic details. Every chapter is supplied with pictures, figures and drawings, to make the different surgical steps immediately understandable.

Young surgeons will find in this book the basic knowledge that they need for their practical experience and the most senior surgeons will discover some interesting tips and tricks to improve their practice.

Benedetta Bedetti

Department of Thoracic Surgery, Malteser Hospital, Von-Hompesch-Str. 1, 53123 Bonn, Germany.

(Email: benedetta.bedetti@gmail.com)

Preface

How could anyone define timely the choice to edit a book about open thoracic surgery in this day and age? A time when minimally invasive is the dogma, ERAS is the path and nano the tool to future surgical practice. A time when VATS is a philosophical approach more than a surgical technique and robotic is rapidly gaining favor for the touch precision and the unprecedented field visualization. A time when open surgery is often not even considered the basic step in the learning curve towards minimally invasive surgery and an entire generation of surgeons is about to be raised handling a thoracoscope as interns. Indeed, trends do not always depict the real situation of the worldwide thoracic surgical practice. Open thoracotomy still represents a most valuable approach which is used in a high percentage of major pulmonary resection. In the vast majority of cases, this is not the old fashioned “coast to coast” thoracotomy but, probably as a direct result of the VATS saga, has become first muscle sparing, then video-assisted in an attempt at reducing invasiveness, and, eventually, hybrid. As a result, we hardly see the 10 to 14-day average length of stay in the hospital in our current practice and most patients are dismissed within a week of the open thoracotomy. While definitive data on the oncologic value of either thoracotomy or VATS aren’t available—but we are entitled not to hold our breath expecting breaking news - we know that the reduced morbidity of the latter may make a difference in the speed and the completeness of patient recovery within the first month after surgery. This alone is a good enough reason for the practice of VATS surgery being increasingly considered a fundamental step in improving the quality metrics of thoracic surgery. Nevertheless, entangled in our—most of the times—arbitrary and personal evaluation of minimal invasiveness, we forget that what is of utmost importance lies in the accuracy of the surgical technique inside the chest and the ability of performing a thorough lymphadenectomy when a lobectomy for cancer is necessary. Dr Scarci needs to be commended for having made an excellent effort at bringing the attention of thoracic surgeons back again on the open approach. While VATS is the approach of the adulthood of thoracic surgical curricula, open surgery is similar to parents for thoracic surgeons: extremely helpful while growing up, now visited only when needed, but good to know they are always there.

Gaetano Rocco, MD, FRCS (Ed)
Division of Thoracic Surgery, Thoracic Department, Istituto Nazionale Tumori, IRCCS, Pascale Foundation, Naples, Italy.
(Email: g.rocco@istitutotumori.na.it)

Table of Contents

General Principles

Lung

Pleura

Trachea

Chest Wall

Diaphragm

Complex Procedures

General Principles

Thoracic incisions for open surgery

Antonio E. Martin-Ucar[1], **Laura Socci**[2]

[1]Thoracic Surgery Units of University Hospitals Coventry and Warwickshire NHS Trust, Coventry, UK; [2]Sheffield Teaching Hospitals NHS Trust, Sheffield, UK

Correspondence to: Mr Antonio E. Martin-Ucar. Consultant Thoracic Surgeon, University Hospitals Coventry and Warwickshire NHS Trust, Clifford Bridge Road, Coventry, UK. Email: antonio.martin-ucar@uhcw.nhs.uk.

Received: 07 April 2017; Accepted: 25 April 2017; Published: 14 August 2017.
doi: 10.21037/shc.2017.05.11
View this article at: http://dx.doi.org/10.21037/shc.2017.05.11

Introduction

Despite the advances of minimally invasive techniques in the surgical management of thoracic diseases open surgery remains an important part of a surgeon's activity. The extension of the disease both in size and location, the surgeon's experience and the resources available will determine the decision to perform open surgery. Over the years, a variety of incisions to access the thoracic cavity have been described some with universal indications and others tailored to particular procedures. The principles remain the facility to perform the procedure safely and efficiently with adequate exposure to deal with the steps of the operation as well as the possible technical complications or difficulties. A surgeon, in order to decide the preferred incision, will take into account the own experience and training but also the indication for surgery, the anatomical location of the pathology, the likehood of encountering difficulties (such as previous surgeries or locally invasive tumours), the preoperative assessment of the patient, the predicted extent of side effects, and also the patients' views in term of cosmesis and recovery.

In order for an incision to be effective we cannot forget some basic principles: careful positioning of the patient with clear identification of anatomical landmarks, correct handling of the tissues, step by step haemostasia, and gradual spread of the bony components (sternum or ribs) to minimise chances of inadvertent fractures. As important as the access is the closure of the incision, with correct suture by layers, haemostasia, and prevention of wound complication such as intercostal haernias, seromas or dehiscence. In this chapter, we will divide the incisions into three main groups: open approaches in lateral decubitus position (muscle and non-muscle sparing), open approaches in supine position (sternotomy, anterior thoracotomy, clamshell and their variations), and hybrid approaches (combination of open and minimally invasive). We will illustrate the main incisions with an interest to potential complications and pitfalls.

Open approaches in lateral decubitus

Lateral decubitus remains the most common position for open approaches to the thoracic cavity. It does allow exposure to the entire cavity, extension of the incision should be necessary, and the variability of anterior and posterior approaches. The positioning of the patient can vary slightly according to surgeons' preferences, but the main principles are similar. Multiple pressure points should be adequately padded including a pillow between the legs and both arms flexed and without tension to avoid possible damage to the brachial plexus. The position of the non-dependent arm varies as per personal preferences and the location of the incision: flexed in a "prayer" position or elevated with a padded support. This can be more useful in anterior incisions. The patient must remain stable on the operating table to allow for table movements during the surgery. Stability can be achieved equally by beanbags, hard stops, or straps. The intercostal spaces should be widened by hyperextending the thorax either breaking the table or with the placement of a roll under the dependent chest at the level of the tip of the scapula. The surgeon will be placed anteriorly o posteriorly to the patient depending of the location of the incision.

Posterolateral thoracotomy

Posterolateral thoracotomy is the most traditional and used

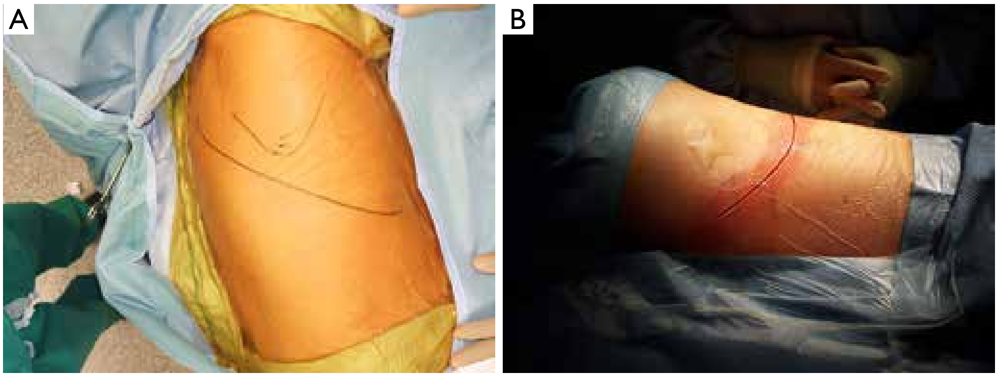


Figure 1 Skin marks of a posterolateral thoracotomy. The incision is performed 1-2 cm below the tip of the scapula, from a equidistant point between the thoracic spine and the midpoint of the spinal border of the scapula, then extended anteriorly.

Figure 2 The subcutaneous tissues are divided, exposing the muscular layers. The Latissimus Dorsi muscle will be divided alongside the lateral border of the Trapezius muscle.

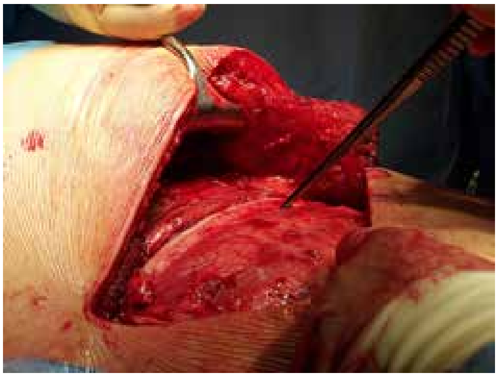


Figure 3 The Latissimus muscle has been divided and its upper end is seen anteriorly. The intercostal space is exposed and will be open subperiostially.

of the thoracic incisions. It is a multi-purpose approach as it will provide excellent exposure to mayor surgery, and it can be extended cranially such as the Poulsen approach or anteriorly if access to the diaphragm or even abdomen is needed.

The anatomical markers will be a point 2–3 cm below the tip of the scapula, the mid-distance point between the middle of the spinal border of the scapula and the spinous process of the vertebra (*Figure 1A*). The skin incision will join these two points and it is extended anteriorly until the anterior axillary line (*Figure 1B*). After incision of the skin and subcutaneous layer (*Figure 2*), the latissimus dorsi muscle is carefully divided with cautery. Anteriorly the serratus anterior muscle was traditionally divided although nowadays is preserved by dividing its attachments to the ribs. Posteriorly the lateral border of the trapezius is exposed and can be divided in cases where more posterior access is required.

After the muscular layers are divided, the surgeon will enter the chosen intercostal space (*Figure 3*). This skin incision will allow deciding from 4^{th} to 7^{th} intercostal spaces without difficulties, and the spaces can be identified by counting the ribs posteriorly from the top. The intercostal space can be divided either directly by dividing the muscles

Figure 4 The intercostal muscle flap has been raised prior to placement of the spreaders.

Figure 5 The exposure is excellent with surgical tapes placed around distal trachea, left main bronchus and right main bronchus (right lung retracted anteriorly) during carinal surgery.

or by lifting the periosteum off the rib below and should extend from costotransverse ligaments posteriorly to the internal thoracic vessels anteriorly (they must be preserved). If an intercostal muscle flap is thought to be necessary in cases of pneumonectomy or bronchoplasties, this flap must be raised at this point before placing the spreader (*Figure 4*). With the lung underneath collapsed the parietal pleura is entered. In cases that we expect adhesions it is advisable to mobilise some of the parietal pleura off the rib above and below the incision prior to enter the cavity to minimise the chances of accidental damage to the lung.

Once the parietal pleura is divided the rib spreader is inserted and should always be opened slowly and progressively, trying to avoid the possible risk of unwanted rib fractures. Manouvres to minimise this risk could be blunt division of the costo-transverse ligaments or even elective transection of the rib posteriorly, always with care to avoid damage to the intercostal vessels proximally. These vessels can retract into the spinal canal if divided accidentally and can be difficult to control.

The traditional posterolateral thoracotomy allows the surgeon to perform the vast majority of thoracic procedures both in the elective and the emergency settings. Excellent exposure of the thoracic cavity and the familiarity with the position are the great advantages of this access. The surgeon is able to visualise and control most parts of the lung, thoracic aorta and oesophagus, diaphragm and pleura (*Figure 5*). It can also extended as mentioned before towards abdomen by converting into a thoraco-phrenotomy by dividing the diaphragm or even Thoraco-laparotomy by division of the costal margin; or towards the upper thoracic cavity by division of the posterior attachment of the scapula in cases of superior sulcus tumours or chest wall involvement.

Once the procedure is finished, the intercostal spaces have to be adequately closed either by pericostal or intracostal sutures. Reducing the hyperextension of the chest by unbreaking the table or removing the roll will facilitate this step. Following this, the muscular layer should be closed with good haemostasia. Care must be put on opposing the ends of the Latissimus Dorsi adequately as when divided the caudal end will retract posteriorly and the cranial end anteriorly. Deficient closure of the muscle will lead to a persistent lump under the skin. Subcutaneous tissues and skin is then closed.

Posterolateral thoracotomy is a very traumatic procedure, carrying a risk for early and long term pain and an early impact on respiratory function following surgery. Division of the latissimus dorsi muscle can cause shoulder movement dysfunction that can delay return to full activities. Surgeons have gradually moved away of dividing serratus anterior or trapezius muscles and reducing the size of the skin incision, but it is still considered a posterolateral thoracotomy.

Muscle-sparing posterolateral thoracotomy

With the same patient position as the posterolateral approach a thoracotomy with preservation of the chest wall muscles can be performed via the Auscultatory triangle (1-7). The skin incision can be as large as required, but normally it is reduced to the initial part of the posterolateral thoracotomy incision without the need to extend the incision anteriorly to the tip of the scapula (*Figure 6*).

Once skin and subcutaneous tissues are divided (*Figure 7*), we identify the auscultatory triangle between the anterior edge of the Trapezius, the posterior edge of the Latissimus

Figure 6 Skin markers for the incision, that will be placed over the auscultatory triangle.

Figure 7 The subcutaneous tissues are divided and subcutaneous flaps are created to allow for retraction of the muscular layer without division.

Figure 8 The posterior edge of the Latissimus Dorsi muscle is identified and the fatty layer is divided alongside this edge with total muscle preservation.

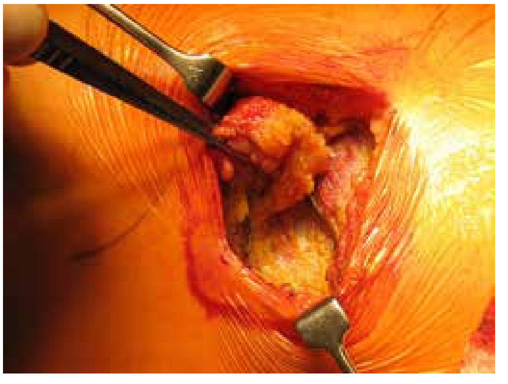


Figure 9 The fat pad in the auscultatory triangle is excised between the posterior edge of the Latissimus Dorsi and the Lateral edge of the Trapezius.

Dorsi, and the vertebral border of the scapula (*Figure 8*). Once identified the surface of the muscles, a subcutaneous flap is raised in all directions that will allow mobilising the muscles without dividing them. The fat and fascia between Latissimus and Trapezius is removed exposing the rib cage (*Figure 9*). The Latissimus musle is the retracted anteriorly and the Trapezius posteriorly as much as required depending of the procedure and exposure required. The intercostal muscle is entered in the same manner as in a posterolateral thoracotomy with the same precautions and the same length (*Figure 10A,10B*). The exposure is secured by the use of two smaller spreaders simultaneously, one retracting the ribs and another one at 90 degrees retracting the trapezius and latissimus muscles creating a square "window" (*Figures 11,12*).

One of the advantages of this approach is the speed of closure of the muscle layer once the intercostal space is closed (*Figure 13*). A single suture is run from the anterior Trapezius to the posterior edge of the Latissimus closing the entire layer with very easy haemostasia (*Figure 14*). Prior to closure of the skin it is important to place a tissue drain under the skin flaps to reduce the risk of seromas. This incision is very versatile as it can be potentially be as large as the posterolateral thoracotomy if required, and it is particularly helpful to treat pathologies of the posterior mediastinum (neurogenic tumours, oesophageal cysts…), which don't require ample exposure to the anterior chest cavity. In terms of lung resections, we have found it extremely useful for anatomical segmentectomies of segment 6, procedures that involve reconstruction of the bronchial tree such as sleeve lobectomies or trauma because

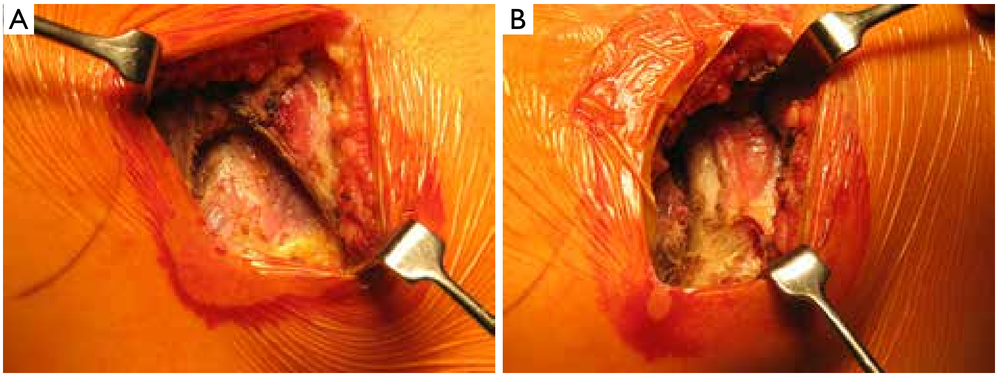


Figure 10 Once the fat pad has been removed the intercostal spaces are identified and entered in the same manner as in the posterolateral approach.

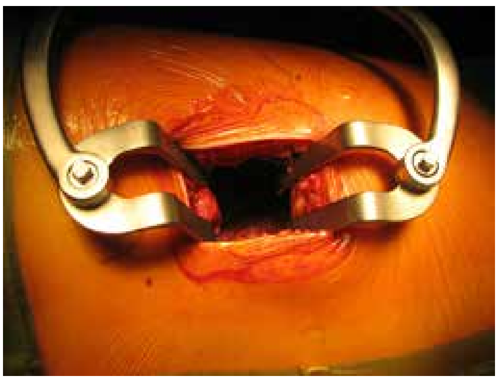


Figure 11 The initial spreader is inserted and opened gradually.

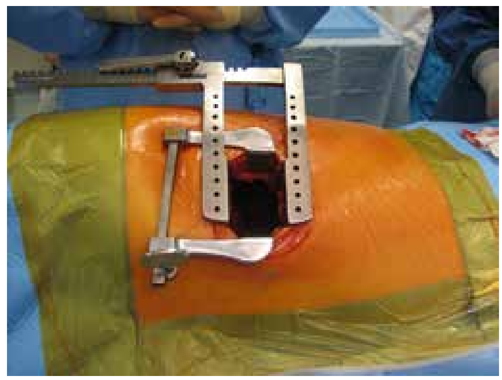


Figure 12 A second spreader is then placed at 90 degrees retracting the Latissimus Dorsi anteriorly and the Trapezius posteriorly.

of their posterior location, and as an initial procedure for pulmonary metastasis as the incision would allow inspection of the entire lung, but it might minimise the adhesions should further procedures are required in the future.

Cosmetically it is an advantage to larger skin incisions and probably reduces the incidence of shoulder problems. Preserving the Latissimus Dorsi and Serratus muscles intact does allow for these muscles to be used in the future as flaps if complications or further procedures are required (4,8). Some of the difficulties with this incision are: the access to the main pulmonary artery in very central tumours can be more complex, there is a reported incidence of seromas of up to 26% so it requires the placement of a self-vacuum subcutaneous drain, and sometimes knot tying can be difficult as well as some angulation required in surgical staplers

A good tip is to create an anterior chest drain port early during the procedure and use it for insertion of the stapler guns, giving a very comfortable angle for placement and firing. It is an excellent incision when hybrid (VATS and limited open) access is planned.

Muscle-sparing antero-lateral thoracotomy

The patient is positioned in lateral decubitus with the same precautions as the posterolateral thoracotomy. The table can be slightly tilted posteriorly to facilitate surgeon's view (who will be standing in the front of the patient). The skin incision is performed starting from the posterior axillary line in front of the tip of the scapula towards the submammary crease. The subcutaneous layers are divided with cautery, it is important to preserve the intercostal brachial nerve that runs in the superior part of the wound. If dissected a postoperative numbness of the lateral breast and the nipple area can occur. Posteriorly the long thoracic nerve can be identified and should be preserved.

The anterior border of the latissimus dorsi is mobilized posteriorly by creating a subcutaneous flap and it is spared.

Figure 13 The intercostal space is closed routinely with pericostal sutures.

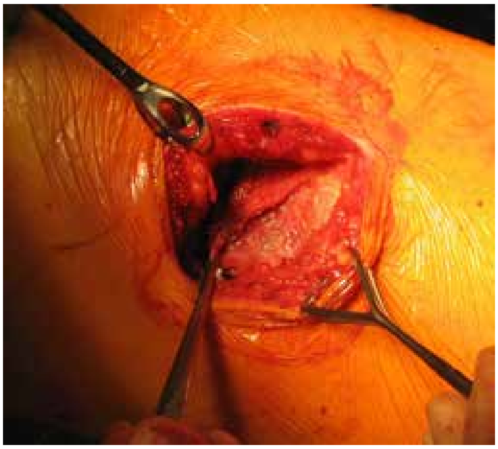


Figure 14 A single running suture is placed between the two chest wall muscles closing the space.

The lateral edges of the Pectoralis muscles are preserved without difficulties. The 4th or 5th intercostal space is entered in the same manner as per an anterior thoracotomy depending of the procedure. While it is more difficult to divide the costo-transverse ligaments to increase rib spreading, the intercostal spaces are wider anteriorly thus facilitating exposure.

The closure will be very similar to the procedure via auscultatory triangle, with the very important subcutaneous drain to prevent seromas or haematomas.

The wide anterior intercostal spaces facilitate exposure compared to the more posterior approaches thus in theory reducing the need for excess rib spreading. It gives a very adequate exposure of lungs, pericardium and diaphragm. Preservation of the chest wall muscles not only reduces impact on shoulder movements, but once again, allows for their potential use as flaps should complications (bronchopleural fistula) arise (4,8).

With the increase in the use of the VATS anterior approach the view is now very familiar for younger Thoracic Surgeons who recognise promptly this view for access to hilar structures even in central tumours. This might help for this incision to become the preferred "open" approach in the future and a good alternative for conversions from VATS to open surgery.

Some procedures might be more difficult, although not impossible, to perform with this approach. If we have to perform a broncho-angioplasty in the right side it will be easier to perform the bronchial reconstruction first (as it is located more posterior) and then the vascular one. For posterior anatomical segmentectomies (segments 3 or lateral basal), this access may prove more difficult than using more posterior approaches. The excellent access to hilar structures makes it extremely helpful for vascular control in central tumours.

Axillary thoracotomy

Axillary thoracotomy is less used than other "lateral" approaches. The lateral decubitus position is slightly altered by tilting the table backwards increasing exposure of anterior chest wall and the ipsilateral arm is secured away from the incision by shoulder abduction and elbow flexion at 90 degrees. As always when the arm is secured, care must be taken for it not to be in tension that might result in brachial plexus traction injury.

The axillary approach can be used for access to the high intercostal spaces (1st) down to 4th or 5th space depending of the indications for surgery. With the patient correctly positioned a transverse incision is performed at the axillary hair-line between the anterior axillary line (posterior edge of Pectoralis Minor) and posterior axillary line (anterior edge of Latissimus Dorsi), which are well demarcated by the bulk of the muscles. The creation of subcutaneous flaps to allow retraction of the latissimus dorsi posteriorly and pectoralis major anteriorly can extend the exposure for more extensive procedures. The digitations of the serratus anterior muscles can either be detached or divided to increase exposure. The ribs are then exposed and entry into the desired intercostal space is then performed according to surgeon's preference.

The development of VATS techniques has reduced the use of these incisions. Traditionally surgeons have used them as an access for apical procedures: surgery for

Figure 15 Longitudinal skin incision for a median sternotomy. Traditionally it extends from supraesternal notch to xyphoid process.

Figure 16 Division of the subcutaneous fat followed by midline between medial ends of the pectoralis muscles.

pneumothorax, sympathectomies and operations at the thoracic outlet (9-12). As a muscle-sparing thoracotomy, it is well tolerated and has got cosmetic results as the incision will remain in a non-exposed area. The exposure can be limited specially in the lower hemithorax.

If the procedure is complex the incision could be extended but it can be quite morbid in the more apical procedures. At the posterior end the long thoracic nerve should be preserved while dividing the serratus anterior. Due to the creation of the flaps this incision carries the risk of seromas and haematomas so care must be taken during closure in terms of haemostasia, approximating the ribs and closure of the serratus anterior. The incision is placed in quite a sensitive area liable to skin discomfort.

Open approaches in the supine position

Median sternotomy

Median sternotomy is the incision most commonly used for cardiac surgical procedures. It is also a very useful access to the thorax for different pathologies and anatomical locations.

With the patient in the supine position with slight neck extension a longitudinal skin incision is performed in the midline from the sternal notch to the tip of the manubrium followed by dissection of the subcutaneous layers and pectoralis fascia (*Figures 15,16*). Once the midline of the sternum is identified accurately to avoid paramedian split of the bone the periosteum is scored with diathermy (*Figure 17*). By retracting the upper end of the incision, the space of Burns is explored, the interclavicular ligament is divided with care of not to damage the underlying inmoninate vein. Following that the xyphoid process is dissected at the bottom end of the incision. Some surgeons elect to blunt dissect the ends of the retrosternal space before splitting the sternum alongside with a saw (*Figure 18*). Haemostasia must be ensured at the periosteum and bone marrow with cautery and/or bone wax prior to spread of the incision by a retractor which must be done gradually.

With this procedure, there is ample exposure to perform surgical procedures such as excision of pathologies in the anterior mediastinum, or by opening the pleurae to access either thoracic cavity (*Figure 19A,19B*). A particular use of median sternotomy is the access to the carina by entering the pericardium and later on the posterior pericardium. At the end of the procedure the sternal ends are approximated with sternal wires, 2 in the manubrium and 4 in the body, although it depends on patient's height (*Figure 20*). A good closure of the sternum is important to minimize the risk of non-union, mediastinitis and wound infection. The pectoralis fascia, the subcutaneous layer and skin are then carefully closed by layers.

In non-cardiac thoracic surgery, median sternotomy has been extensively used in the management of large anterior mediastinal masses, maximal thymectomy for myasthenia gravis and bilateral pathologies such as multiple lung

Figure 17 The periosteum is scored at the midline to guide the saw when dividing the sternum.

Figure 18 After division of the xyphoid process, a sternal saw is used to perform the sternotomy. Some surgeons stop pulmonary ventilation during this step.

metastases. Median sternotomy was also the incision of choice following the resurgence of Lung Volume Reduction Surgery in the 1990s although more recently bilateral VATS (even as staged procedures) is more commonly used as it might reduce morbidity (13-18).

But median sternotomy can also be used in occasions for surgery of pleuropulmonary diseases specially on the right side when the surgeon can predict difficulties in exposing the main pulmonary vessels, such as central primary cancers in which pericardial involvement is suspected, or re-do procedures such as completion pneumonectomies for central tumours. The authors found out that right extrapleural pneumonectomies for mesothelioma were feasible via median sternotomy and indeed reduced the incidence of postoperative complications.

The advantages are a great exposure of mediastinal structures (even carina), easy access to control main pulmonary vessels, and ability of entering both pleural cavities. From the experience in the postoperative management and analgesia requirements following cardiac surgery we learnt that a median sternotomy is very well tolerated by patients with lesser incidence of pain related complications in the short and the long term than a large posterolateral thoracotomy.

Infective and sternal complications are uncommon (less than 5%) but potentially very morbid (19,20). Unfortunately, median sternotomy provides poor exposure to the posterior areas of the lung and mediastinum, as well as a very difficult access to the left lower lobe due to the position of the heart.

Thoracosternotomy (clamshell and hemiclamshell)

The Clamshell incision of a bilateral anterior thoracotomy with transverse sternotomy has been the choice for bilateral

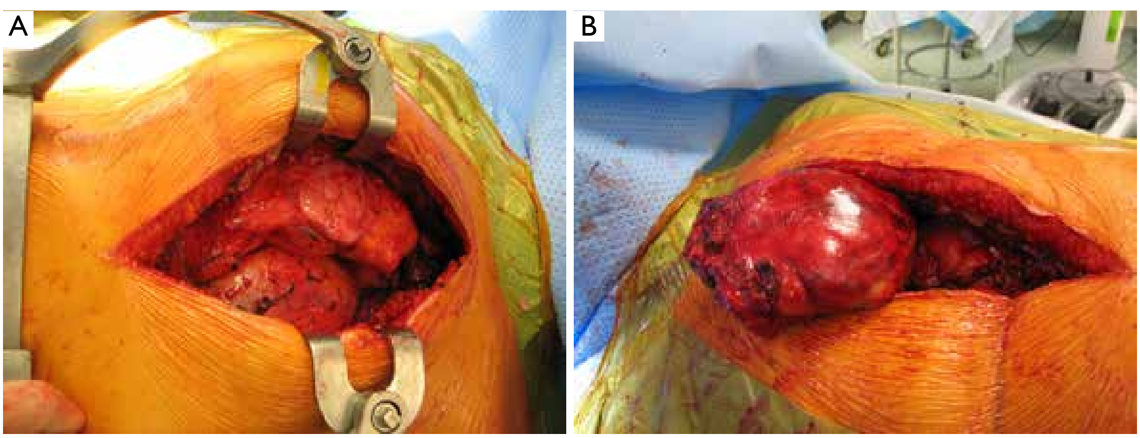


Figure 19 Excellent exposure of the mediastinum with median sternotomy, both for dissection and retrieval of large specimens.

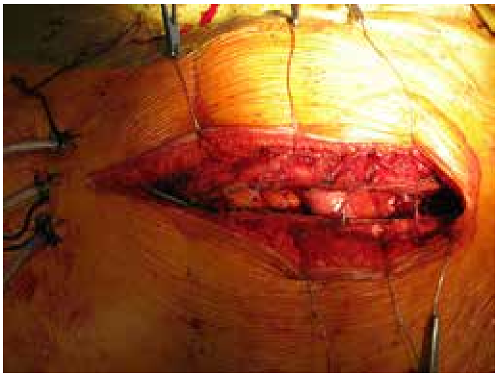


Figure 20 Closure by wires. Care has to be taken not to injury the internal thoracic vessels during insertion of wires.

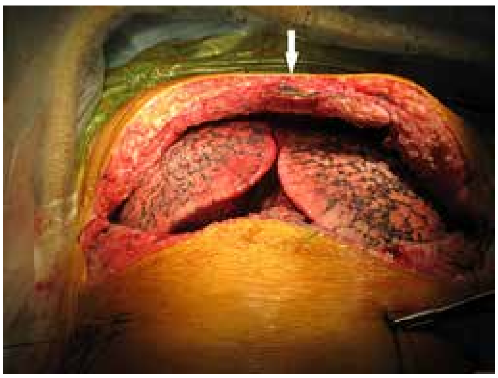


Figure 21 A Clamshell incision has been performed. The skin and muscles have been divided, as well as the transverse Sternotomy. *Courtesy of Dr Arango.*

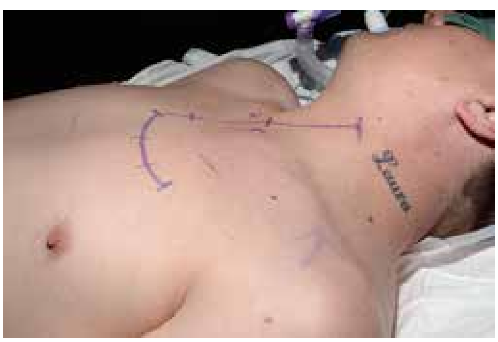


Figure 22 GrunenWald's approach for a Pancoast Tumour. The skin incision will extend alongside the anterior border of the Sternomastoid muscle, over the sternal manubrium and then alongside a high intercostal space.

Figure 23 Once the soft tissues have been divided, the manubrium is left to divide last.

lung transplantation and access to pericardium in the past. Today ituse is restricted to very uncommon indications but remains a valuable tool mainly in trauma settings (21-25). A unilateral approach such as the hemiclamshell has also been described for diverse indications (26).

With the patient in the supine position the skin incision is made along the inframammary skin creases from the midaxillary/anterior axillary lines. The subcutaneous tissues are divided with cautery and the pectoralis major muscles are raised from their inferior and sternal attachments. The 4th or 5th intercostal spaces are identified and entered bilaterally. The internal mammary vessels are identified and ligated. The sternal body is divided transversally with a saw and after haemostasia the ends are spread with two sternal retractors (*Figure 21*). In the hemiclamshell approach the skin incision is performed starting on the sternal notch on the midline and running over the inframammary crease towards the anterior axillary line. The pectoralis major is raised or incised over the 5th rib. The 4th intercostal space is entered. The mammary bundle is equally ligated. Variants of this incision include a cervical extension of the incision along the medial edge of the sternocleidomastoid muscle with sternal splitting (Grunenwald's, *Figures 22-25*), or the Dartevelle's approach that include the sectioning of the medial half of the clavicle. These variants are extremely useful for excision of Superior Sulcus tumours and the hemiclamshell tends to be performed at higher intercostal spaces.

For closure, the sternal ends are approximated with wires, the intercostal spaces are closed routinely and the pectoralis major muscles are reattached to lower ribs and

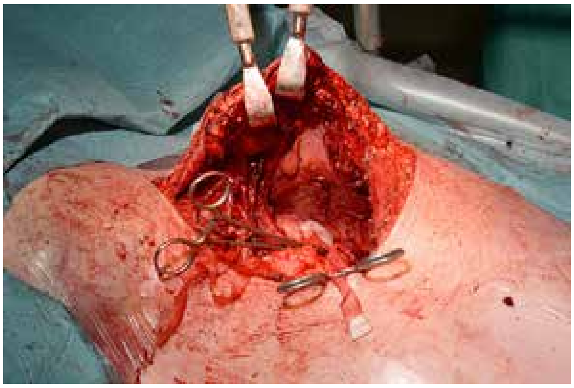


Figure 24 With the manubrium divided the exposure of the thoracic cavity and the Thoracic Outlet is excellent for extended resections of first rib and/or subclavian vessels.

Figure 25 The sternotomy is closed with a stell wire and the extent of the incisioni s seen prior to skin closure.

Figure 26 Large wound closed revelaing the extent of the Clamshell incision from anterior axillary lines. *Courtesy of Dr Arango.*

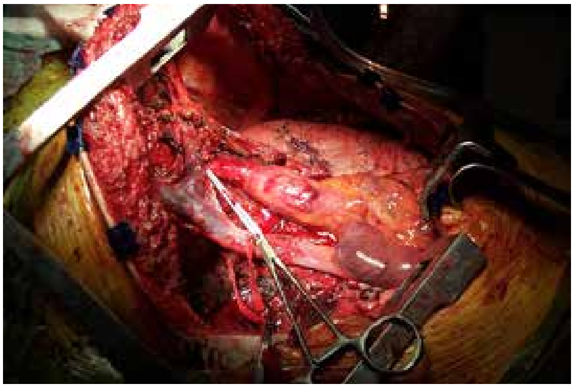


Figure 27 The exposure of the Clamshell incisioni s maximal, allowing access for any thoracic surgical procedure. In this case, a giant mediastinal mass has been excised and all intrathoracic and mediastinal estructures are exposed. *Courtesy of Dr Arango.*

sternum (*Figure 26*).

The clamshell incision provides the maximal exposure of thoracic cavities (*Figure 27*), but its comorbidities and the trauma involved have restricted its use to specific indications. Currently its use is limited to very large mediastinal masses (*Figure 28*), bilateral lung transplantation and trauma. Its use on bilateral lung metastases or excision of pericardium has declined in favour of other approaches.

The rationale for the restriction in its use is mainly due to its consequences. Transternal division carries a high risk of sternal healing complications of up to 30% compared to 1-2% after median sternotomy. In a comparative series, Machiarinni et al reported more postoperative pain, deformities, need for surgical revision and more impact on respiratory mechanics following clamshell than median sternotomy after double lung or heart-lung transplant (25).

Anterior thoracotomies

The anterior thoracotomy did regain some popularity with the advent of Minimal Invasive Cardiac Surgery (mitral valve surgery and MIDCAB) (27), although its use in thoracic surgery remains limited to non-complex procedures.

The patient is positioned supine with a roll under the ipsilateral side of the operation to increase intercostal spaces separation. The skin incision is made from the anterior axillary line curving under the breast towards the sternum for procedures that require access through the 4th

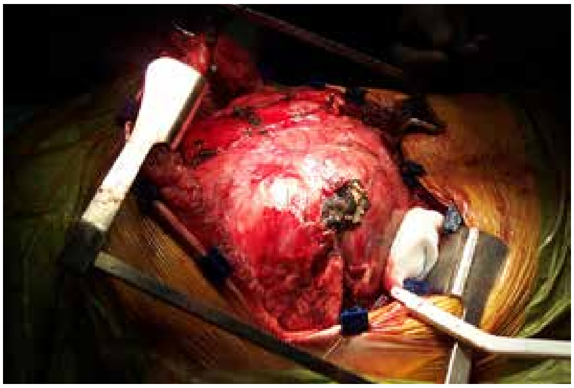


Figure 28 View of the giant mediastinal mass prior to excision. Clamshell did allow safe excision with good exposure. *Courtesy of Dr Arango.*

Figure 29 CT Scan of a Middle Lobe cancer with both chest wall and pericardial invasion.

or 5th intercostal space. A lower approach of an anterior thoracotomy would be a submammary incision that can be very useful for insertion of pacemakers or creation of pericardial windows. In procedures for staging of lung cancer the incision is placed at the level of the 2nd-3rd intercostal space with or without excision of the sternocostal cartilage.

A limited anterior thoracotomy is a good approach for patients that require a lung biopsy but is not fit enough for a single lung ventilation that could make VATS approach more difficult, and it can be used as invasive mediastinal staging of lung cancer in the form of an anterior mediastinotomy for biopsy of lymph nodes or to confirm suspected direct mediastinal invasion. A good advantage is the fact that the intercostal spaces are wider anteriorly so less rib retraction is required, even being substituted by soft tissue retractors.

In the field of more extensive thoracic procedures, pure anterior thoracotomies provide a restricted exposure hence it is rarely used (28). If the costal cartilage is excised there is a risk of seromas or intercostal haernias, and the possibility of damage to the internal thoracic arteries.

Figure 30 With the help of Thoracoscopy the limits of the chest wall invasion are identified and marked with thin hypodermic needles.

Hybrid approaches

The application of VATS to assist open surgery has been used by surgeon since the advent of minimally invasive techniques. It can help reduce size of the incision and increase view in some areas (29). Authors have described the use of hybrid procedures in lung tumours involving the chest wall by performing the pulmonary resection through VATS and then the chest wall resection and reconstruction via a limited open approach even on superior sulcus tumours (30-32). The authors reported the use of single port VATS for the confirmation and "mapping" of the chest wall involvement thus allowing correct placement of the incision with limitation of trauma to the tissues (33) (*Figures 29-32*). Another use of the hybrid techniques is the initial assessment of patients requiring open re-do surgery where dense adhesions are expected and "blind" redo thoracotomy could lead to damage to pulmonary parenchyma. With the help of a single port VATS (whose port will be used for the intercostal drain placement) we can identify the safe area to perform the open incision and even divide adhesions under direct optical vision. New hybrid approaches have also been described for mediastinal surgery (34).

Summary

The access to the thoracic cavity during surgery is open to

Figure 31 The incision is placed anteriorly and the chest wall is entered beyond the invaded areas safely.

Figure 32 The chest wall resection has been performed and then the lung disection can be performed with the assistance of VATS.

many incisions and approaches. The surgeons' experience and training, adequate planning and the indications and anatomical locations of the surgery will influence the choice of approach. All the incisions have advantages and limitations, and it is important to be familiar with the different possibilities. All these incisions should be part of the surgeons' arsenal of choices in order to individualise patients' care providing adequate exposure with the minimal trauma. It is important to be aware of the specific tips regarding identification and preservation of vascular and neural structures to minimise adverse consequences. Equally important is a correct closure of the different planes and prevention of seromas and haernias.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Mitchell R, Angel W, Wuerflein R, et al. Simplified lateral chest incision for most thoracotomies other than sternotomy. Ann Thorac Surg 1976;22:284-6.
2. Bethencourt DM, Holmes EC. Muscle-sparing posterolateral thoracotomy. Ann Thorac Surg 1988;45:337-9.
3. Horowitz MD, Ancalmo N, Ochsner JL. Thoracotomy through the ausculatory triangle. Ann Thorac Surg 1989;47:782-3.
4. Ziyade S, Baskent A, Tanju S, et al. Isokinetic muscle strength after thoracotomy: standard vs. muscle-sparing posterolateral thoracotomy. Thorac Cardiovasc Surg 2010;58:295-8.
5. Hazelrigg SR, Landreneau RJ, Boley TM, et al. The effect of muscle-sparing versus standard posterolateral thoracotomy on pulmonary function, muscle strength, and postoperative pain. J Thorac Cardiovasc Surg 1991;101:394-400; discussion 400-1.
6. Athanassiadi K, Kakaris S, Theakos N, et al. Muscle-sparing versus posterolateral thoracotomy: a prospective study. Eur J Cardiothorac Surg 2007;31:496-9; discussion 499-500.
7. Nazarian J, Down G, Lau OJ. Pleurectomy through the triangle of auscultation for treatment of recurrent pneumothorax in younger patients. Arch Surg 1988;123:113-4.
8. Li S, Feng Z, Wu L, et al. Analysis of 11 Trials Comparing Muscle-Sparing with Posterolateral Thoracotomy. Thorac Cardiovasc Surg 2014;62:344-52.
9. Becker RM, Munro DD. Transaxillary minithoracotomy: the optimal approach for certain pulmonary and mediastinal lesions. Ann Thorac Surg 1976;22:254-9.
10. Ochroch EA, Gottschalk A, Augoustides JG, et al. Pain and physical function are similar following axillary, muscle-sparing vs posterolateral thoracotomy. Chest 2005;128:2664-70.
11. Freixinet JL, Canalís E, Juliá G, et al. Axillary thoracotomy versus videothoracoscopy for the treatment of primary spontaneous pneumothorax. Ann Thorac Surg 2004;78:417-20.
12. Han S, Yildirim E, Dural K, et al. Transaxillary approach in thoracic outlet syndrome: the importance of resection of the first-rib. Eur J Cardiothorac Surg 2003;24:428-33.

13. Meng RL, Jensik RJ, Kittle CF, et al. Median sternotomy for synchronous bilateral pulmonary operations. J Thorac Cardiovasc Surg 1980;80:1-7.
14. Urschel HC Jr, Razzuk MA. Median sternotomy as a standard approach for pulmonary resection. Ann Thorac Surg 1986;41:130-4.
15. Martin-Ucar AE, Stewart DJ, West KJ, et al. A median sternotomy approach to right extrapleural pneumonectomy for mesothelioma. Ann Thorac Surg 2005;80:1143-5.
16. Edwards JG, Martin-Ucar AE, Stewart DJ, Waller DA. Right extrapleural pneumonectomy for malignant mesothelioma via median sternotomy or thoracotomy? Short- and long-term results. Eur J Cardiothorac Surg 2007;31:759-64.
17. Asaph JW, Handy JR Jr, Grunkemeier GL, et al. Median sternotomy versus thoracotomy to resect primary lung cancer: analysis of 815 cases. Ann Thorac Surg 2000;70:373-9.
18. Welti H. Upper median sternotomy in the treatment of mediastinal tumors; 7 personal cases. Mem Acad Chir (Paris) 1950;76:638-54.
19. Zacharias A, Habib RH. Factors predisposing to median sternotomy complications. Deep vs superficial infection. Chest 1996;110:1173-8.
20. Robicsek F, Daugherty HK, Cook JW. The prevention and treatment of sternum separation following open-heart surgery. J Thorac Cardiovasc Surg 1977;73:267-8.
21. Bains MS, Ginsberg RJ, Jones WG 2nd, et al. The clamshell incision: an improved approach to bilateral pulmonary and mediastinal tumor. Ann Thorac Surg 1994;58:30-2; discussion 33.
22. Germain A, Monod R. Bilateral transversal anterior thoracotomy with sternotomy; indications and technics. J Chir (Paris) 1956;72:593-611.
23. Bains MS, Ginsberg RJ, Jones WG 2nd, et al. The clamshell incision: an improved approach to bilateral pulmonary and mediastinal tumor. Ann Thorac Surg 1994;58:30-2; discussion 33.
24. Sarkaria IS, Bains MS, Sood S, et al. Resection of primary mediastinal non-seminomatous germ cell tumors: a 28-year experience at memorial sloan-kettering cancer center. J Thorac Oncol 2011;6:1236-41.
25. Macchiarini P, Ladurie FL, Cerrina J, et al. Clamshell or sternotomy for double lung or heart-lung transplantation? Eur J Cardiothorac Surg 1999;15:333-9.
26. Dartevelle PG, Chapelier AR, Macchiarini P. Anterior transcervical-thoracic approach for radical resection of lung tumors invading the thoracic inlet. J Thorac Cardiovasc Surg 1993;105:1025-34.
27. Lucà F, van Garsse L, Rao CM, et al. Minimally invasive mitral valve surgery: a systematic review. Minim Invasive Surg 2013;2013:179569.
28. Schuchert MJ, Souza AP, Abbas G, et al. Extended Chamberlain minithoracotomy: a safe and versatile approach for difficult lung resections. Ann Thorac Surg 2012;93:1641-5; discussion 1646.
29. Giudicelli R, Thomas P, Lonjon T, et al. Video-assisted minithoracotomy versus muscle-sparing thoracotomy for performing lobectomy. Ann Thorac Surg 1994;58:712-7; discussion 717-8.
30. Berry MF, Onaitis MW, Tong BC, et al. Feasibility of hybrid thoracoscopic lobectomy and en-bloc chest wall resection. Eur J Cardiothorac Surg 2012;41:888-92.
31. Demmy TL, Nwogu CE, Yendamuri S. Thoracoscopic chest wall resection: what is its role? Ann Thorac Surg 2010; 89:S2142-5.
32. Shikuma K, Miyahara R, Osako T. Transmanubrial approach combined with video-assisted approach for superior sulcus tumors. Ann Thorac Surg 2012;94:e29-30.
33. Bayarri CI, de Guevara AC, Martin-Ucar AE. Initial single-port thoracoscopy to reduce surgical trauma during open en bloc chest wall and pulmonary resection for locally invasive cancer. Interact Cardiovasc Thorac Surg 2013;17:32-5.
34. Zieliński M, Kuzdzał J, Szlubowski A, et al. Transcervical-subxiphoid-videothoracoscopic "maximal" thymectomy--operative technique and early results. Ann Thorac Surg 2004;78:404-9; discussion 409-10.

doi: 10.21037/shc.2017.05.11
Cite this article as: Martin-Ucar AE, Socci L. Thoracic incisions for open surgery. Shanghai Chest 2017;1:20.

Video-assisted thoracoscopic surgery (VATS) conversion to thoracotomy

John Agzarian, Yaron Shargall

Division of Thoracic Surgery, Department of Surgery, Faculty of Health Sciences, McMaster University, St. Joseph's Healthcare Hamilton, Hamilton, Canada

Correspondence to: John Agzarian, MD, MPH, FRCSC. Division of Thoracic Surgery, Department of Surgery, Faculty of Health Sciences, McMaster University, St. Joseph's Healthcare Hamilton, T2105-50 Charlton Ave East, Hamilton ON L8N 4A6, Canada. Email: john.agzarian@medportal.ca.

Received: 15 June 2017; Accepted: 01 August 2017; Published: 30 August 2017.
doi: 10.21037/shc.2017.08.03
View this article at: http://dx.doi.org/10.21037/shc.2017.08.03

Introduction

With the advent of minimally invasive surgery, video-assisted thoracoscopic surgery (VATS) has developed substantial traction since its introduction in the early 1990s (1-4). Despite some initial trepidation regarding comparative safety profile and oncologic equivalence to thoracotomy, VATS approaches are becoming a mainstream technique within the discipline of thoracic surgery (5-7). This minimally invasive approach is currently employed for diagnostic and therapeutic lung surgery, as well as other procedures involving the mediastinum, chest wall, pericardium, esophagus and diaphragm. Emerging data continues to support the safety of VATS with associated decreases in postoperative morbidity, pain scores and hospital length of stay (8-10). In addition, various reports have demonstrated equivalence with regards to oncologic and long-term survival outcomes (11,12). Recent efforts have focused on expanding the application of VATS to high-risk patients with poor preoperative performance status as well as the elderly (13,14).

This increased prevalence of VATS has led to a large paradigm shift in training, where trainees and surgeons alike continue to expand on and adjust their "open" surgery skills to minimally invasive approaches. While some technical concepts are transferrable, the transition has led to increased complexity and a steep learning curve. The latter remains the largest obstacle to widespread application of VATS. As new trained thoracic surgeons continue to expound their minimally invasive armamentarium, the technical considerations distinguishing minimally invasive approaches [including VATS and robotic-assisted thoracic surgery (RATS)] continue to be defined. Most VATS training principles focus on correctly choosing the appropriate VATS candidate and outlining unique technical approaches to thoracoscopic surgery. Just as valuable however is to consider when VATS should not be considered, and even more important, when a case that began as VATS should be converted to thoracotomy, and if so, then how. This chapter outlines some of the technical differences in choosing the different surgical approaches, and outlines contraindications to VATS, and the various considerations when converting from thoracoscopic surgery to open thoracotomy.

Contraindications to VATS

The scope of thoracoscopic approaches continues to evolve and expand. Surgeons (as one would expect) are steadily and safely pushing the envelope of VATS, and there are now few complete limitations of VATS. Minimally invasive thoracic surgeons are eager to demonstrate the limitless scope of VATS and in so doing have demonstrated remarkable proficiency and outcomes. Nonetheless, a selection bias exits and VATS technical aptitude continues to demonstrate large variance (15).

Over the last 3 decades, the contraindications of VATS have continued to decrease. Surgeons have been able to extend indications and overcome previous challenges. Historically, contraindications to VATS included: prior chest surgery, neoadjuvant chemotherapy or radiation, central or endobronchial lesions, chest wall involvement and vessel involvement (16). Today the only documented absolute contraindication to VATS is the inability to achieve adequate visualization of the hemithorax. Patients who cannot tolerate single lung ventilation and situations in which lung isolation is not possible (previous pneumonectomy on the contralateral side, challenging airway anatomy, technical challenges with double-lumen endotracheal tube placement or bronchial blockers) typically are not amenable to thoracoscopic approaches. However, brief operations (bullectomy or pleural/lung biopsies) can be undertaken via VATS using intermittent apnea, without the need for thoracotomy. In addition, the use of VATS for spontaneously breathing patients continues to increase, with the assistance of regional anesthesia and conscience sedation. This technique has been safely employed for procedure involving the lung, pleura and mediastinum and has recently expanded to include complex airway surgery, bronchoplastic procedures and vascular resections/reconstruction (17-30).

Relative contraindications to VATS include: bronchoplastic procedures (sleeve resection), chest wall deformities limiting visualization, large lesions that limit visibility and would ultimately require a large incision and rib spreading for extraction (a threshold of 6 cm has been previously reported) (21), central/hilar lesions requiring proximal and/or intrapericardial dissection, dense adhesions (due to infectious etiology or previous surgery) requiring decortication, calcified hilar adenopathy, neoadjuvant chemotherapy or radiation with challenging dissection, or extensive chest wall involvement. The limitations of VATS in redo surgery have been challenged recently, particularly given the fact that thoracoscopic approaches facilitate adhesiolysis and visualization of the pleural space. The question of VATS as an oncologically sound technique in the setting of non-small cell lung cancer (NSCLC) with N2 disease has been debated. Some argue that complete mediastinal lymphadenectomy is limited in VATS, however published retrospective series have repeatedly demonstrated comparable efficacy of nodal dissection between both VATS and thoracotomy (31-33).

It is important to note however, that these only stand as relative contraindications. Many surgeons are not limited by these factors and consider VATS as an advantage in these scenarios, particularly due to heightened visualization. Nonetheless, for less experience individuals, the above represent obstacles that tend to sway the surgical decision-making towards thoracotomy. Even when VATS techniques are chosen in such scenarios, there is often a low threshold for conversion intraoperatively.

VATS adjunctive to thoracotomy

An important distinction needs to be made between conversion to thoracotomy and the planned use of thoracoscopy as an adjunct to an already planned open resection via thoracotomy. Given the amply available technology, surgeons may often choose to perform an intra-operative VATS exploration prior to thoracotomy. In such a setting, this should not be considered a conversion. Instead we offer the term "adjunctive VATS" to clarify the distinction. Surgeons often begin with a thoracoscopic port placed in the anterior axillary line anywhere in the 8th–9th intercostal space and ultimately utilize that incision as the site for chest tube insertion at the end of the procedure. This is distinctively different from aborting a planned VATS procedure and performing a thoracotomy.

This technique is often utilized when undertaking a planned large resection. Even in the era where preoperative staging technology continues to improve and minimize false negatives. In the setting of extensive surgery, surgeons can utilize VATS as a prior assessment of the hemithorax and the pleural space prior to committing the patient to a thoracotomy. This can prove advantageous in evaluating for disseminated pleural carcinomatosis, examining pleural effusions prior to resection in order to rule out metastatic disease, and in performing biopsies in order to establish a definitive diagnosis. Moreover, intraoperative pleuroscopy can assist in planning a thoracotomy to locate the ideal location of the incision. This is particularly true in the setting of large tumour involving the chest wall or Pancoast tumors. Adjunctive VATS is not only limited to a single port, and often multiple other ports can be used to facilitate the insertion of minimally invasive VATS instruments in order to assist with the planned resection. At times, parts of the resection can be performed thoracoscopically (such as vessel division, fissure completion, nodal dissection) and thereafter, the remaining extended resection can follow via thoracotomy.

The use of VATS as an adjunct to an open resection is encouraged in the following scenarios: when undergoing a major resection to rule out metastases and confirm resectability, to outline anatomy that may be distorted by the underlying pathology, in the setting of diagnostic uncertainty, to establish a definitive tissue diagnosis when one could not be performed prior to surgery, to complete mediastinal/hilar lymph node biopsies for nodal stating, to perform adhesiolysis in the apex of the hemithorax or the diaphragmatic sulcus (where visualization during thoracotomy is relatively limited), or in the setting of chest wall involvement requiring concomitant chest wall resection.

Causes of conversion to thoracotomy

Published reports outlining the conversion rate from VATS procedures to thoracotomy vary, and differ based on surgeon experience, institutional practice patterns and type of resection. Published rates of conversion range from as low as 2% to as high as 23% (24-40). Early single-center cohort studies by Krasna *et al*. [1996] (41) and Yim *et al*. [1995] (42) reported conversion rates of 8% and 11% respectively, and nearly one-third of conversions were for non-oncologic reasons. Continued experience has led to a decrease in reported conversion rates. In a review of 1,093 VATS procedures by Imperatori *et al*. in 2008, the conversion rate was only 1.7% (43). Similarly, a 2013 single-institution cohort analysis at Duke University of 916 attempted VATS lobectomies reported a 4% conversion rate (44). The evolution of time and heightened experience has led to greater surgeon resolve in pursing VATS approaches for operations that would only be deemed feasible via thoracotomy. Moreover, continued technologic advances have also allowed for an expansion of technique. Better equipment that is easier to use allows for easier and safer conduct of operations. Accordingly, this has certainly contributed to the decrease in conversion rates of VATS operations.

In their review of VATS contraindications and complications, Hanna *et al*. identify four distinct categories for causes of conversion from VATS to thoracotomy (16).

Intraoperative complications

Intraoperative complications typically are the result of a surgical misadventure due to surgical error or a complicated procedure leading to an adverse outcome (either due to difficult dissection or poor technique). The most concerning complication leading to conversion is bleeding from the pulmonary artery or arterial branches. This can be a result of inadvertent injury during dissection or excessive tension during retraction leading to vascular rupture. Indeed, this can even be misconstrued as stapler malfunction, when in reality it represents an operative error. Injuries can also occur to the pulmonary vein leading to bleeding, esophagus, or bronchus.

Operative features concerning for bleeding include dense adhesions secondary to prior intervention, neoadjuvant chemotherapy/radiation or an infectious etiology. Moreover, large tumors or masses may often limit adequate visualization and require excessive force of retraction. Such a force can lead to vessel rupture and dangerous bleeding.

Despite a large variance in rates of conversion, the literature demonstrates that bleeding and vascular anatomical variations remain a major cause for conversion from VATS to a thoracotomy. This is a consistent finding irrespective of how often conversion occurs. In a retrospective review of 63 VATS lobectomies, Flores *et al*. converted 12 cases (1% conversion rate), with 7 conversions (58%) of bleeding or inadvertent stapling of the main pulmonary artery of the main pulmonary vein (45). Similarly, in a published abstract reviewing the results of 1,009 VATS lobectomies from Cornell, there were 66 (6.5%) conversions, and of those 21.2% were secondary to bleeding (46).

Technical challenges

In contrast to surgical error, technical challenges can also lead to conversion to thoracotomy, and are the result of equipment failure or limited visualization rendering the VATS approach either non-feasible or unsafe. Examples of technical causes of conversion include stapler malfunction, poor visualization or limited access to necessary minimally-invasive equipment. Although staple line malfunctions can be associated with bleeding (particularly when attempting to ligate pulmonary vessels), these challenges may not necessitate emergent conversion, and are often results of poor procedural progression. Of note, it is important to ensure proper utilization of equipment for optimal results. For example, the use of metal clips during hilar or parenchymal dissection can interfere with the appropriate stapler function and lead to significant bleeding.

Anatomical problems

Anatomical problems are typically patient-related factors that challenge the surgeon's ability to complete a VATS procedure. This type of limitation is more frequent when performing anatomic lung resections, esophagectomies or mediastinal VATS surgery. Expertise obviously serves as a key determinant in a surgeon's ability to navigate anatomical challenges and complex dissection. Examples of anatomic features complicating VATS procedures include: fused fissures, calcified lymph nodes in close proximity to pulmonary artery branches, dense pleural adhesions with limited working space or visualization, chest wall invasion necessitating a large incision, aberrant anatomy, morbid obesity or large tumour size with difficulty removing the specimen via a standard utility incision.

In order to anticipate and possibly prevent conversions due to anatomic abnormalities, it is imperative to carefully evaluate the patient's preoperative imaging prior to embarking on an unexpectedly challenging VATS procedure. CT scans of the chest with contrast are an integral and necessary part of the preoperative work-up for most patients, and provide fine detail outlining any aberrant anatomy (particularly abnormal vasculature or airway changes, as well as involvement of adjacent structures)

The presence of calcifications and dense hilar adhesions should always alert the surgeon as to the probability of a difficult dissection, and potentially a low threshold for conversion. Samson *et al*. and Park *et al*. identify hilar calcification and fibrosis as the inciting cause of conversion in 37% and 41% of lobectomy conversions from VATS to thoracotomy (47-49).

During VATS, non-anatomic or sublobar resection, it can sometimes be difficult to identify a specific lesion. This is more typical with central small lesions, partly solid or pure ground glass opacities. If the anatomic location of a nodule is not easily correlated between preoperative imaging and thoracoscopy, then careful palpation of the lung may need to be performed by thoracotomy—although a VATS utility incision may also prove valuable for this purpose.

Oncological conditions

Oncological conditions represent the most relative indication for conversion, and heavily rely on surgeon experience and comfort. The presence of mediastinal nodal disease requiring mediastinal lymphadenectomy can serve as an indication for conversion to some surgeons in order to assure adequate removal of lymph nodes. Local invasion is also a common cause of conversion, however, with improved technology and precision of preoperative imaging, invasion has become much less of a surprise to surgeons than historically. Finally, inadequate oncologic surgery via VATS is a clear cause to perform a thoracotomy for adequate resection.

The decision to convert

As important as the technique of conversion, is the ability to make a timely and systematic decision to abort a VATS procedure. The choice to convert to a thoracotomy is not only made at times of emergencies or to deal with intra-operative catastrophes. Given the large difference in surgeon expertise and comfort the determinants of need for conversion will always vary. Nonetheless, surgeons should have a clear perception of their abilities and level of comfort and identify individualized criteria serving as markers of the need for conversions.

A balance needs to be struck between deterministic conversion, and a surgeon's ability to push the envelope, accept new challenges and enhance his or her skills. This is often a fine balance that evolves over time. However, it is important to note that anticipatory/planned conversion, prior to any major incident allows for the best outcomes and the safest completion of the procedure. One must anticipate the complexity of an operation and develop a sense of anticipation when continued VATS may prove excessively challenging. Preoperative imaging identifying features of pleural thickening and calcifications can assist in identifying VATS procedures at high risk of conversion (42).

Certain characteristics can allow surgeons to anticipate the need for conversion prior to any injury or forced thoracotomy. Failure to progress via thoracoscopy is always a sign of possible need for conversion. Of course, progress is a vaguely defined concept lacking specific qualifiers. Nonetheless, surgeons should have an internal assessment of their ability to progress through the various technical steps of an operation. Other identifiers of a low threshold for conversion include: calcified lymph nodes, extensive perivascular scarring, extensive pleural adhesions limiting visualization or the need for proximal vascular control.

Most importantly, surgeons must be aware that a conversion from VATS to thoracotomy does not represent surgical failure. The primary goal is the safe completion of a technically sound operation, following good surgical and/or oncologic principles. VATS and thoracotomy are means that are available to the surgeon for the completion of the task. A safe and planned conversion does not constitute technical incompetence. This is an important fallacy that should not guide surgical decision making when performing any VATS operation.

Conversion techniques

There are essentially two types of conversions: planned and emergent. Based on the type of conversion, the approach to thoracotomy can differ. Once the decision to convert to VATS is made, several important conversion principles need to be followed. These generally apply to the context of emergent and planned conversion.

Firstly, it is important to maintain visualization during the conversion. This can guide the incision, and also ensures safety. With the thoracoscope in place, it is easy for the surgeon to have the assistant hold the camera in place to maintain visualization of the hemithorax. The camera allows for choice of the correct interspace for entry into the chest and assists in surgical planning. In the setting of bleeding from a pulmonary arterial branch or the pulmonary vein, it is crucial to maintain visualization of the bleeding vessel. Usually, the bleeding is temporarily controlled with local compression and pressure. If during conversion, loss of control occurs, visualization can alert the surgeon for the need to re-establish control or expedite the conversion. The camera can also serve the added benefit of maintaining good communication within the operating room, and keeping team members aware as to the nature of the situation. For example, if the anesthesiologist can see that bleeding is controlled, then he or she can accordingly plan for resuscitation as necessary. Finally, if conversion is due to limited visualization due to dense adhesions requiring decortication, the camera is an important adjunct to assist in performing adhesiolysis even through the thoracotomy incision. This is particularly useful when mobilizing the lung in the apex of the lung or the diaphragmatic sulcus.

If bleeding is present, it is imperative to have thoracoscopic control of bleeding while performing the thoracotomy. When bleeding is present, the focus should first be on achieving control without worsening the situation—not on the performance of the thoracotomy. Several steps are important when substantial bleeding is encountered. Keeping visualization is the first key step. The assistant holding the camera should retract the camera far enough to prevent soiling the lens with blood, and yet maintain an accurate view of the site of bleeding. Adequate suctions must be available, and should be used by the assistant and surgeon to maintain a clear field. When substantial bleeding exists, two suctions should be available.

Certain maneuvers can also be used to temporarily control bleeding while conversion occurs. The most conservative approach is to tamponade the bleeding with gentle pressure using a pledgetted thoracoscopic instrument. The pulmonary vasculature represents a low-pressure system, and accordingly, local pressure can often sufficiently control bleeding. It is crucial to resist the tendency to apply excessive pressure over a bleeding area, even if only partial control is obtained. Most disastrous outcomes are a result of a series of actions leading to a larger, uncontrollable tear, usually secondary to excessive force over delicate vascular structures. As such, if the primary surgeon is to perform the thoracotomy, he/she should give clear and deliberate instructions to the assistant providing local pressure, while instructing the rest of the team and opening the chest. Other control measures include the use of topical hemostatic agents, thoracoscopic clipping of bleeding vessels or intracorporeal suturing. If an initially controlled situation begins to bleed again while converting, focus should be placed on re-establishing control if possible prior to expediting conversion. Occasionally, retracting and pushing the lung on top of a bleeding vessel might help with partial control, until safe open access is achieved.

The choice of incision needs to be guided based on the operation being performed and the location of bleeding (if that is the reason for conversion). In a controlled situation, the use of muscle sparing thoracotomies can serve as a middle-ground between a large posterolateral thoracotomy and minimally invasive techniques. Preserving the latissimus dorsi and serratus anterior muscles potentially minimizes post-operative pain, and does not require extensive operating time. Based on the extent of thoracoscopic dissection already performed, the thoracotomy incision may be tailored for the completion of the procedure. If several steps of the operation had already been completed, smaller incisions may be feasible for the completion of the procedure. Of course, in the context of an emergent conversion for bleeding, one must not compromise adequate exposure for fear of post-operative pain.

Planning the thoracotomy incision can often be challenged by the presence of the VATS incisions/ports in place. In an emergent situation, a standard posterolateral thoracotomy should be performed irrespective of the incisions already present. VATS incisions, which are typically small and not associated with any rib spreading will add minimal morbidity to the thoracotomy being performed and should be disregarded when the need for quick conversion exists. In the setting of a planned conversion, the surgeon may choose to tailor their incision in order to incorporate one or more of the VATS incisions in place. For example, a more anterior thoracotomy can be performed in the 4th or 5th intercostal space in order to incorporate the most anterior access/utility incision (which is often the largest in the setting of VATS). In fact, some surgeons plan their thoracoscopic incisions along the line of a thoracotomy incision should one be required. Finally, the camera port can continue to be used for visualization, and at the end of the procedure can serve as the chest tube insertion site.

Most importantly, effective and clear communication is vita during the process of conversion. In addition to the technical aspects/considerations, the surgeon should demonstrate strong leadership skills—notifying the operative and anesthesia teams of the situation at hand, providing status updates, and clarifying concrete steps of action. With the entire team focused and aware, a series of clear instructions and demands should be given outlining the need for equipment, additional intravenous access, blood products and personnel. At such a critical juncture, communication is as important as the technical maneuvers to be performed. The surgeon should maintain constant dialogue with the anesthesiologist and together, both should outline a resuscitative and operative plan.

Outcomes following conversion

The core tenant of performing minimally invasive surgery is to ensure safety and not to comprise surgical outcomes for the sake of a smaller incision. Evidence demonstrates that complication rates are greater following VATS conversions as compared to procedures entirely performed thoracoscopically. Retrospective cohort studies have shown that as compared to completed VATS operations, VATS conversions were associated with increased risk of postoperative atrial fibrillation, increased length of stay, increased duration of chest tube drainage, as well as longer operating time and greater estimated blood loss (47,50). Interestingly, these findings are not echoed when comparing converted VATS operations to planned resections via thoracotomy. In such a context, VATS conversion has only been independently associated with longer operating time, but no difference in immediate and long-term postoperative outcomes (16,51). These findings are to be expected, given that cases requiring conversion likely represent a subset of attempted VATS procedures with increased complexity and accordingly, greater likelihood of postoperative complications.

A large-scale collaborative effort by the European Society of Thoracic Surgeons (ESTS), combining the results of six European centres evaluated the associated complication of VATS lung resection in 3,076 patients (52). The reported conversion rate was 5.5% (21.8% for oncologic reasons, 29.4% for technical reasons, and 48.8% for operative complications). The data demonstrated that while infrequent, VATS intraoperative complications were not always necessarily related to surgeon experience, highlighting the importance of planning and preparation. Importantly, patients who had intraoperative complications also had associated post-operative complications with worsened immediate outcomes. Accordingly, in their publication, the ESTS outlines recommendations and preventive measures resulting from panel discussion reflective of the complications presented in the report. These are valuable, and should be seriously evaluated and considered by surgeons performing VATS surgery (52).

Future considerations

Much of the literature evaluating VATS conversions is based on retrospective single-institution reviews and is inherently subject to selection and recall bias. More importantly, the majority of publications on the topic of conversion to thoracotomy are in patients undergoing lobectomies. While conversions during sub-lobar resections are less likely, they do constitute a small subset of converted procedures—typically in the setting of an unidentifiable nodule not amenable to resection. Moreover, the indications for VATS continue to expand, with a large array of operations being performed thoracoscopically, including mediastinal and foregut surgery. With a growing procedure base, the causes for conversion will continue to change based on the associated technical challenges of difference procedures. For example, minimally invasive esophagectomies with a thoracoscopic component are less likely to require conversion due to pulmonary arterial bleeding. However, a conversion to thoracotomy may be the result of inadvertent airway injury, inadequate resection margins or inability to perform a proper anastomosis. As the prevalence of VATS operations and indications continue to grow, the incidence of conversions will naturally continue to decrease given the heightened experience and comfort. However, the implications surrounding conversions will continue to evolve, and will require careful analysis in order to improve patient outcomes and surgeon aptitude.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Levi JF, Kleinmann P, Riquet M, et al. Percutaneous parietal pleurectomy for recurrent spontaneous pneumothorax. Lancet 1990;336:1577-8.
2. Lewis RJ, Sisler GE, Caccavale RJ. Imaged thoracic lobectomy: should it be done? Ann Thorac Surg 1992;54:80-3.
3. Nathanson LK, Shimi SM, Wood RA, et al. Videothoracoscopic ligation of bulla and pleurectomy for spontaneous pneumothorax. Ann Thorac Surg 1991;52:316-9.
4. Maziak DE, McKneally MF. Video-assisted thoracic surgery. Ann Thorac Surg 1995;59:780-1.
5. Ceppa DP, Kosinski AS, Berry MF, et al. Thoracoscopic lobectomy has increasing benefit in patients with poor pulmonary function: a Society of Thoracic Surgeons Database analysis. Ann Surg 2012;256:487-93.
6. Seder CW, Salati M, Kozower BD, et al. Variation in Pulmonary Resection Practices Between The Society of Thoracic Surgeons and the European Society of Thoracic Surgeons General Thoracic Surgery Databases. Ann Thorac Surg 2016;101:2077-84.
7. Falcoz PE, Puyraveau M, Thomas PA, et al. Video-assisted thoracoscopic surgery versus open lobectomy for primary non-small-cell lung cancer: a propensity-matched analysis of outcome from the European Society of Thoracic Surgeon database. Eur J Cardiothorac Surg 2016;49:602-9.
8. Villamizar NR, Darrabie MD, Burfeind WR, et al. Thoracoscopic lobectomy is associated with lower morbidity compared with thoracotomy. J Thorac Cardiovasc Surg 2009;138:419-25.
9. Paul S, Altorki NK, Sheng S, et al. Thoracoscopic lobectomy is associated with lower morbidity than open lobectomy: a propensity-matched analysis from the STS database. J Thorac Cardiovasc Surg 2010;139:366-78.
10. Agzarian J, Fahim C, Shargall Y, et al. The Use of Robotic-Assisted Thoracic Surgery for Lung Resection: A Comprehensive Systematic Review. Semin Thorac Cardiovasc Surg 2016;28:182-92.
11. Whitson BA, Groth SS, Duval SJ, et al. Surgery for early-stage non-small cell lung cancer: a systematic review of the video-assisted thoracoscopic surgery versus thoracotomy approaches to lobectomy. Ann Thorac Surg 2008;86:2008-16; discussion 2016-8.
12. Whitson BA, Andrade RS, Boettcher A, et al. Video-assisted thoracoscopic surgery is more favorable than thoracotomy for resection of clinical stage I non-small cell lung cancer. Ann Thorac Surg 2007;83:1965-70.
13. Bravo Iñiguez CE, Armstrong KW, Cooper Z, et al. Thirty-Day Mortality After Lobectomy in Elderly Patients Eligible for Lung Cancer Screening. Ann Thorac Surg 2016;101:541-6.
14. Donahoe LL, de Valence M, Atenafu EG, et al. High Risk for Thoracotomy but not Thoracoscopic Lobectomy. Ann Thorac Surg 2017;103:1730-5.
15. Gezer S, Avcı A, Türktan M. Cusum analysis for learning curve of videothoracoscopic lobectomy. Open Med (Wars) 2016;11:574-7.
16. Hanna JM, Berry MF, D'Amico TA. Contraindications of video-assisted thoracoscopic surgical lobectomy and determinants of conversion to open. J Thorac Dis 2013;5 Suppl 3:S182-9.
17. Lesser TG. Laser application enables awake thoracoscopic resection of pulmonary nodules with minimal access. Surg Endosc 2012;26:1181-6.
18. Noda M, Okada Y, Maeda S, et al. Is there a benefit of awake thoracoscopic surgery in patients with secondary spontaneous pneumothorax? J Thorac Cardiovasc Surg 2012;143:613-6.
19. Pompeo E, Tacconi F, Mineo D, et al. The role of awake video-assisted thoracoscopic surgery in spontaneous pneumothorax. J Thorac Cardiovasc Surg 2007;133:786-90.
20. Rocco G, La Rocca A, Martucci N, et al. Awake single-access (uniportal) video-assisted thoracoscopic surgery for spontaneous pneumothorax. J Thorac Cardiovasc Surg 2011;142:944-5.
21. Pompeo E, Mineo TC. Awake pulmonary metastasectomy. J Thorac Cardiovasc Surg 2007;133:960-6.
22. Rocco G, Romano V, Accardo R, et al. Awake single-access (uniportal) video-assisted thoracoscopic surgery for peripheral pulmonary nodules in a complete ambulatory setting. Ann Thorac Surg 2010;89:1625-7.
23. Tseng YD, Cheng YJ, Hung MH, et al. Nonintubated needlescopic video-assisted thoracic surgery for management of peripheral lung nodules. Ann Thorac Surg 2012;93:1049-54.
24. Mineo TC, Pompeo E, Mineo D, et al. Awake nonresectional lung volume reduction surgery. Ann Surg 2006;243:131-6.
25. Pompeo E, Rogliani P, Tacconi F, et al. Randomized comparison of awake nonresectional versus nonawake resectional lung volume reduction surgery. J Thorac Cardiovasc Surg 2012;143:47-54, 54.e1.
26. Tacconi F, Pompeo E, Fabbi E, et al. Awake video-assisted pleural decortication for empyema thoracis. Eur J Cardiothorac Surg 2010;37:594-601.
27. Pompeo E, Tacconi F, Frasca L, et al. Awake thoracoscopic

bullaplasty. Eur J Cardiothorac Surg 2011;39:1012-7.
28. Pompeo E, Tacconi F, Mineo TC. Awake video-assisted thoracoscopic biopsy in complex anterior mediastinal masses. Thorac Surg Clin 2010;20:225-33.
29. Pompeo E, Mineo TC. Awake operative videothoracoscopic pulmonary resections. Thorac Surg Clin 2008;18:311-20.
30. Li J, Wang W, Jiang L, et al. Video-Assisted Thoracic Surgery Resection and Reconstruction of Carina and Trachea for Malignant or Benign Disease in 12 Patients: Three Centers' Experience in China. Ann Thorac Surg 2016;102:295-303.
31. Sagawa M, Sato M, Sakurada A, et al. A prospective trial of systematic nodal dissection for lung cancer by video-assisted thoracic surgery: can it be perfect? Ann Thorac Surg 2002;73:900-4.
32. Kaseda S, Hangai N, Yamamoto S, et al. Lobectomy with extended lymph node dissection by video-assisted thoracic surgery for lung cancer. Surg Endosc 1997;11:703-6.
33. Watanabe A, Koyanagi T, Ohsawa H, et al. Systematic node dissection by VATS is not inferior to that through an open thoracotomy: a comparative clinicopathologic retrospective study. Surgery 2005;138:510-7.
34. Hennon M, Sahai RK, Yendamuri S, et al. Safety of thoracoscopic lobectomy in locally advanced lung cancer. Ann Surg Oncol 2011;18:3732-6.
35. McKenna RJ Jr, Houck W, Fuller CB. Video-assisted thoracic surgery lobectomy: experience with 1,100 cases. Ann Thorac Surg 2006;81:421-5; discussion 425-6.
36. Roviaro G, Varoli F, Vergani C, et al. Video-assisted thoracoscopic major pulmonary resections: technical aspects, personal series of 259 patients, and review of the literature. Surg Endosc 2004;18:1551-8.
37. Solaini L, Prusciano F, Bagioni P, et al. Video-assisted thoracic surgery (VATS) of the lung: analysis of intraoperative and postoperative complications over 15 years and review of the literature. Surg Endosc 2008;22:298-310.
38. Walker WS, Codispoti M, Soon SY, et al. Long-term outcomes following VATS lobectomy for non-small cell bronchogenic carcinoma. Eur J Cardiothorac Surg 2003;23:397-402.
39. Gharagozloo F, Tempesta B, Margolis M, et al. Video-assisted thoracic surgery lobectomy for stage I lung cancer. Ann Thorac Surg 2003;76:1009-14; discussion 1014-5.
40. Nomori H, Horio H, Naruke T, et al. What is the advantage of a thoracoscopic lobectomy over a limited thoracotomy procedure for lung cancer surgery? Ann Thorac Surg 2001;72:879-84.
41. Krasna MJ, Deshmukh S, McLaughlin JS. Complications of thoracoscopy. Ann Thorac Surg 1996;61:1066-9.
42. Yim AP. Port-site recurrence following video-assisted thoracoscopic surgery. Surg Endosc 1995;9:1133-5.
43. Imperatori A, Rotolo N, Gatti M, et al. Peri-operative complications of video-assisted thoracoscopic surgery (VATS). Int J Surg 2008;6 Suppl 1:S78-81.
44. Villamizar NR, Darrabie M, Hanna J, et al. Impact of T status and N status on perioperative outcomes after thoracoscopic lobectomy for lung cancer. J Thorac Cardiovasc Surg 2013;145:514-20; discussion 520-1.
45. Flores RM, Ihekweazu U, Dycoco J, et al. Video-assisted thoracoscopic surgery (VATS) lobectomy: catastrophic intraoperative complications. J Thorac Cardiovasc Surg 2011;142:1412-7.
46. Rahouma M, Kamel M, Harrison S, et al. MINI01.07: Predictors of Conversion to Thoracotomy in VATS Lobectomy Patients: Topic: Surgery. J Thorac Oncol 2016;11:S260.
47. Samson P, Guitron J, Reed MF, et al. Predictors of conversion to thoracotomy for video-assisted thoracoscopic lobectomy: a retrospective analysis and the influence of computed tomography-based calcification assessment. J Thorac Cardiovasc Surg 2013;145:1512-8.
48. Park JS, Kim HK, Choi YS, et al. Unplanned conversion to thoracotomy during video-assisted thoracic surgery lobectomy does not compromise the surgical outcome. World J Surg 2011;35:590-5.
49. Mason AC, Krasna MJ, White CS. The role of radiologic imaging in diagnosing complications of video-assisted thoracoscopic surgery. Chest 1998;113:820-5.
50. Sawada S, Komori E, Yamashita M. et al. Evaluation of video-assisted thoracoscopic surgery lobectomy requiring emergency conversion to thoracotomy. Eur J Cardiothorac Surg 2009;36:487-90.
51. Jones RO, Casali G, Walker WS. Does failed video-assisted lobectomy for lung cancer prejudice immediate and long-term outcomes? Ann Thorac Surg 2008;86:235-9.
52. Decaluwe H, Petersen RH, Hansen H, et al. Major intraoperative complications during video-assisted thoracoscopic anatomical lung resections: an intention-to-treat analysis. Eur J Cardiothorac Surg 2015;48:588-98; discussion 599.

doi: 10.21037/shc.2017.08.03
Cite this article as: Agzarian J, Shargall Y. Video-assisted thoracoscopic surgery (VATS) conversion to thoracotomy. Shanghai Chest 2017;1:31.

Left sided lobectomies

Benedetta Bedetti[1], Philipp Schnorr[1], Davide Patrini[2], Marco Scarci[2], Joachim Schmidt[1]

[1]Department of Thoracic Surgery, Malteser Hospital, Bonn, Germany; [2]Department of Thoracic Surgery, University College London Hospitals, London, UK

Correspondence to: Benedetta Bedetti. Department of Thoracic Surgery, Malteser Hospital, Von-Hompesch-Str. 1, 53127, Bonn, Germany. Email: benedetta.bedetti@gmail.com.

Received: 24 May 2017; Accepted: 25 May 2017; Published: 30 May 2017.
doi: 10.21037/shc.2017.05.14
View this article at: http://dx.doi.org/10.21037/shc.2017.05.14

Introduction

Lobectomies can be performed in case of both malignant and non-malignant lung diseases. Preoperative assessment is fundamental and should always include lung function tests, as the patients should have an adequate pulmonary reserve in order to tolerate the resection. Echocardiography and spiroergometry should be performed, if needed, in correlation with the patient's previous medical history.

In patients with proven or suspect of lung cancer, further preoperative staging is required and it includes chest computed tomography, positron emission tomography scan, and, if indicated, endobronchial ultrasound-guided mediastinal lymph node biopsy or mediastinoscopy. In planning the resection, the surgeon should be sure that the tumour can be dissected from the main central structures, so that a safe, and oncological radical, resection can be performed.

Video-assisted thoracoscopic (VATS) lobectomies are increasingly performed as standard for early stage lung cancer, so the indication for open approaches are evolving and often depends on the surgeon's experience with VATS techniques (1,2).

Open lobectomies are still generally performed in case of large tumours or in more difficult resections, as the open technique allows more space and so a better access and control of the intrathoracic structures.

Operative technique

Positioning

As in most thoracic surgery procedures, whether done as a VATS or open, the procedure is performed in right lateral decubitus position (*Figure 1*).

The most important but also avoidable hazards regarding the positioning are injuries due to nerve stretching or compression at pressure points. Every clinic should have their own positioning standard. An axillary roll should be placed to prevent the injury of the brachial plexus or

shoulder. All pressure points should be padded. The patient is held and stabilized by a stiff bean bag, which should hug the patient bilaterally for better support.

Incision

The standard approaches be performed through a posterolateral thoracotomy or a muscle-sparing anterolateral thoracotomy, as preferred from the authors (*Figure 1*).

The Dartevelle incision gives a better access to the apex, whereas the hemiclamshell incision can be used to have a better access of the anterior mediastinum and subclavian vessels.

Exposition

After the beginning of one-lung ventilation the skin incision is performed on the forth intercostal space, in case of anterolateral thoracotomy. Whenever possible the latissimus dorsi muscle should only be elevated and retracted, but not incised. The serratus anterior is also only split in the direction of his fibres. The underlying intercostal muscles are cut carefully in the lower portion of the intercostal space to avoid injuries of the neurovascular bundle. The intercostal incision is performed with the help of a Mikulicz liver retractor posteriorly to the level of the paraspinal muscles and anterior to the curve of the ribs. Then one (or two) rib spreaders can be positioned, according to the surgeon's preference.

Figure 1 Positioning of the patient and marking points to perform an anterolateral thoracotomy.

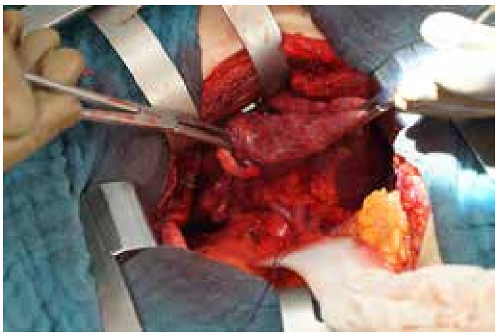


Figure 2 Dissection of the superior pulmonary vein.

Next step is the mobilization of the lung to get a better exposition to verify the indication or exclude possible contraindications, e.g. tumorous pleural dissemination or invasion of hilar structures.

Left upper lobectomy

Operation

Depending on the surgical indication, the different steps of the surgery can be performed in a different order. As lung cancer is the indication for most lobectomies, we will describe the classical technique for left upper lobe resections, starting with the division of the superior pulmonary vein (SPV).

(I) Isolation and division of the SPV:

The left superior pulmonary vein is to be exposed by retracting the lung inferiorly and incising the anterior mediastinal pleura, paying attention to the left phrenic nerve. After opening the pleura, the superior and inferior pulmonary vein should be identified to exclude a common confluence of the pulmonary venous blood support (*Figure 2*). Particular attention should be payed to the lingular branches, making sure that they originate from the SPV. Now the vein can be cleared with a blunt preparation from all overlying tissue in its whole circumference. The vein can be grasped with broad forceps/graspers during the dissection. Note that behind the superior margin of the SPV normally is located the arterial branch for the 3rd segment (A3). Then the SPV can be divided with a stapler or a suture ligature. In this last case, a vascular clamp is applied proximally on the SPV, then the vein is divided and closed with a vascular suture, to avoid the ligature falling off the SPV. Sometimes the extrapericardial length of the vein is too short to put a ligature safely, so in this particular situation the pericardium has to be opened and the vein has to be divided intrapericardially.

(II) Dissection and division of the arterial branches for the upper lobe:

Continuing the opening of the mediastinal pleura overlying the aortopulmonary window and then posteriorly along the anterior margin of the esophagus allows the exposition of the underlying pulmonary artery (PA).

The dissection of the segmental arteries can be very challenging because of their numerous anatomic variations. The most common order should be: A3, A1, A2, A4 and A5 (or A4+5). Essentially, every surgeon has to identify every branch of the PA based on its position and topography. To start, retract the lobe inferiorly and the first branches that should be identified are the A3 and right behind the A1+2a. Be aware that there can also be a common branch for A3+1+2, which has to be dissected very carefully. Then, retracting the lung anteriorly, occasionally a small branch can be identified as the A1+2b+c. The fissure should be completely opened or at least long enough to identify the last posterior branches to the left upper lobe (A4+5) and the first lower lobe branch (A6). Normally the A4+5 is to be found distally from A6, but it can also come from A8. All the branches are to be separately ligated, stapled or clipped (*Figure 3*). Finally, complete the anterior and posterior fissures if not preformed yet.

(III) Dissection and division if the left upper lobe bronchus:

Next and last step is to dissect and divide the left

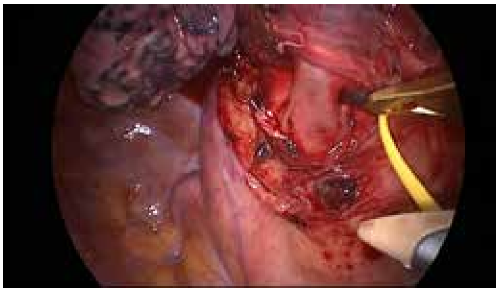


Figure 3 Exposition of one of the subsegmental branches of the pulmonary artery (foto taken with the perspective of the thoracoscope).

Figure 4 Left upper lobe after removal, hilar anatomy.

upper lobe bronchus. Retracting the lobe anteriorly, roll the interlobar pulmonary artery posteriorly and try to palpate the gap between the two lobar bonchi. After identifying the upper lobe bronchus, the best way to dissect it is to bluntly strip with a peanut the bronchus and the peribronchial lymph nodes distally to become part of the lobar specimen. Usually, the best way to divide the bronchus is using a stapler. In positioning the stapler, make sure that the whole bronchus is included but that the lower lobe bronchus is not constricted. To check this, the anaesthesiologist can help by inflate the lower lobe or pass the bronchoscope in the left bronchial system (*Figure 4*).

Completion

In case of lung tumors, a mediastinal lymph node dissection and should always be performed for staging. Lymph nodes in station 5 and 6 are removed from the space between the aorta and the main PA. Station 4 lymph nodes can be reached by retracting the left PA and exposing the tracheobronchial angle anteriorly.

The dissection in the aortopulmonary window should be carried on close to the PA to avoid the injury of the recurrent laryngeal nerve.

The infra-carinal lymph nodes (station 7) should be approached from behind, opening the plane between the esophagus and left main bronchus.

The inferior pulmonary ligament should also be taken down, if not already done. In doing this, the lymph nodes in station 8 and 9 can be removed and the lung can be mobilized, allowing a better expansion of the remaining lung in the thoracic cavity.

Note that in case of pulmonary sequestration a systemic artery could be located in the pulmonary ligament, so the dissection must be particularly careful.

Station 10 and 11 lymph nodes are normally removed during the procedure together with the lobe or singularly during the exposition of other structures (3).

Always check for air leaks of the remaining lower lobe and the bronchial stump under warm saline irrigation with a pressure up to 30 cm H_2O. A careful hemostasis should be performed prior closure of the chest. One or two chest tubes are then placed and the ribs are approximated with four single heavy absorbable pericostal sutures. Before rib approximation, the remaining lung should be inflated, checking that it does not rotate during this manoeuvre.

Left lower lobectomy

Operation

The left lower lobectomy is under normal conditions considered the easiest anatomic resection in lung surgery and the surgery involves three main steps, similarly to the left upper lobectomy.

(I) *Dissection and division of the inferior pulmonary vein (IPV)*

The first step is to carefully divide the pulmonary ligament using the cautery until finding station 9 lymph nodes and the inferior margin of the IPV. Then the anterior and posterior mediastinal pleura is opened to get full access to the IPV. The IVP is then dissected bluntly, circled and then divided with a stapler order manually with ligatures. As for the left upper lobectomy, it is always mandatory to check the presence of the SPV before dividing the IPV. In case of large tumors invading the IVP, it may be necessary to open the pericardium and divide the vein intrapericardially.

(II) *Dissection and division of the interlobar pulmonary artery (ILPA)*

In case of complete fissure the ILPA can be clearly identified in the interlobar fissure. If the fissure is incomplete, the dissection of the fissure should be performed with cautery, peanuts or scissors until finding the station 11 lymph nodes: posteriorly to these nodes normally is located the ILPA. The small bleeding caused from the fissure dissection can be stilled with cauterization or using metallic clips.

Normally the anatomy of ILPA consists in a single superior segmental branch and in the common basal segmental branch. After identification and dissection, the two branches can be divided separately using a stapler or ligatures.

Rarely, arterial branches for the upper lobe originates from the ILPA, so during the dissection the surgeon must recognize this anatomical variation and preserve the upper lobe branch.

(III) *Dissection and division of the lower lobe bronchus*

The lower lobe bronchus is normally located behind the ILPA, so after the division of the ILPA it is relatively easy to find it. After its identification, the peribronchial tissue is swept toward the specimen and then the bronchus is divided using a stapler, after checking on the upper bronchus inflating the lung or by bronchoscopy.

Completion

The rest of the steps are the same as for the left upper lobectomy: mediastinal lymphadenectomy, hemostasis and proper closure of the chest after tube placement.

Comments

(I) Use of the stapler
- (i) Good dissection of the planes to have enough space to insert the anvil;
- (ii) It may be helpful to pass the stapler through a separate incision, in case of difficult angles. This incision can then be used for the chest tube;
- (iii) Always encircle the vessels with a vessel loop/ligature, as it can be useful to retract and to expose better the entry point of the stapler;
- (iv) The stapler should not be forced, but should pass without resistance;
- (v) Be careful of the structures located in the area around the target, as they can be pushed away from the anvils;
- (vi) Have a sponge stick ready when working on the vessels.

(II) PA branches of smaller size can be clipped with polymer ligating clips, like it is usually done in the minimally invasive technique.

(III) The introduction of an enhanced recovery pathway for thoracic surgery patients should improve the quality of care, accelerating the recovery and shortening hospital stay postoperatively. It means that the management of patients should be structured starting from the preoperative preparation and it should involve all medical figures involved in patient care and deal with all its aspects (4).

(IV) Controlling the main pulmonary artery during difficult dissection allows a better vascular control in case of arterial bleeding.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Bendixen M, Jørgensen OD, Kronborg C, et al. Postoperative pain and quality of life after lobectomy via video-assisted thoracoscopic surgery or anterolateral thoracotomy for early stage lung cancer: a randomised controlled trial. Lancet Oncol 2016;17:836-44.
2. Wright CD, Gaissert HA, Grab JD, et al. Predictors of prolonged length of stay after lobectomy for lung cancer: A Society of Thoracic Surgeons General Thoracic Surgery Database risk adjustment model. Ann Thorac Surg 2008;85:1857-65.
3. Zhang W, Wei Y, Jiang H, et al. Thoracotomy is better than thoracoscopic lobectomy in the lymph node dissection of lung cancer: a systematic review and meta-analysis. World J Surg Oncol 2016;14:290.
4. Scarci M, Solli P, Bedetti B. Enhanced recovery pathway for thoracic surgery in the UK. J Thorac Dis 2016;8:S78-83.

doi: 10.21037/shc.2017.05.14

Cite this article as: Bedetti B, Schnorr P, Patrini D, Scarci M, Schmidt J. Left sided lobectomies. Shanghai Chest 2017;1:6.

Open surgical approach and technique in left pneumonectomy

Nikolaos Kostoulas, Kostas Papagiannopoulos

Department of Thoracic Surgery, St. James's University Hospital, Leeds, UK

Correspondence to: Kostas Papagiannopoulos, MMED THORAX, MD, CTH. Department of Thoracic Surgery, St. James's University Hospital, Bexley Wing, Level 3, Beckett St, LS9 7TF, Leeds, UK. Email: k.papagiannopoulos@nhs.net.

Received: 04 August 2017; Accepted: 16 August 2017; Published: 22 August 2017.
doi: 10.21037/shc.2017.08.10
View this article at: http://dx.doi.org/10.21037/shc.2017.08.10

Operative technique

Preparation

All patients should have a rigid or flexible bronchoscopy. Left lung isolation should be performed with a right-sided double lumen tube as the left main bronchus must be free of endoluminal objects.

Following confirmation of isolation, the patient is placed in the right lateral position. The right knee is flexed at 90 degrees, the left lower limb remains straight and a pillow is cushioned between them. Both upper limps are flexed at 'praying' position to allow exposure of the left axilla. There is no need to place the left arm on a frame. Flexing the operating table at the level of the xiphoid process splays the intercostal spaces (*Figure 1*). The patient is secured by using a special 'bean' bag and a wide strap across the pelvis.

The patient is prepped from the left shoulder to the pelvis and from the spine to the sternum, including the left axilla. In the same fashion drapes are placed around the above mentioned anatomical boundaries.

Incision

Access to the chest cavity can achieved either by anterior or posterolateral thoracotomy.

In our Institution, the posterolateral approach is recommended as rib approximation is easier and minimum disruption of muscle fibers is required through the posterior auscultatory triangle (*Figure 2*).

The presence of adhesions is not a contraindication to surgery but requires extra skills with attention to:

(I) Identification of appropriate planes;
(II) Dry division of adhesions with haemostasis;
(III) Avoidance of visceral pleura disruption and;
(IV) Complete adhesiolysis with mobilization to the whole lung and access to all hilar structures.

When such maneuvers are not possible an extra pleural dissection is the way forward. The surgeon should remain confident that the provision of correct planes does not compromise an oncological operation and cancer margins are not compromised (*Figure 3*).

Operation

A thorough inspection of the pleural cavity is important to exclude pleural deposits in pneumonectomies for lung cancer. Furthermore, any unsuspected pleural effusion should be sent for cytology in cancer operations (1,2).

Hilar dissection (3)

This step of the operation has several benefits including:

(I) Assessment of each hilar structure;
(II) Recognition and preservation of mediastinal structures;
(III) Assessment of resectability in cancer surgery;
(IV) Full lymphadenectomy or lymph nodal sampling if required.

The assistant retracts the left lung medially and the hilum is dissected at the level of the left pulmonary artery (PA). Following disruption of the parietal pleura all fatty and nodal tissue at the aortopulmonary window is resected isolating small vessels and branches of the vagus nerve with clips or ligatures. Diathermy is discouraged at this territory due to the close proximity of the left recurrent laryngeal nerve (3,4).

The main trunk of the left pulmonary artery is dissected with blunt dissection. Care is taken to avoid injury to

Figure 1 Anterior view of a patient prepared for left thoracotomy. Please note the arrow points at the xiphoid process and this is where the table needs to be flexed for best results in splaying the ribs and access through the intercostal space. Additionally, this maneuver drops the pelvis away from the surgical field in case a telescope is required for inspection of the apex.

Figure 2 Left thoracotomy position. The skin incision follows always the intercostal space to be accessed and it curves superiorly alongside the medial border of the scapula if extension is required. Please note the lines depicting the sterile field and position of drapes in case a paravertebral catheter is necessary to be inserted for postoperative pain management.

the vessel wall using gentle finger rolling dissection and/or blunt dissection with a 'peanut'. A clamp is positioned around the vessel only when circumferential dissection has been achieved and a vascular tape is applied and allowed to rest in the thoracic cavity.

The dissection continues posteriorly and inferiorly in the groove between the lung hilum and the esophagus. At this point, bronchial vessels might be encountered as well as bigger branches of the left vagus nerve. We prefer individual

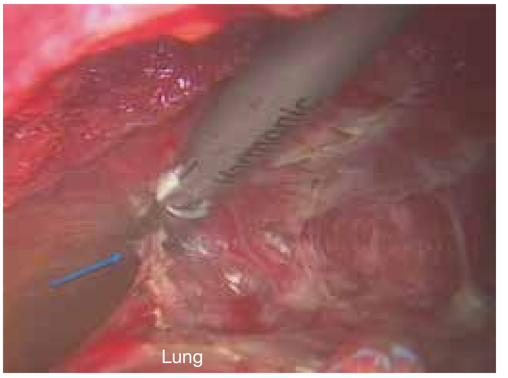


Figure 3 Adhesions (blue arrow) are best dealt with diathermy or high energy devices. A dry field is of paramount importance to avoid annoying spilling or pooling of blood during hilar dissection.

ligation with retraction of ligatures which allow suspension of the posterior mediastinum from the lung hilum. At this point, all left 10 lymph nodes are dissected from the groove between the left pulmonary artery and the bronchus and careful haemostasis is achieved.

Further dissection inferiorly exposes the left inferior pulmonary vein. The inferior pulmonary ligament needs to be divided until the rest of the vein is exposed circumferentially and all left 9 lymph nodes can now be exposed and harvested (*Figure 4*). It is now easy to tease off the rest of the circumference of the vein with finger dissection, apply a clamp (*Figure 5*) and circumvent the vein with a vascular tape. The tape is again allowed to rest in the thoracic cavity.

The hilar dissection is guided now anteriorly by simply retracting the lung laterally. The phrenic nerve should be identified, especially in obese patients in whom it might rest within a generous pericardial fat. The nerve should be freed from the hilum with blunt dissection. No diathermy should be employed at this stage of the dissection (5,6).

The circumferential dissection will now allow exposure of the last hilar structure, the superior pulmonary vein. Quite often this proves to be multi-segmental and wide and the dissection should be facilitated by the index finger and thumb taking the previously dissected pulmonary artery as a pivot point at the most superior aspect of the vein. In a similar fashion the vein can be encircled with a vascular tape.

The last hilar structure is the left main bronchus, but accessibility at this point is extremely difficult as it is surrounded by all vascular hilar structures.

There are various techniques and instruments that may

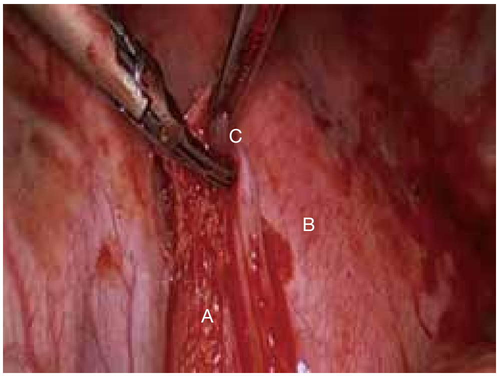


Figure 4 It is essential that the underlying mediastinum following dissection of the inferior pulmonary ligament should be checked for any bleeding prior to closing the thoracotomy. (A) Dissected inferior pulmonary ligament; (B) descending aorta; (C) left 9 lymph nodes.

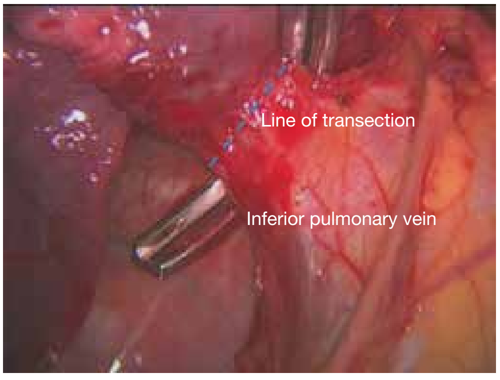


Figure 5 Dissected inferior pulmonary vein with vascular clamp placed around. Please note the dotted line representing the desired level of stapling. This provides adequate length of vein stump in case of bleeding.

be used for dividing the pulmonary vessels. The easiest and most efficient way nowadays is by dividing the vessels with readily available vascular staplers. They can be easily applied in the operating field through the thoracotomy incision and slide behind each vessel by following the previously applied vascular tape or sling.

In case that a surgeon wishes to perform a very small thoracotomy the staplers can be manipulated through an anterior small incision which will serve later as the chest tube port (7).

We prefer to transect the pulmonary artery in order to avoid lung congestion if veins are sacrificed first (8). Using the vascular tape, the PA is gently retracted and the anvil of the stapler is slid underneath the artery lumen in a medial to lateral fashion. In those who prefer a small access thoracotomy, direct vision might be difficult. In such cases the right index finger of the surgeon might be placed around the PA and the anvil positioned against the tip of the index finger which serves as a guide for safe passage of the stapler jaw under the PA. Care should be exercised to isolate the full diameter of the PA before applying the stapler. Vascular clamps should be at close proximity in case of hemorrhage.

The inferior pulmonary vein can now be transected with the stapler sliding from the pericardial aspect towards the posterior mediastinum. Care should be exercised to remove the vascular tapes before firing the staplers to avoid these being trapped at the proximal stump of the vein.

The superior pulmonary vein can now be transected in a similar fashion. The lung is now much easier to manipulate as it is anchored only by the main bronchus.

In practices were staplers might not be available or financially affordable classic techniques of suturing or ligation might be employed. In general terms, the pulmonary artery can be isolated with 2 vascular clamps, neatly divided and then over sawn with non-absorbable monofilament suture with an atraumatic needle such as prolene 4/0. Veins can be taken care in a similar fashion. We would not advocate the use of single ligatures as these might slip and end up in a catastrophic bleed. Our experience suggests that veins are more susceptible to such accidents as they often have a pericardial reflection rendering safe ligation a risk.

The distal stumps of the vessels can be ligated with comfort but we would advocate transfixion as distal bleeding exposes a surgeon to unnecessary discomfort, disrupts the flow of the operation and leads to a 'wet' and hostile operating field.

As described earlier, the division of the bronchus can be employed either by the use of a stapler or sutures.

Before transecting the bronchus, care should be taken to remove all subcarinal nodes if surgery is performed for cancer. The bronchus should be cleaned from surrounding fat and the dissection should ensure that the subcarinal region is reached. This maneuver will guide the position of the stapler and prevent a long bronchial stump be left behind. The stapler can be routinely applied in an inferior to superior direction with the lung retracted posteriorly. Quite often the stapler can compress the aortic arch to secure a short remaining bronchial stump.

At stapling, the lung is retracted and the stapler is applied to the bronchus by collapsing the membranous part against the anterior wall. During stapling the tension on the lung should be released to avoid rupture of the bronchus.

If sutures are to be applied the bronchus should not be transected to avoid soiling the pleural cavity with respiratory flora. Specially designed curved bronchial clamps are available and should be applied close to the carina. The bronchus is transected allowing the lung to be extirpated from the pleural space.

With the bronchial clamp in situ, the bronchus is sutured with a double horizontal mattress technique with mono or poly filament suture with a cutting needle (9). There is enough evidence in the literature showing that monofilament or poly filament sutures can be successfully employed providing that:

(I) Good bronchial wall approximation is achieved (10);
(II) The bronchial tissue is healthy and no suture overcrowding is employed;
(III) The bronchial stump is short.

It is not necessary to cover the left bronchial stump routinely as it is naturally covered by mediastinal structures unless (11,12):

(I) The bronchial tissue quality is questionable;
(II) The patient has received preoperative chemotherapy and/or radiotherapy;
(III) The patient will require adjuvant chemotherapy and/or radiotherapy;
(IV) The operation has been performed in an infected or inflamed pleural cavity;
(V) The patient's nutritional status is poor.

Completion

Following or completing the lymphadenectomy the pleural cavity is washed with water (13,14). The bronchial stump can be checked for possible air leaks. If such is identified care should be taken to isolate it with fine sutures.

There has been significant discussion regarding the use of chest tubes following pneumonectomies. Either practice has proved to be safe and effective as long as the appropriate protocols are followed.

In our Institution, a single chest drain is left in the chest until the first postoperative day (POD 1). Our protocol consists of:

(I) Clamping the drain in theatre after the patient has been turned in supine position;
(II) Open the drain every hour to check for bleeding;
(III) Keep it clamped as soon as no drainage is identified;
(IV) Remove the drain the following morning (POD 1).

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Saso S, Rao C, Ashrafian H, et al. Positive pre-resection pleural lavage cytology is associated with increased risk of lung cancer recurrence in patients undergoing surgical resection: a meta-analysis of 4450 patients. Thorax 2012;67:526-32.
2. Shoji F, Yamazaki K, Kouso H, et al. The Impact of Pleural Lavage Cytology Both Before and After Lung Resection on Recurrence of Non-Small Cell Lung Cancer. Ann Thorac Surg 2016;101:2141-6.
3. Nohl-Oser HC, Nissen R, Schreiber HW. Surgery of the lung. Stuttgart, New York: Thieme-Stratton, 1981:79-90.
4. Filaire M, Mom T, Laurent S, et al. Vocal cord dysfunction after left lung resection for cancer. Eur J Cardiothorac Surg 2001;20:705-11.
5. Burns J, Dunning J. Is the preservation of the phrenic nerve important after pneumonectomy? Interact Cardiovasc Thorac Surg 2011;12:47-50.
6. Kocher GJ, Mauss K, Carboni GL, et al. Effect of phrenic nerve palsy on early postoperative lung function after pneumonectomy: a prospective study. Ann Thorac Surg 2013;96:2015-20.
7. Ugalde P, Miro S, Provencher S, et al. Ipsilateral diaphragmatic motion and lung function in long-term pneumonectomy patients. Ann Thorac Surg 2008;86:1745-51; discussion 1751-2.
8. Szwerc MF, Landreneau RJ, Santos RS, et al. Minithoracotomy combined with mechanically stapled bronchial and vascular ligation for anatomical lung resection. Ann Thorac Surg 2004;77:1904-9; discussion 1909-10.
9. Refaely Y, Sadetzki S, Chetrit A, et al. The sequence of vessel interruption during lobectomy for non-small cell lung cancer: is it indeed important? J Thorac Cardiovasc Surg 2003;125:1313-20.
10. Scott RN, Faraci RP, Hough A, et al. Brochial stump closure techniques following pneumonectomy: A serial comparative study. Ann Surg 1976;184:205-11.

11. Kakadellis J, Karfis EA. The posterior membranous flap technique for bronchial closure after pneumonectomy. Interact Cardiovasc Thorac Surg 2008;7:638-41.
12. Panagopoulos ND, Apostolakis E, Koletsis E, et al. Low incidence of bronchopleural fistula after pneumonectomy for lung cancer. Interact Cardiovasc Thorac Surg 2009;9:571-5.
13. Lardinois D, Horsch A, Krueger T, et al. Mediastinal reinforcement after induction therapy and pneumonectomy: comparison of intercostal muscle versus diaphragm flaps. Eur J Cardiothorac Surg 2002;21:74-8.
14. Tsakok T, Tsakok M, Damji C, et al. Washout after lobectomy: is water more effective than normal saline in preventing local recurrence? Interact Cardiovasc Thorac Surg 2012;14:200-4.

doi: 10.21037/shc.2017.08.10
Cite this article as: Kostoulas N, Papagiannopoulos K. Open surgical approach and technique in left pneumonectomy. Shanghai Chest 2017;1:23.

Lung

Left side sleeves

Domenico Galetta[1], Lorenzo Spaggiari[1,2]

[1]Division of Thoracic Surgery, European Institute of Oncology, Milan, Italy; [2]University School of Milan, Italy

Correspondence to: Domenico Galetta, MD, PhD. Division of Thoracic Surgery, European Institute of Oncology, Via Ripamonti 435, Milan, Italy. Email: domenico.galetta@ieo.it.

Received: 07 April 2017; Accepted: 27 April 2017; Published: 30 May 2017.
doi: 10.21037/shc.2017.05.10
View this article at: http://dx.doi.org/10.21037/shc.2017.05.10

Introduction

Sleeve bronchial lobectomy (SL) is defined as the resection of a pulmonary lobe associated with resection and reconstruction of the bronchus and, in some instances, depending on the site of the infiltration of the neoplasm, it can be associated with resection and reconstruction of the pulmonary artery (PA).

The principles and the basic technique of these particular reconstructive procedures were established in the 1940s and 1950s by Prince-Thomas and Johnson and promoted by the improved definition of the pulmonary anatomy.

Since the mid 1970s, conservative techniques (sleeve lobectomies) have been widely accepted in the management of lung cancer with best long-term results compared to those reported following pneumonectomy (1-3).

The association of SL to PA resection and reconstruction (double sleeve) has been less widely used compared to bronchial reconstruction alone, probably due to the discouraging results in terms of complications and to the heterogeneity of populations and varying surgical techniques reported in published studies (4-8). To date there are few reports on broncho-angioplastic intervention (BAI) in literature. This may be due to the particularly risk patients, to the surgical intervention which may be complicated, and to the apparently dismal long-term results (4-8). However, these surgical procedures remain technically demanding and have finally gain a definitive role in the management of lung cancer.

Indications for BAI in patients with lung cancer are: (I) when a tumor infiltrates the origin of the lobar bronchus (usually the upper one) and the PA or the origin of the lobar branches of the PA (*Figure 1A,B*), a condition that debar simple lobectomy but does not require pneumonectomy; (II) in case of N1 (hilar) lymph node infiltration of the bronchus and the PA (*Figure 1C*) or its branches, as is often the case in the left upper lobe tumors; (III) after induction treatments when unremovable fibrotic tissue or residual tumor is simultaneously embedded in the bronchus and PA; (IV) to avoid pneumonectomy in patients with compromised cardiac and/or pulmonary function. Our policy in case of locally advanced lung cancer was to preserve as much lung parenchyma as technically and oncologically possible. Thus, arterial sleeve resection was carried out when possible and not only in cases of respiratory impairment contraindicating pneumonectomy. Sometimes a BAI is associated with an upper bilobectomy due to the tumor or nodal infiltration at the level of intermediate bronchus.

PA can be infiltrated by the tumor to various levels, from partial infiltration to a more extensive and even circumferential involvement. In case of partial involvement, a partial resection with suture of the PA is indicated; in case of extended involvement, the reconstruction of the PA may be made by using pericardial patch, end-to-end anastomosis, or by the interposition of a prosthetic conduit.

Preoperatively, patient undergo standardized diagnostic and staging procedures. Key point in the preoperative staging are chest/upper abdomen computed tomography (CT) scan, positron emission tomography scan, and bronchoscopy. This latter examination may easily ascertain the infiltration of the origin of the lobar bronchus and allows to obtain specimens for cyto-or histopathology. If at the CT scan are present enlarged mediastinal lymph nodes (paratracheal or subcarinal regions) greater than 1 cm or PET-positive, or both, the patient underwent endobronchial ultrasound-guided transbronchial needle aspiration. R2 or L2 node involvement is an absolute contraindication to surgery even in case of a partial or complete response to induction chemotherapy. Adenopathy in mediastinal station

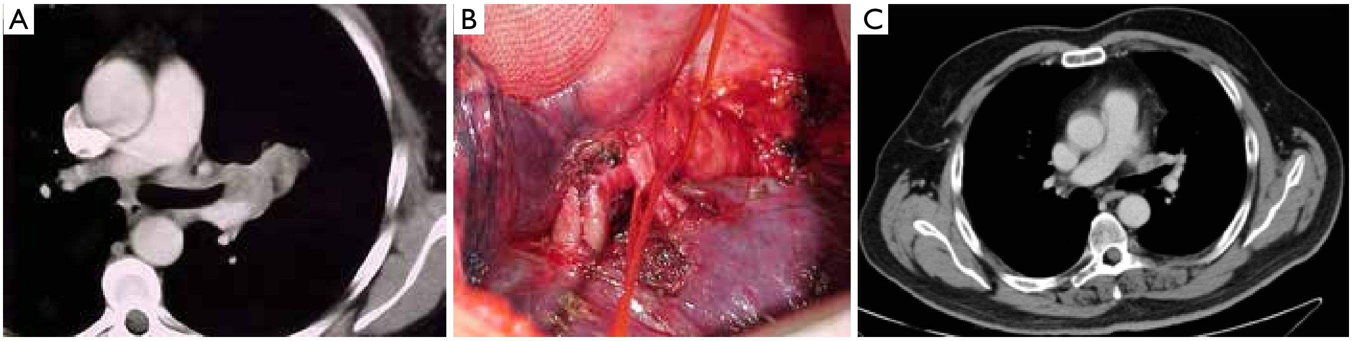


Figure 1 Radiologic and intraoperative images of bronchial and vascular infiltration. (A) CT scan showing NSCLC infiltrating the origin of the left upper lobar bronchus and the PA. (B) Intraoperative view of the right PA infiltrated by NSCLC. (C) CT scan showing left pulmonary hilar lymph nodes infiltrating the origin of right upper lobar bronchus.

Figure 2 Patient' position and surgical skin incision (read line).

R4 is not an absolute contraindication to surgery; in these cases, patients receive preoperative chemotherapy with the intent to treat systemic microscopic metastases and to identify progressive disease, which would contraindicate surgical resection. At the end of the scheduled induction treatment, patients underwent total-body CT scan and PET scan for re-stage the disease.

Preoperative pathologic confirmation of PA infiltration is impossible to obtain. It may be suspected and assessed by CT scan and eventually angiography and magnetic resonance imaging scans, but the need of resection is usually made intraoperatively.

Preoperative cardiac evaluation including echography should be performed in every case. Sometimes, a stress electrocardiography, myocardial scintigraphy, or coronary angiography may be performed in case of presence of cardiovascular symptoms. Respiratory function is assessed by blood gas analysis, spirometry with the evaluation of carbon monoxide lung diffusing capacity, and lung perfusion scan.

Operative technique

Preparation

The patient is intubated with a double-lumen for a one-lung ventilation. Patient is monitored with continuous arterial and venous pressure measurements. The patient is placed in the lateral position with the back moved towards the edge of the table. The sterile field include the axilla, anterior chest across the sternum and neck, and the spine.

Exposition

Surgical team is placed as follows: the surgeon is placed to the patient's back; the first assistant across the table, and the second assistant near to the surgeon. The intervention is performed trough a muscle sparing lateral thoracotomy. The incision is made in the fourth or fifth right intercostal space from the anterior edge of the latissimus dorsi muscle to the posterior edge of the pectoralis major (*Figure 2*). In females, the axillo-mammary fold is cosmetically preferred.

Operation

The first step of the intervention is the pleural cavity

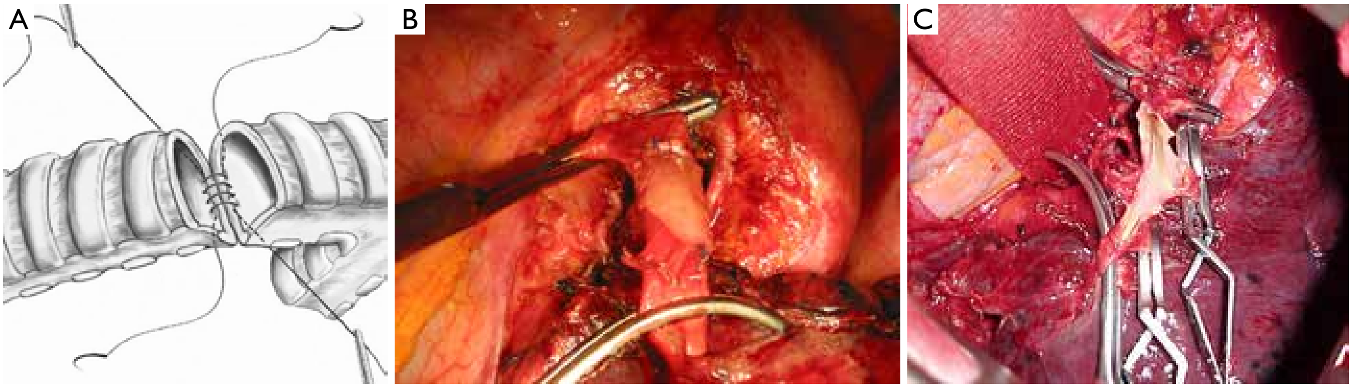


Figure 3 Sleeve bronchial reconstruction of the left upper bronchus and control of the PA for arterial resection and reconstruction. (A) After isolation of the left main bronchus and the left lower bronchus the two bronchial ends are approximated and two separated non-absorbable monofilament are used for approximating the two bronchial ends. (B) The left main PA is controlled proximally (extra-pericardically) by placing an atraumatic vascular clamp. Distal control of the PA is obtained in the pulmonary fissure with another vascular clamp. (C) In some instances, the distal control of the PA is obtained by the use of bulldog clamps allowing more room for the reconstructive procedures.

exploration and then a complete dissection of the fissure. Mediastinal lymph node dissection is routinely performed at the beginning of the procedure trying not to devascularise the bronchus beyond the line of section. When the distal parenchyma is free of tumor and/or invasive growth lymph nodes, a sleeve resection is performed. The main and distal bronchus are isolated; after the resection of the bronchial segment concerned and severance of the pulmonary ligament for mobilization, the corresponding ands of the bronchus can usually be readily brought together. Resection is considered complete if resection margins were free of tumor at frozen section.

The anastomosis between the main left bronchus and the left lower bronchus is performed with two running sutures with a non-absorbable monofilament (3/0 polypropylene; Ethicon, Inc, Sommerville, NJ). The stitches are positioned at the far side of the cartilaginous wall and subsequently fixed. Afterwards, two running sutures, first passed and secondarily tied, are performed in order to obtain a telescopic anastomosis (*Figure 3A*).

The surgical technique for pulmonary artery resection included the following steps: the first step is to isolate the main PA which is usually controlled proximally, extra-pericardically (*Figure 3A*); in some instances (involvement of the initial portion of the PA), the temporary proximal occlusion is done intra-pericardically. On the left side, the problems of dissection are less, since the PA can be readily mobilized after severance of the ligamentum arteriosus and the pericardial fold avoiding left recurrent laryngeal nerve damage. Centrally, the main PA must be carefully occluded with a soft atraumatic vascular clamp in order to avoid intimal injuries of the frequently sclerotic vessels. Distal control of the PA is usually obtained in the pulmonary fissure with another vascular clamp (*Figure 3A*) and/or bulldog vascular clamp allowing sufficient room for the operating surgeon (*Figure 3B*). Sometimes, to have a more room for the surgical resection and reconstruction and to prevent back-bleeding, it is possible to clamp the vein of the other lobe. The pulmonary vein of the lobe which should be resected is isolated and then sectioned using a vascular stapler. Systemic anticoagulation is initiated (3,000 to 5,000 IU heparin sodium) and not reversed by protamine at the end of the procedure. Thereafter, resection of the targeted lobe is carried out en bloc with the invaded portion of the PA. The pulmonary lobe containing the tumor is removed from the operative field offering to the surgeon more room for complete the work. Frozen section of both the margins (bronchus and PA) should be sent. If a bronchial positive margin is found at the frozen section, a pneumonectomy is performed whenever functionally tolerable.

In all cases of the bronchial and vascular reconstruction, we prefer to perform the arterial reconstruction first which decrease the clamp time, followed by the bronchial reconstruction.

The resected PA is now evaluated to determine the type of arterial reconstruction: if the residual arterial calibre is ≥50%, a direct suture is carried out using 5-0 or 6/0 polypropylene suture (*Figure 4A,B*). Otherwise, application

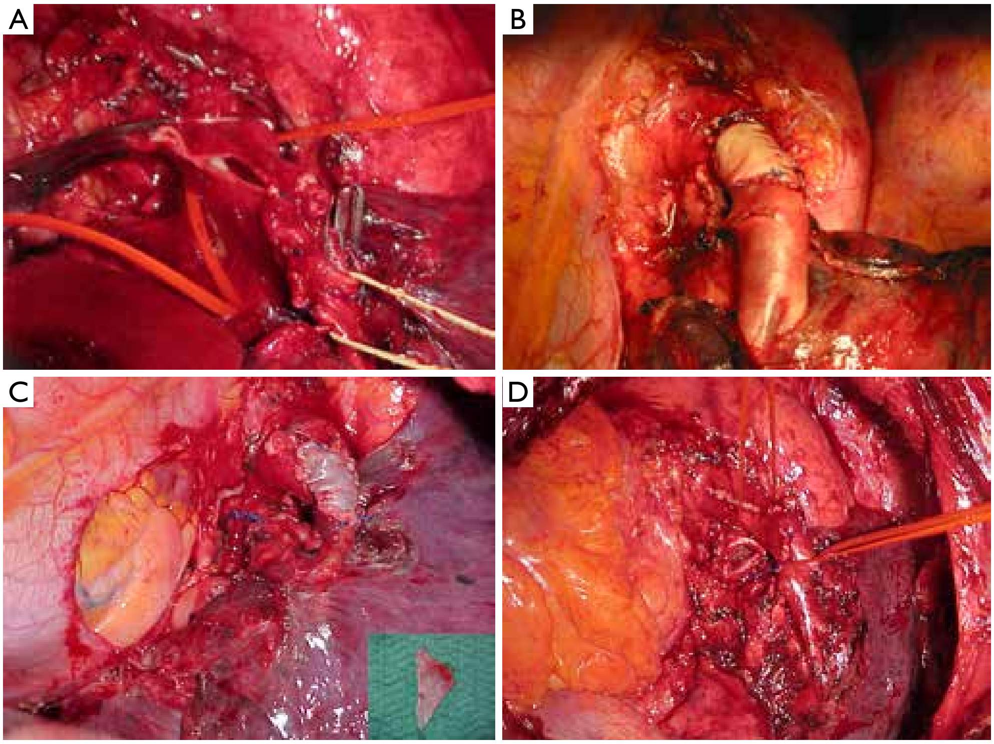


Figure 4 Techniques of the PA reconstruction (1). (A) The resected PA with evident arterial wall defect is reported. (B) A direct suture of the arterial resected wall is usually performed using 5-0 or 6/0 polypropylene suture. In case of resection of a larger PA wall, a pericardial patch may be used to close the arterial defect: it may be autologous (C, and inset) or heterologous (bovine) (D).

of an autologous (*Figure 4C*) or heterologous (bovine) pericardial patch is used (*Figure 4D*). After the resection of the upper lobe and the PA, a longitudinal arterial defect ensues (*Figure 5A*). A patch is held in place by two stay sutures. The shape and size of the patch should be tailored to the resected portion of the PA. The patch is sutured with 5/0 or 6/0 non-absorbable monofilament after adequately trimming it (*Figure 5B*). In some circumstances, a sleeve resection of the PA is required with end-to-end anastomosis avoiding irregular and uneven edges of the transacted PA facilitates proper placement of the stitches. In this case, calibre discrepancy is compensated by elasticity of the wall of the vessel. If a long circumferential resection of the PA is required the interposition of a conduit (autologous or heterologous) is performed. This may occur in the case of extended defects in which end-to-end anastomosis is not possible because the PA is extensively infiltrated by the tumor, and the vascular edges remain far away after the bronchial sleeve resection. PTFE grafts (*Figure 6A*) used for PA reconstruction have some risks including the risk of infection, and thrombosis, and the need for postoperative anticoagulation. Moreover, in some instances, the autologous pericardium may be insufficient to construct a long tube. For this reason, we have suggested the use of a bovine custom-made pericardial prosthesis (*Figure 6B*) which is resistant to the infection, it is easy to handling, and it does not need for anticoagulation. In this case, the proximal anastomosis between the PA and the custom-made pericardial prosthesis is performed first while the distal one is performed last. Suturing is carried out using 5-0 polypropylene suture. Just before tying the arterial suture, the distal clamp is taken off from the PA or the pulmonary vein to help remove the air from the PA. Then the proximal vascular clamp is removed from the PA to ensure haemostasis of the sutured line. It is crucial the absence of tension on the graft. Moreover, graft redundancy should be avoided because it could cause the torsion or kinking of the graft.

After completion of anastomoses, air leaks is checked by inflating the lung after immersing the anastomosis under fluid. In every case, a pedicled flap (intercostal pedicle or pericardial fat pad) is used to encircle the bronchial anastomosis favouring protection and revascularization

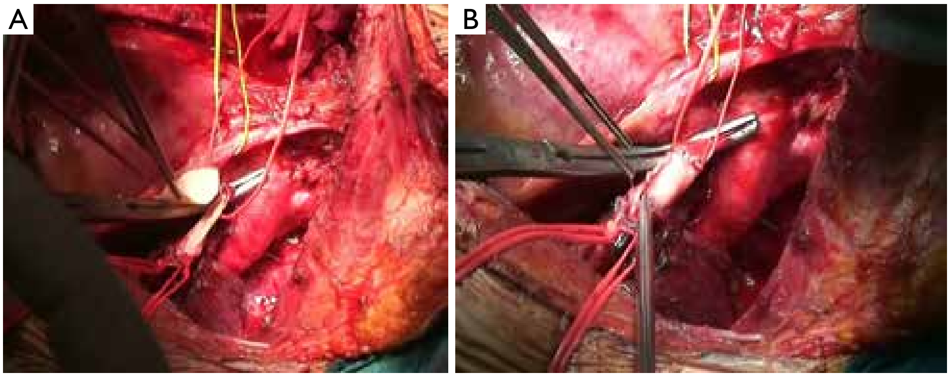


Figure 5 Techniques of the PA reconstruction (2). (A) The bovine pericardial patch is tailored according to the PA defect and is held in place by two semi-continuous sutures. (B) After adequately trimming the patch it is sutured with 5/0 or 6/0 non absorbable monofilament.

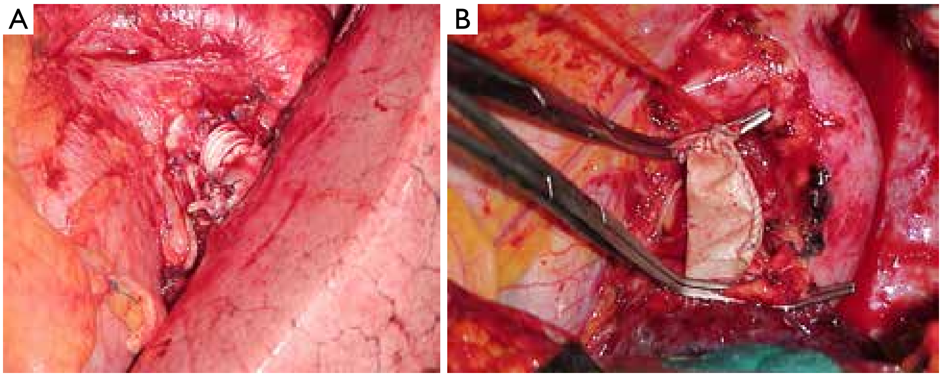


Figure 6 Techniques of the PA reconstruction (3). In case of a long circumferential PA resection the arterial defect is compensated by interposition of a conduit which may be a PTFE graft (A) or a custom-made bovine pericardial tubular prosthesis (B).

of the bronchus and to separate it from the PA avoiding broncho-arterial fistulas (*Figure 7*). A bronchoscopic check of the anastomosis is carried out intraoperatively in order to be able to correct incorrectly placed sutures, stenoses or kinks immediately.

The patient is rapidly extubated, possibly in the operating room. Postoperative management include aggressive physiotherapy for an adequate cleaning of the bronchial secretions and early mobilization, usually on the day after surgery. Mucus retention due to the disturbed mucociliary function can be controlled by intensive preoperative and postoperative physiotherapy and, whenever necessary, by bronchoscopic aspiration. Patient after sleeve resections is treated by low dose steroid inhalation in order to reduce airway secretions and atelectasis, facilitating parenchymal re-expansion, and minimizing the risk of dehiscence and granuloma formation. Before discharge, a bronchoscopy is performed to evaluate the status of the bronchial anastomosis and to identify necroses or smaller fistulae with encapsulated abscesses. Larger bronchopleural fistulae or suture dehiscences may rapidly become clinically noticeable.

Postoperatively the patient received perioperative antithrombotic prophylaxis with low-molecular weight heparin at preventive dose for about 2 weeks.

Comments

Preservation of pulmonary tissue is become a standard practice in lung surgery and lobectomy with bronchial reconstruction is one of the most commonly used technique to spare lung tissue. In fact, sleeve lobectomy is become a useful and accepted surgical procedure among the technical armamentarium of the thoracic surgeon. Different studies

Figure 7 Intraoperative view anastomoses' protection. After performing both the vascular and bronchial anastomoses, a pedicled flap (pericardial fat pad) is used to encircle the bronchial anastomosis favouring protection and revascularization of the bronchus and to separate the bronchus from the PA avoiding broncho-arterial fistulas.

on SL showed that the long-term outcomes (survival) were at least equal to those of pneumonectomy but with better functional results. Moreover, the extended use of angioplastic techniques also in the thoracic domain, made possible to perform SL with associated PA reconstruction. These broncho-angioplastic techniques were initially offered to those patients with a respiratory impairment in order to avoid a pneumonectomy which would not tolerate. Initial experiences on this kind of surgical procedures reported an increased rate of morbidity and mortality due to complication of the broncho-vascular anastomosis (broncho-vascular fistula and/or risk of tumor recurrence). In recent years, several published studies on bronco-vascular resection and reconstruction reported that bronchial sleeve resection was associated with both a mortality risk and an incidence of bronchial anastomotic complication lower than that of pneumonectomy, and sometimes comparable to standard lobectomy. Long-term results in terms of survival and disease free interval for this particular type of surgical procedure have documented good outcomes not inferior to those after pneumonectomy. Vogt-Moykopf and colleagues (5,6) reported good long-term results but a high operative mortality (up to 14%). The reported high incidence of complications of the vascular anastomosis (5,6) has led many surgeons to consider angioplastic procedure not safe inducing them to become reluctant to employ this technique. However, recent experiences on broncho-angioplastic procedures showed that they could be performed with good early and late results even after preoperative chemotherapy (5-9). Encouraging results have recently been reported on morbidity and mortality of BAI showing favorable results in terms of operative mortality (3.3%), postoperative complications (32.4%), and 5-year survival rate (38.7%) resulting better than those of pneumonectomy. Our recent results indicate that broncho-vascular resections and reconstruction for treating of central located lung cancer can be performed with a low perioperative risk (7,8).

In conclusion, BAI are safe procedures comparable to bronchial sleeve resections with similar results to those of pneumonectomy. At the light of these results, it seems reasonable to also apply BAI more liberally.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Deslauriers J, Gaulin P, Beaulieu M, et al. Long-term clinical and functional results of sleeve lobectomy for primary lung cancer. J Thorac Cardiovasc Surg 1986;92:871-9.
2. Ludwig C, Stoelben E, Olschewski M, et al. Comparison of morbidity, 30-day mortality, and long-term survival after pneumonectomy and sleeve lobectomy for non-small cell lung carcinoma. Ann Thorac Surg 2005;79:968-73.
3. Takeda S, Maeda H, Koma M, et al. Comparison of surgical results after pneumonectomy and sleeve lobectomy for non-small cell lung cancer: trends over time and 20-year institutional experience. Eur J Cardiothorac Surg 2006;29:276-80.
4. Shrager JB, Lambright ES, McGrath CM, et al. Lobectomy with tangential pulmonary artery resection without regard to pulmonary function. Ann Thorac Surg 2000;70:234-9.
5. Vogt-Moykopf I, Frits TH, Meyer G, et al. Bronchoplastic and angioplastic operation in bronchial carcinoma: long-term results of e retrospective analysis from 1973 to 1983. Int Surg 1986;71:211-20.
6. Vogt-Moykopf I, Fritz TH, Bulzerbruck H, et al. Bronchoplastic and angioplastic operation in bronchial

carcinoma. Langenbecks Arch Chir 1987;371:85-101.
7. Galetta D, Solli P, Borri A, et al. Bronchovascular reconstruction for lung cancer: does induction chemotherapy influence the outcome? Ann Thorac Surg 2012;94:907-13.
8. Galetta D, Borri A, Gasparri R, et al. Surgical Techniques and Long-Term Results of Pulmonary Artery Reconstruction in Patients With Lung Cancer. Ann Thorac Surg 2015;100:1196-202.
9. Lausberg HF, Greater TP, Wendler O, et al. Bronchial and bronchovascular sleeve resection for treatment of central lung tumors. Ann Thorac Surg 2000;70:367-7.

doi: 10.21037/shc.2017.05.10
Cite this article as: Galetta D, Spaggiari L. Left side sleeves. Shanghai Chest 2017;1:8.

Right side lobectomies

Luca Bertolaccini[1], Alessandro Pardolesi[2], Piergiorgio Solli[1,2]

[1]Department of Thoracic Surgery, AUSL Romagna Teaching Hospital, Ravenna, Italy; [2]Department of Thoracic Surgery, AUSL Romagna Teaching Hospital, Forlì, Italy

Correspondence to: Luca Bertolaccini, MD, PhD, FCCP. Department of Thoracic Surgery, AUSL Romagna Teaching Hospital, Viale Vincenzo Randi 5, 48121 Ravenna, Italy. Email: luca.bertolaccini@gmail.com.

Received: 03 April 2017; Accepted: 02 May 2017; Published: 30 May 2017.
doi: 10.21037/shc.2017.05.09
View this article at: http://dx.doi.org/10.21037/shc.2017.05.09

Introduction

Lobectomy remains the "how to do it" type of resection because assures removal of the regional lymph nodes and thus provides the best information for staging and local control. Doing less than a lobectomy must be considered a compromise because a wedge excision does not include the lobar bronchus, impeding evaluation of lobar lymph nodes, but also usually it provides only a minimal parenchymal margin and, thus, is accompanied by a significant incidence of local recurrence. Before the operation, at a minimum, patients should have a recent chest CT scan. Most, if not all, should have a Positron Emission Tomography (PET) scan. An important aspect of the preoperative assessment of a patient with lung cancer is the assessment of pulmonary function. Preoperative spirometry to measure flows and volumes should be performed including forced expiratory volume in 1 second (FEV_1), diffusive capacity, FEV_1/forced vital capacity (FVC) ratio, and the ratio of the residual volume (RV) to total lung capacity (TLC). FEV_1 <40% of predicted has been associated with increased postoperative morbidity and mortality. A reduced diffusing capacity has also been related to postoperative morbidity. In addition to pulmonary function studies, a valuation of exercise capability for the patient with compromised lung function may be appropriate in some circumstances. This evaluation may range from something as simple as having the patient climb one or two flights of stairs while monitoring oxygen saturation and pulse rate to, better, formal exercise testing and calculation of maximal oxygen consumption (VO_2 max). Nevertheless, we can be reasonably sure that a patient who can walk up two flights of stairs can tolerate a lobectomy. For indeed borderline patients, measurement of VO_2 max may be the deciding test. A value of <15 ml/kg/min has been associated with significantly increased postoperative morbidity and mortality. Patients in this category should be scrutinised carefully before one decides to proceed with resection. Other parameters suggesting high risk included a pCO_2 >45 mm Hg and elevated PA pressures (1,2).

Operative techniques

Lobectomies are approached via standard lateral decubitus position. The pleural cavity is entered through the fifth intercostal space or the bed of the fifth rib using a muscle sparing thoracotomy if possible. If adhesive pleuritis are anticipated, entrance through the bed of the resected fifth rib allows for more expeditious mobilisation of the lung, either in the intrapleural or extrapleural plane. Finger dissection manages weblike avascular adhesions and a sponge stick; cautery should be applied for vascular adhesions. Lesions adherent to the parietal pleura is mobilised in the extrapleural plane. The key to an orderly lobectomy is an accurate knowledge of the anatomy of the PA, the variations of branching, and its proper dissection (*Figure 1*) (2).

Right upper lobectomy

The anatomy of the hilar structures of the right upper lobe is more involved than in any other lobe, and, fortunately, arterial anomalies are more common. Usually, the anterior segment of the right upper lobe is partially or wholly fused to the middle lobe. The mediastinal pleura is sectioned around the hilum, lateral to the superior vena cava, inferior to the azygos vein, going posteriorly over the bronchus, anterior to the vagus nerve (visible subpleural), to the level of the bronchus intermedius. Anteriorly, the incision is

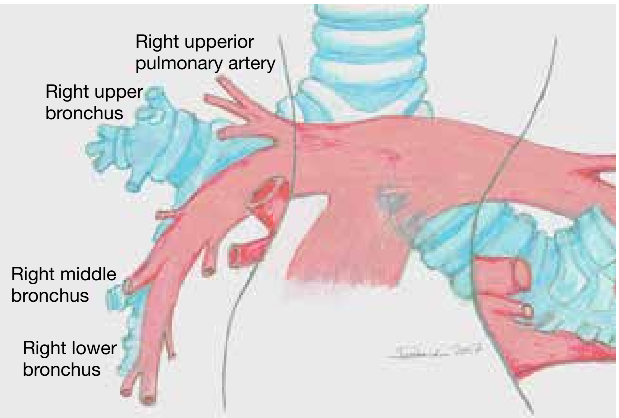


Figure 1 Anatomy of the pulmonary artery (courtesy of Riccardo Pardolesi).

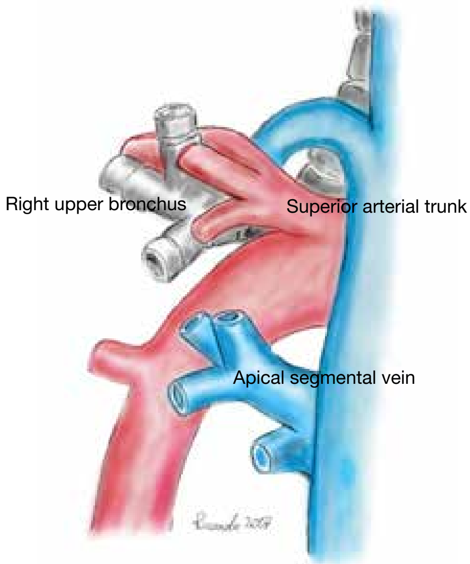


Figure 2 The superior arterial trunk is visualised; this artery and apical and anterior segmental branches are dissected; the apical segmental vein crosses the anterior segmental artery, and it should be ligated and divided before dealing with the artery (courtesy of Riccardo Pardolesi).

carried to the degree of the superior pulmonary vein (PV), posterior to the phrenic nerve. The azygos vein superiorly is pushed with a pledget dissector, demonstrating the upper border of the right main bronchus and the top lobe bronchus originating from it. Inferior to the azygos-cava junction, a lymph node is found and below this the upper border of the PA. The tissue overlying the PA is dissected,

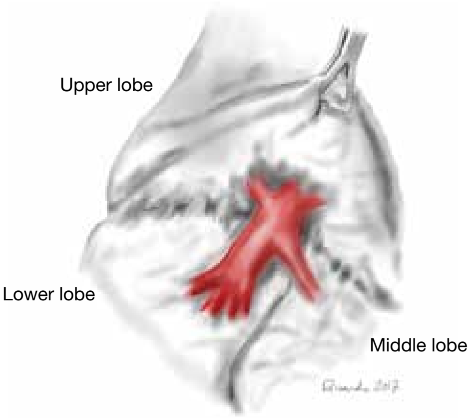


Figure 3 The retrograde approach to the posterior segmental artery on the oblique fissure is acceptable if the oblique fissure is virtually complete (courtesy of Riccardo Pardolesi).

and the superior arterial trunk is visualised. This artery and apical and anterior segmental branches are dissected; the apical segmental vein crosses the anterior segmental artery, and it should be ligated and divided before dealing with the artery. The superior arterial trunk is doubly tied or separated by a stapling device; the apical and segmental branches are linked and then divided (*Figure 2*). After the division of the superior trunk of the PA, the common stem of the apical anterior segmental veins is dissected and divided. The interlobar trunk of the PA lies directly underneath the upper and middle stems of the superior PV, and this dissection must be cautious. The remaining arterial supply to the right upper lobe is the posterior ascending artery and dissection can be the most difficult task in the procedure. The anterior approach requires the prior division of the posterior and inferior venous tributaries of the superior vein, strictly applied to the anterior surface of the inferior trunk of the Pulmonary Artery (PA). Isolation of the right PA may be required because of laceration of the posterior ascending artery or the interlobar artery during this dissection. An approach to the posterior segmental artery on the oblique fissure is acceptable if the oblique fissure is virtually complete (*Figure 3*). Otherwise, PA branch is again at risk for injury. The retrograde method for completion of the dissection is both harmless and quick. Retrograde exposure of the posterior ascending artery proceeds with the grasping and retraction of the vagus nerve, demonstrating arterial branches to the right upper lobe who are divided. Deep to the vagal branches,

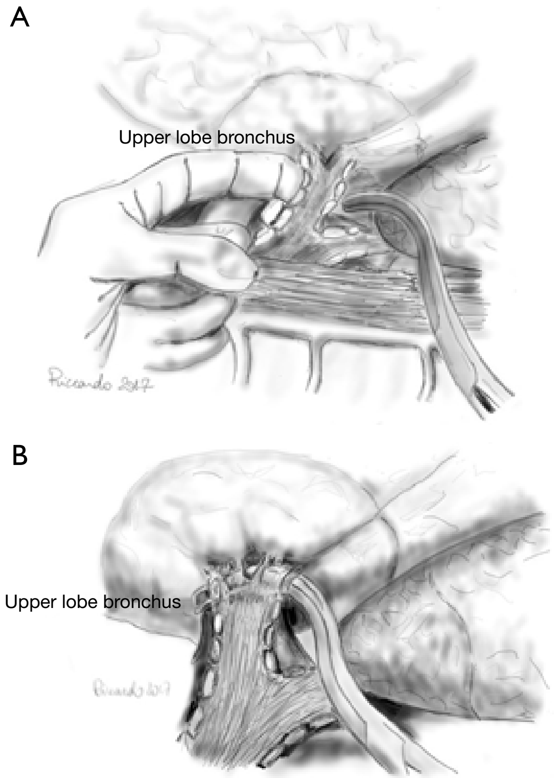


Figure 4 The lower border of the upper lobe bronchus is dissected. In the cross between the upper lobe bronchus and the intermediate bronchus is a constant lymph node; his dissection toward the specimen, clear the inferior border of the right upper lobe bronchus. Scissor dissection of the bronchus medial surface is performed. The bronchus is not uncovered of its fascia, and a finger can be inserted along the anterior aspect to reach its lower border (courtesy of Riccardo Pardolesi).

the bronchial artery may be observed (clipped and divided). The lower border of the upper lobe bronchus is then dissected. In the cross between the upper lobe bronchus and the intermediate bronchus is a constant lymph node; his dissection toward the specimen, clear the inferior border of the right upper lobe bronchus. It is not safe to pass a clamp from the lower edge of the right upper lobe bronchus medially to encircle the bronchus for the risk of laceration of the posterior ascending artery. Scissor dissection of the bronchus medial surface is performed. The bronchus is not uncovered of its fascia, and a finger can be inserted along the anterior aspect to reach its lower border (*Figure 4*). The bronchus is stapled and divided or manually sutured. The cut edge of the specimen side of the bronchus is grasped and elevated to facilitate the fissure dissection. With medial traction on the bronchus, the areolar tissue and nodes are dissected off the interlobar PA, and the posterior ascending artery is identified, ligated, and divided. The fissures should be managed by sharp dissection along the intersegmental vein using partial inflation of the middle and lower lobes against the upper lobe, by stapled division, or by a combination of both methods. With the bronchus divided and the posterior segmental artery transected, it is safe to pass a stapling device to separate the posterior aspect of the oblique fissure. The minor fissure is similarly completed. Medial traction of the bronchus clamp and dissection of the interlobar artery under direct vision lead to the middle trunk of the superior pulmonary vein and its posterior and inferior branches. The common stem of the posterior and inferior veins is identified. The site of insertion of the middle lobe vein into the superior PV is preserved. The venous stem is divided with a stapling device. After the specimen is removed, the pleural cavity is irrigated, and the bronchial closure is tested. The inferior pulmonary ligament is divided, allowing rotation of the lower lobe to facilitate the complete fill of the pleural space (2-5).

Right middle lobectomy

The inferior pulmonary ligament is mobilised. The right middle lobe lies against the anterior chest wall. The mediastinal pleura is incised to identify and ligate the right middle lobe vein, usually a branch of the right superior PV. The fissure between the upper and middle lobe is typically incomplete. After the exposition of anterior mediastinum and anterior surface of the upper and middle lobes, the venous drainage of these two lobes is recognised. The fissure line is developed as described previously. The development of the fissure between the upper and lower lobes reveals the lymph nodes in the area and the mean pulmonary artery. The right middle lobe PA arises from the intermediate artery near the superior segmental artery of the lower lobe. The right middle lobe PA is defined and stapled. The surgeon should avoid the posterior recurrent ascending branch to the upper lobe or the superior segmental branch to the lower lobe. All these vessels come off very close to one another. Finally, the right middle lobe bronchus is closed with a stapling device. Care must be taken to avoid injury to the superior segmental bronchus which comes out very close to the right middle lobe orifice. After the specimen is removed, the pleural cavity is irrigated, and the bronchial closure is tested (2,3,6).

Right lower lobectomy

The oblique fissure is opened retracting the right upper and middle lobes anteriorly and the lower lobe posteriorly. The interlobar PA is deeply situated in the region where the oblique and horizontal fissures meet. The visceral pleura overlying the interlobar artery is opened. The PA is dissected. The middle lobe artery, originating from the anteromedial surface of the interlobar artery, must be demonstrated. The superior segmental artery lies posterolaterally. Rarely, the posterior ascending artery to the upper lobe arises from the superior segmental artery. Occasionally, the basal arteries may have a short common trunk from which two branches arise: one for the anterior and medial segments, the other the posterior and lateral segments. Attention is then directed to securing the superior segmental artery, taking care to preserve the posterior segmental artery to the right upper lobe. The lobe is retracted anteriorly and superiorly. The inferior pulmonary ligament is divided up to the lower border of the inferior PV. The posterior mediastinal pleura is incised over the posterior surface of the inferior PV, which is cleared of tissue, and the pleural incision is carried superiorly to the bronchus intermedius. The interval between the lower border of the bronchus and the superior PV is dissected. The anterior surface of the inferior PV is then cleared. With a finger serving as a guide, the inferior PV is then isolated and closed by a vascular stapler. The lower lobe bronchus is then dissected. Since the middle lobe bronchus and the superior segmental bronchus derive from the intermediate bronchus, it may be necessary to divide the basal segmental bronchus and the superior segmental bronchus separately to avoid the obstruction of the middle lobe bronchus. Usually, an oblique application of the stapling device does not occlude the middle lobe bronchus. On the contrary, the lower lobe bronchus may be sutured as previously described. After the specimen is removed, the pleural cavity is irrigated, and the bronchial closure is tested (1,3,4).

Bilobectomy

Sporadically, the location of a lesion dictates removal of the middle and lower portions, a procedure that can be accomplished *en bloc* because of the common origin of these lobes as the bronchus intermedius. Where an indication exists for bilobectomy the vessels for each lobe are isolated and divided as described for each lobectomy. Once the PA branches have been divided the point of separation of the bronchus becomes apparent; the bronchus should be divided above the origin of the middle lobe bronchus just distal to the upper lobe take-off. If upper and intermediate lobes are resected, the bronchi are separately closed. For middle and lower lobectomy, the bronchus intermedius is divided distal to the right upper lobe bronchus. The major fissure is opened, and the lower lobe is retracted posteriorly. By following the posterior edge of the middle lobe as it joins the major fissure, and dissecting within the fissure, lymph nodes are evidentiated, indicating the site of the interlobar PA. The artery is dissected in the subadventitial plane, and the middle lobe artery is identified. Two middle lobe arteries exist: one defined arises from the interlobar artery anteriorly, opposite to the superior segmental artery. Proximal dissection of the interlobar artery shows a second (rarely a third) artery to the middle lobe. After the division of the middle lobe vein, the bronchus is readily accessible. After the sample is removed, the pleural cavity is irrigated, and the bronchial closure is tested (3-5).

Comments

There are several significant anatomic features relating to right-sided pulmonary resections that are unique to the right chest. The right main PA is relatively long and courses posterior to the superior vena cava and across the carina. This extra length of the artery is an advantage for some proximal lesions that in a comparable location on the left side would not be resectable because of the short length of the left main PA about the bifurcation. There should be enough length of artery distal to the bifurcation to be able to place a clamp and divide and suture the artery so that the lesion can be removed. The distance between the carina and the origin of the right upper lobe bronchus usually is <2 cm, and the Carina is readily mobilised from the right side. Access to the proximal left mainstem bronchus is significantly easier from the right side compared to the left side. The superior mediastinum is well visualised from the right side. The area bounded by the azygous vein (inferior), the trachea (posterior), the subclavian vein (superior), and the superior vena cave (anterior) delineates this compartment, whose lymph node bearing contents may be removed *en bloc* from the right side. In evaluating resections from the right side, the upper lobectomy probably is the most straightforward resection, although the location of the posterior segmental arterial branch may, at times, be problematic. Right lower lobectomy is complicated by the site of the middle lobe artery and bronchus. Major nonfatal events most commonly are respiratory related with patients developing significant infiltrates and pneumonitis. A small percentage of patients require reintubation in the postoperative period for respiratory failure usually related to the development of an infiltrate. Pulmonary complications can be minimised with meticulous attention to postoperative respiratory manoeuvres including chest physiotherapy and preoperative teaching. Cardiac complications also account for a significant percentage of mortality, whereas technical problems such as haemorrhage, bronchopleural fistula, and empyema account for a small but important percentage of complications leading to death. The most common minor complication is a supraventricular arrhythmia depending on how closely patients are monitored. Most of these respond to simple pharmacologic manipulation and rarely are hemodynamically significant at onset. With appropriate treatment, the rhythm reverts to sinus rhythm quickly, and patients may be taken off the antiarrhythmic drugs usually after one month. Other minor complications include postoperative air leaks lasting more than seven days and atelectasis. Meticulous attention to detail in all phases of management preoperative, intraoperative, and postoperative goes a long way toward keeping problems to a minimum (1-3).

doi: 10.21037/shc.2017.05.09
Cite this article as: Bertolaccini L, Pardolesi A, Solli P. Right side lobectomies. Shanghai Chest 2017;1:7.

Acknowledgements

The authors would like to thank Dr Eng. Riccardo Pardolesi for the indispensable help in the elaboration of the figures.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Baumgartner F. Cardiothoracic Surgery (Vademecum), 3rd Edition. CRC Press, 2004.
2. Shields TW, Lo Cicero J, Ponn RB, et al. General Thoracic Surgery, 6th Edition. Lippincott Williams & Wilkins, 2005.
3. Kaiser LR, Kron IL, Spray TL. Mastery of Cardiothoracic Surgery, 2nd Edition. Lippincott Williams & Wilkins, 2007.
4. Riquet M, Le Pimpec Barthes F. Linfectomie nel corso delle exeresi polmonari per cancro. EMC – Tecniche Chirurgiche Torace 2012;16:1-12.
5. Renaud S, Renaud C, Seguin A, et al. Principi della chirurgia di exeresi polmonare. EMC – Tecniche Chirurgiche Torace 2013;17:1-9.
6. Ellison EC. Zollinger's atlas of surgical operations, Tenth edition. McGraw – Hill, 2016.

Lung

Right pneumonectomy

Diego Avella Patino, Mark K. Ferguson

Department of Surgery, The University of Chicago, Chicago, IL 60637, USA

Correspondence to: Mark K. Ferguson, MD. Department of Surgery, The University of Chicago, 5841 S. Maryland Avenue, MC 5040, Chicago, IL 60637, USA. Email: mferguso@surgery.bsd.uchicago.edu.

Received: 28 March 2017; Accepted: 17 May 2017; Published: 02 June 2017.
doi: 10.21037/shc.2017.05.08
View this article at: http://dx.doi.org/10.21037/shc.2017.05.08

Indications

A right pneumonectomy most commonly is performed to treat lung cancer that is centrally located (1). Other indications for malignancy involve multiple lung metastases that cannot be resected using parenchymal sparing techniques and rare vascular tumors arising from the pulmonary artery or veins. Pneumonectomy is occasionally indicated for benign conditions, such as bronchiectasis and chronic infection resulting in a destroyed lung that is associated with respiratory symptoms and poses a risk of infecting the remaining good lung. We have performed a right pneumonectomy on rare occasions for recurrent massive hemoptysis without a localized source and after having exhausted interventional management options.

In patients in whom cancer is suspected, it is critical to obtain histologic confirmation, make a physiologic assessment of resectability, and rule out the existence of distant metastases. Bronchoscopy, chest and upper abdomen computed tomography (CT) with intravenous contrast, positron emission tomography (PET), and endobronchial ultrasound or mediastinoscopy for nodal assessment are generally required.

All candidates for a pneumonectomy should undergo a preoperative cardiopulmonary function evaluation. This assessment includes a complete history and physical exam, and measurement of spirometry and diffusing capacity. Additionally, in patients with borderline function, quantitative perfusion (V/Q) scan and measurement of maximum oxygen consumption during exercise (peak VO_2) are indicated.

Operative technique

Preparation

A double lumen endotracheal tube is preferred for airway management and right lung isolation. Place the patient in the left lateral decubitus position. The type and location of the incision must be decided based on the indication for surgery, the amount of exposure needed, and the physical characteristics of the patients. We prefer to use a lateral muscle sparing thoracotomy in order to maintain shoulder girdle function, decrease postoperative pain, and preserve chest wall muscles for treatment of potential airway complications. Nevertheless, a wider field of exposure is sometimes necessary if the patient has a large central tumor making access to the hilum difficult, proximal airway involvement, or if challenging vascular dissections are encountered. Usually, the chest is accessed through the fifth intercostal space. However, in obese patients with high diaphragms, the fourth intercostal space is preferred.

Exposition

Chemoprophylaxis for venous thromboembolism is used routinely perioperatively. Before beginning the dissection, explore the chest cavity. A full assessment of the lung, hilar vessels, and nodes is performed to ensure that an R0 resection is feasible. The pulmonary ligament is divided. A complete mediastinal nodal dissection is performed, including stations R9, R8, 7 and R4. Suspicious nodes are assessed with frozen section if the identification of N2 nodal involvement would alter the surgical plan.

Operation

Begin by dividing the pleura surrounding the hilum. Both pulmonary veins are dissected circumferentially (*Figure 1*). After ascertaining that the pneumonectomy can be completed safely, these vessels are divided with a linear

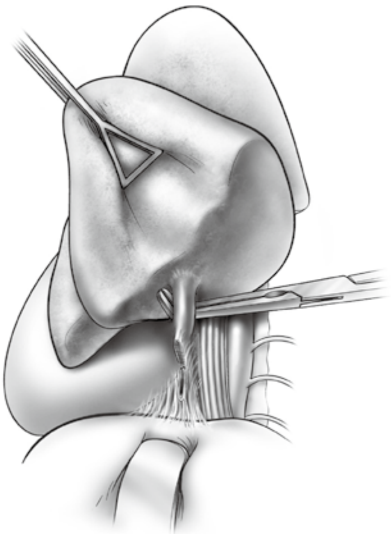


Figure 1 Dissection of the right inferior pulmonary vein (From: Ferguson MK: Thoracic Surgery Atlas. Philadelphia, PA: Saunders; 2007, with permission from author).

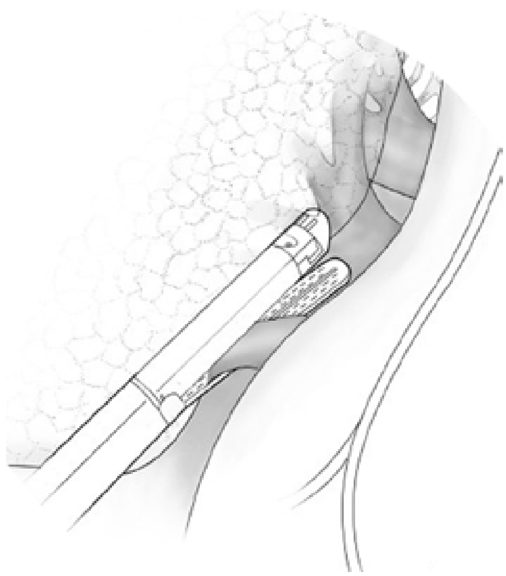


Figure 2 Division of the right inferior pulmonary vein with a linear stapler. (From: He J and Xu X. Thoracoscopy anatomic pulmonary resection. J Thorac Dis 2012;4(5):520, with permission from AME Publishing Company).

cutting stapler or with sequential application of an anvil-type stapler (*Figures 2,3*). The right pulmonary artery is dissected circumferentially to the pericardial reflection (*Figure 4*). The artery is divided with sequential application

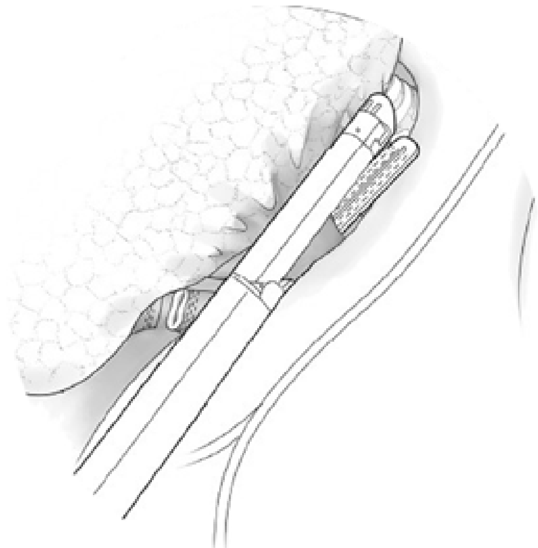


Figure 3 Division of right superior pulmonary vein with a linear stapler. (From: He J and Xu X. Thoracoscopy anatomic pulmonary resection. J Thorac Dis 2012;4(5):520, with permission from AME Publishing Company).

of anvil-type staplers (*Figure 5*) or a linear stapler, or may be clamped, divided, and oversewn if application of staplers is technically difficult (*Figure 6*).

If dissection of one of these three vessels is likely to be difficult, the other two vessels are dissected first and then encircled with a vessel loop and gently snared. If injury to the third vessel occurs, bleeding can be greatly reduced by closing the snares to occlude the other two vessels. Injuries to the right pulmonary artery are challenging to control because there is very little room available to place an occluding vascular clamp. An intrapericardial dissection between the superior vena cava and the aorta allows cross clamping of the right pulmonary artery at its take off from the pulmonary trunk (*Figure 7*). In other circumstances, inflow occlusion obtained by snaring down both vena cava may provide a few minutes of bleeding control and sufficient exposure to repair the pulmonary artery injury.

The bronchus is dissected circumferentially at its origin, taking care not to devascularize the trachea or left main bronchus. An adequate dissection of the subcarinal space and sometimes resection of the azygos arch are necessary to provide better exposure to the origin of the right main bronchus. The right main bronchus is then closed with a linear non-cutting stapler, occluded distally with a bronchial clamp and divided (*Figure 8*). An appropriate staple height commensurate with the thickness of the bronchus should

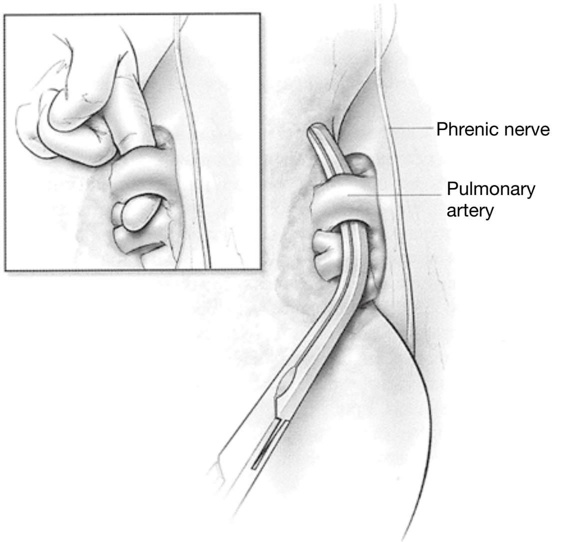


Figure 4 Dissection of right pulmonary artery (inset demonstrates blunt digital dissection) (From: Ferguson MK: Thoracic Surgery Atlas. Philadelphia, PA: Saunders; 2007, with permission from author).

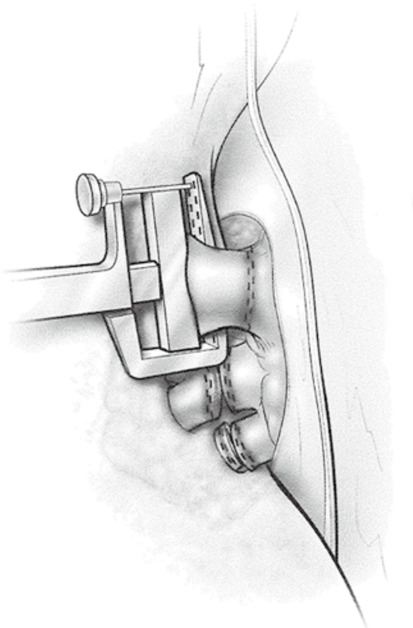


Figure 5 Division of the right pulmonary artery after sequential application of staplers (From: Ferguson MK: Thoracic Surgery Atlas. Philadelphia, PA: Saunders; 2007, with permission from author).

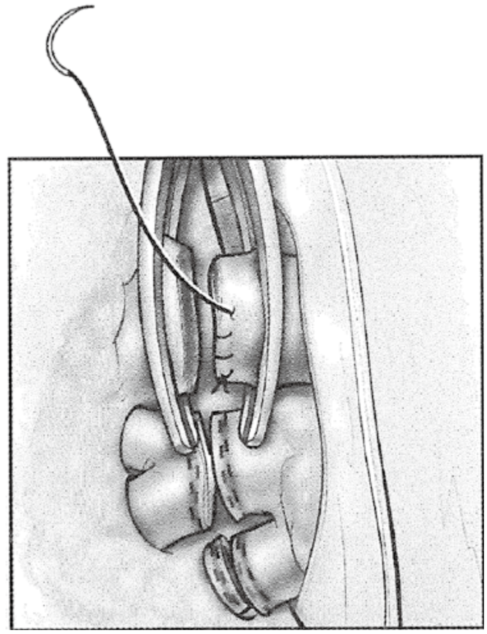


Figure 6 Division of the right pulmonary artery using a clamp, cut, and sew technique (From: Ferguson MK: Thoracic Surgery Atlas. Philadelphia, PA: Saunders; 2007, with permission from author).

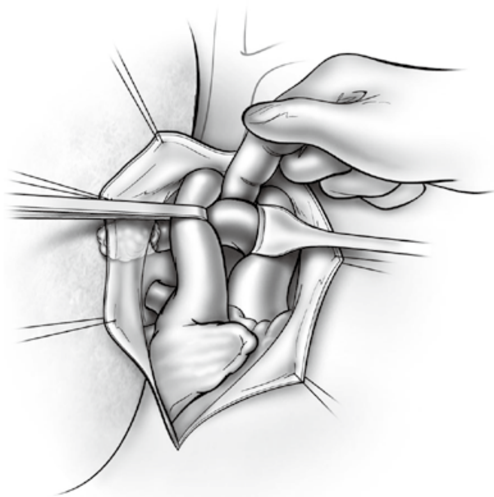


Figure 7 Obtaining control of the right pulmonary artery between the superior vena cava and the ascending aorta (From: Ferguson MK: Thoracic Surgery Atlas. Philadelphia, PA: Saunders; 2007, with permission from author).

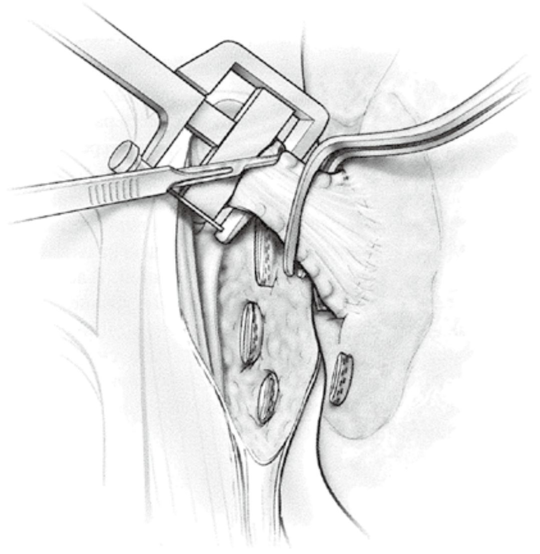


Figure 8 Right main bronchus closed with a stapler, occluded distally with a bronchial clamp, and divided (From: Ferguson MK: Thoracic Surgery Atlas. Philadelphia, PA: Saunders; 2007, with permission from author).

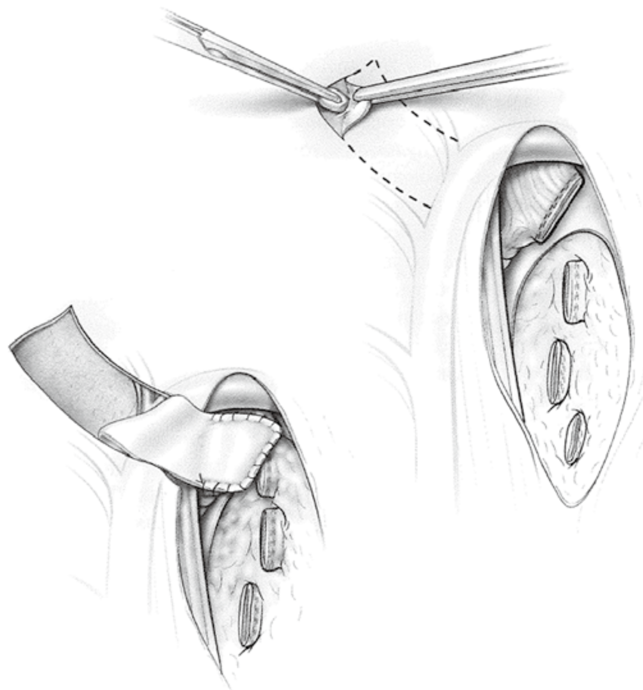


Figure 9 Preparation and application of a pleural flap for bronchial stump coverage (From: Ferguson MK: Thoracic Surgery Atlas. Philadelphia, PA: Saunders; 2007, with permission from author).

be selected to ensure an airtight closure. When the tumor is close to the carina, the bronchus is divided with a knife at the carina without clamping the airway. The bronchus is then closed with interrupted absorbable sutures, taking care to avoid damaging the bronchial balloon of the double lumen endotracheal tube.

The risk of stump leak can be reduced by covering the stump with a flap of vascularized tissue. One option is to raise a pleural flap lateral to the azygos based superiorly (*Figure 9*). The flap must be sufficiently wide to be sutured to viable soft tissue at the medial extent of the bronchial dissection and sufficiently long to reach over the azygos vein to cover the stump without tension. Interrupted sutures should be used to tailor the pleural flap coverage over the bronchial stump. Other options for tissue flaps include intercostal muscle, pericardial fat (*Figure 10*), pericardium, the azygos vein, and a muscle flap such as latissimus dorsi or serratus anterior transposed into the chest.

The pericardium must be closed after a right intrapericardial pneumonectomy to avoid cardiac herniation. Primary closure is sometimes possible, but the use of a patch to eliminate the pericardial defect has advantages. A pneumonectomy, particularly on the right side, is associated with significant right heart dysfunction and right ventricular dilatation. Primary pericardial closure reduces the size of the pericardial space, restricting cardiac function. The effects of this are usually negligible in healthy people, but in the postpneumonectomy patient, this can lead to restrictive effects that become evident 24 to 48 hours postoperatively and are poorly tolerated. Use of a small fenestrated patch, such as expanded polytetrafluoroethylene (PTFE) that is sutured to the pericardium edges, prevents cardiac herniation and eliminates the risks of pericardial restrictive effects in the immediate postoperative period (*Figure 11*).

Meticulous hemostasis should be obtained because postoperatively there is no longer a lung to tamponade minor sources of bleeding.

There is controversy as to whether a pleural drain should be used postoperatively. One advantage of the drain is that it may be used after the thoracotomy incision is closed to balance the mediastinum in the center of the chest. This is done by first positioning the patient, who is still intubated and sedated, supine on the operating table. The pleural drainage system is then placed at the level of the right heart and on water seal. The contralateral lung is inflated and maintained at a constant airway pressure of 40 cmH_2O for 5 to 10 seconds. After excess air is evacuated from the pneumonectomy space during the positive

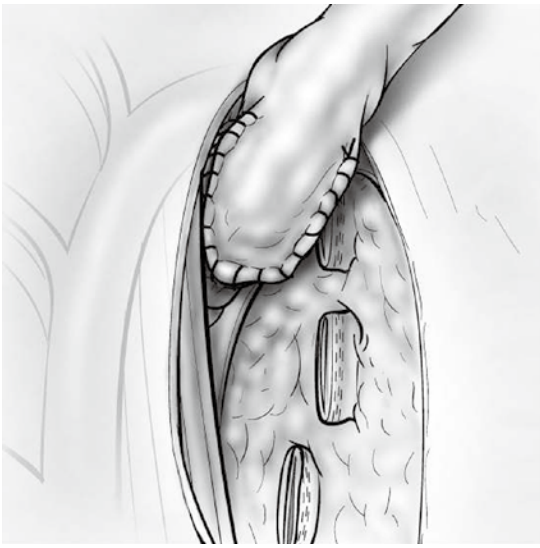


Figure 10 Pericardial fat pad coverage of the bronchial stump (From: Ferguson MK: Thoracic Surgery Atlas. Philadelphia, PA: Saunders; 2007, with permission from author).

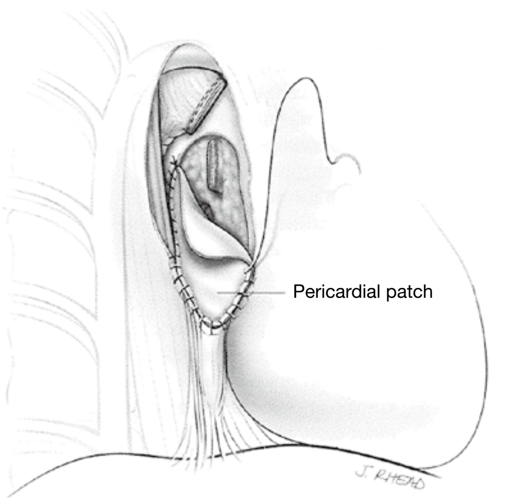


Figure 11 Use of a synthetic patch to close the pericardial defect after an intrapericardial pneumonectomy (From: Ferguson MK: Thoracic Surgery Atlas. Philadelphia, PA: Saunders; 2007, with permission from author).

pressure inspiration, the drainage tube is clamped before the inspiratory cycle is terminated. The drainage tube is then left clamped unless a large hemothorax or hydrothorax develops, which is relieved by temporarily unclamping the chest tube. The potential down side of placing a chest tube is that there is an increased risk of contaminating the pleural space, leading to postpneumonectomy empyema. If a tube is used, it should be connected to a balanced drainage system, which prevents the development of excessive negative or positive intrathoracic pressure that can lead to mediastinal shift with its attendant cardiovascular consequences or to volotrauma of the remaining lung.

An alternative method of balancing the mediastinum when a drain is not left in place is to position a soft rubber catheter through the incision as it is being closed, weaving the catheter gently through the layers as they are sutured so that the tube does not lie in a straight tract. Before the skin is closed but after an airtight seal is achieved, the tube is placed under water seal and the patient is given a sustained breath as previously described. Once excess air has been evacuated, the tube is quickly withdrawn and normal ventilation is resumed. The remainder of the incision is then closed.

If the mediastinum has not been adequately medialized with these techniques based on postoperative chest radiograph, and if there is hemodynamic compromise, the mediastinum should be repositioned while the patients is in the postanesthesia care area. A large bore angiocath attached to a stopcock is inserted in the fourth intercostal space in the midclavicular line under sterile conditions, and an appropriate volume of air (usually 500 to 1,000 mL) is added or removed as is necessary to achieve the desired result.

Completion

Analgesia after pneumonectomy is crucial to prevent respiratory complications, allow early mobilization from bed to chair, and facilitate early ambulation. Multimodality analgesia is usually necessary in the early postoperative period, which includes oral or intravenous narcotics and nonsteroidal anti-inflammatory drugs (NSAIDs), intercostal blocks with local anesthetics, and epidural infusion of narcotics and local anesthetics.

Clearance of respiratory secretions and re-expansion of the atelectatic contralateral lung are facilitated by early and frequent use of incentive spirometry. Intravenous fluid administration is restricted to avoid fluid overload and pulmonary edema. Oral alimentation is resumed on the same day of surgery after recovery from anesthesia.

Chemical prophylaxis against atrial fibrillation is routinely used beginning in the immediate postoperative period.

Patients are discharged after the pleural drain is removed if they are ambulating independently, if pain control with oral analgesics is adequate, and when vital signs are close to normal. All patients are discharged on pharmacological prophylaxis for atrial fibrillation. If the operation was performed for cancer, patients are discharged on pharmacological thromboembolic prophylaxis for four weeks. Ambulation and frequent use of the incentive spirometer after discharge are encouraged.

Comments and tips

Dissection of the pulmonary artery

Certain techniques can be used to avoid injuries of the pulmonary artery, including handling the adventitia instead of grasping the vessel directly, and using blunt dissection instead of placing a right angle clamp behind the vessel until it has been circumferentially dissected. Some surgeons emphasize that the safest instrument to use to encircle the pulmonary artery is their own index finger (*Figure 4*).

The vessels are then occluded and divided with a linear cutting vascular stapler. Alternatively, in cases where the placement of the linear stapler is not feasible, an anvil non-cutting stapler is sometimes easier to pass under the vessel. The anvil of the stapler can be directed across the vessels with the guidance of a right angle clamp advanced from the opposite end. Wide dissection of the vessel is needed to allow two separate fires of the stapler and the ability to cut in between them (*Figure 5*). Another option is clamping and oversewing the medial portion of the vessel with a Blalock stitch using a permanent monofilament suture (*Figure 6*).

It is wise to assess whether the patient can tolerate loss of the lung by test clamping the pulmonary artery for a minute or two and ensuring there are no signs of the development of right heart failure. The anesthesiology team should be warned to watch for development of sinus tachycardia, supraventricular arrhythmias and signs of bilateral ventricular strain in the electrocardiogram. In such instances, pharmacological support of the right ventricle and reduction of pulmonary vascular resistance without lowering the systemic blood pressure are advised.

Intrapericardial pneumonectomy

If the patient has (I) extensive fibrosis and inflammation after radiation, (II) a tumor encroaching on any of the main vessels close to the pericardial reflection or (III) pericardial involvement by bulky tumors, proximal vascular control can be obtained by intrapericardial dissection. The pericardium should be opened longitudinally from below the inferior pulmonary vein to above the pulmonary artery posterior to the phrenic nerve to spare it. The vessels can then be easily isolated and encircled.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Kozower BD, Larner JM, Detterbeck FC, et al. Special treatment issues in non-small cell lung cancer: Diagnosis and management of lung cancer, 3rd ed: American College of Chest Physicians evidence-based clinical practice guidelines. Chest 2013;143:e369S-99S.

doi: 10.21037/shc.2017.05.08

Cite this article as: Avella Patino D, Ferguson MK. Right pneumonectomy. Shanghai Chest 2017;1:10.

Right side sleeves

Domenico Galetta[1], Lorenzo Spaggiari[1,2]

[1]Division of Thoracic Surgery, European Institute of Oncology, Milan, Italy; [2]Department of Oncology and Hematology-Oncology-DIPO, University of Milan, Milan, Italy

Correspondence to: Domenico Galetta, MD, PhD. Division of Thoracic Surgery, European Institute of Oncology, Via Ripamonti 435, Milan, Italy. Email: domenico.galetta@ieo.it.

Received: 31 August 2017; Accepted: 01 August 2017; Published: 12 September 2017.
doi: 10.21037/shc.2017.09.01
View this article at: http://dx.doi.org/10.21037/shc.2017.09.01

Introduction

Bronchial and vascular reconstructive procedures are demanding operations performed in case of infiltration of the bronchial tree and/or the pulmonary artery (PA) and its branches.

In the past these procedures were described for patients with lung tumors whose pulmonary reserve was judged inadequate to permit pneumonectomy. Since then, many clinical series confirm that these bronchoplastic/angioplastic procedures may provide as good as better results than pneumonectomy in selected cases of lung tumors involving the bronchial/vascular tree.

Nowadays, these lung-sparing reconstructive procedures are been widely adopted in many centers with good long-term outcomes above all if compared to the results reported after pneumonectomy (1-3).

The basic technique and the principles of broncho/vascular reconstructive procedures were well previously established (4-7). In every case, it is essential to recognize the surgical anatomy of the bronchial and vascular tree in order to safety perform bronchoplastic and angioplastic procedures and reduce the risks of complications.

Tracheal carina is located in correspondence of the IV dorsal vertebra. At this level, trachea bifurcates into mainstem bronchi (right and left). Right mainstem bronchus is in the same axis of the trachea and the distance between carina and the orifice of the right upper lobar bronchus varies between 1.5 and 2.0 cm. Distal to this latter, there is the bronchus intermedius whose length is about 2.0 cm. The greater length of the bronchus intermedius makes a bronchial sleeve resection easier and explains why bronchoplasties are frequently associated with right upper lobectomies. The bronchus for the middle lobe originates from the frontal aspect of the bronchus intermedius at the same level of the orifice of the superior segmental bronchus of the lower lobe. This one originates at the posterior portion of the bronchus intermedius. Sometimes, when a right upper sleeve lobectomy is performed, the distal bronchial resection may fall proximally to the origin of these two segmental bronchi: in this case, great attention should be taken to avoid their stenosis during bronchial reconstruction. There is sometimes a significant mismatch between the bronchi due to their different diameter: in these cases, a “telescopic” bronchial anastomosis may solve this problem.

Another important aspect is the bronchial vascularization anatomy in order to prevent anastomotic complications. Site of origin, number, and course of bronchial arteries is rather variable, sometimes originating from descending thoracic aorta or from intercostal arteries. On the right side, there is generally a single bronchial artery which originates from an intercostal artery. This artery runs in the posterior portion of the mainstem bronchus (membranous aspect), parallel to the azygous vein. Anyway, the bronchial circulation system has a wide anastomotic network connecting it with the pulmonary arterial circulation.

Very important is also the surgical anatomy of the PA. After its origin below the aortic arch, the right PA moves in a horizontal plane, posteriorly to the aorta and superior vena cava, below the carina, running for the majority of its course intrapericardially. Then, once it is left out the pericardium, PA passes anteriorly to the right mainstem bronchus. This is the place where a bronchovascular fistulas may occur after bronchoplasty and for this reasons a pedunculated flap should be always used to wrap the bronchial anastomosis. Then, from the PA rises the first arterial branch, the truncus

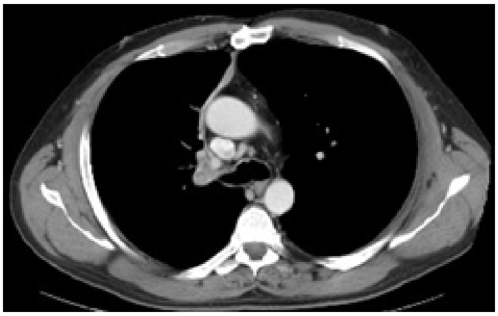


Figure 1 Radiologic image of bronchial infiltration. CT scan shows the case of a lung cancer invading the origin of the right upper lobar bronchus.

anterior or Boyden trunk for the upper lobe. Then it runs inferiorly between the bronchus intermedium posteriorly and the superior pulmonary vein anteriorly. At this level, the PA is closely applied to the undersurface of the vein, and careless dissection may be hazardous.

Indications for right sleeve resections are the presence of tumors which infiltrate usually the origin of the upper lobar bronchus (*Figure 1*), associated or not to invasion of PA or the origin of vascular branch. Moreover, a right sleeve resection may be indicated in case of presence of infiltration of the bronchial tree and/or the PA by a hilar lymph node. In some instances, the presence of fibrotic tissue or residual tumor after neoadjuvant treatments may also be another indication to perform broncho-angioplastic procedures.

Preoperative assessment has been largely reported in the Chapter of Left Side Sleeves. Briefly, preoperative evaluation includes computed tomography scan of the brain, chest, and upper abdomen, and PET scan. Bronchoscopy is always performed to evaluate the level of bronchial infiltration and for obtaining the diagnosis. EBUS is usually preoperatively performed for evaluating the mediastinal nodes involvement. Preoperative cardiologic and pneumologic evaluation is mandatory.

Operative technique

Preparation and Exposition

Patient's preparation and exposition has been reported in the Chapter of Left Side Sleeves. Briefly, after general anesthesia, a double-lumen endotracheal tube is placed in the left mainstem bronchus and confirmed by fiberoptic bronchoscopy. The intervention is performed with the

Figure 2 The patient is installed on the operative table in a later position. Skin incision (read line) is drowned at the IV intercostal space.

patient in lateral position entering into the thorax through the 4th of 5th intercostal space (*Figure 2*).

Operation

When entering the chest, the right hemithorax is carefully examined for evidence of intrathoracic spread. Fissures are completely dissected. The right lower and middle lobes are carefully examined for evidence of second primaries or metastatic disease. The right mediastinal pleura are circumferentially incised around the hilum and the inferior pulmonary ligament is mobilized. The posterior hilum is examined for unexpected extension of the tumor into the mainstem bronchus or distal bronchus intermedius. Dissection of mediastinal and hilar nodes is performed avoiding to devascularise the bronchial tree at the level of the section line. The proximal main PA and superior pulmonary vein are fully dissected. The main PA is encircled with vascular tape which facilitates proximal clamping of the PA in case of an angioplastic procedure or vascular sleeve resection is required. Although angioplasty is unusual in right upper-lobe sleeve resections, mobilization of the entire PA is required for an adequate airway dissection. In addition, the vascular tape facilitates exposure of the airway with anterior retraction of the ongoing PA.

When the hilum is dissected, the truncus anterior artery is divided with a vascular stapler. The vascular stapler we typically use is a 30-mm thoracoscopic stapler that can also be used to transect the superior pulmonary vein. After

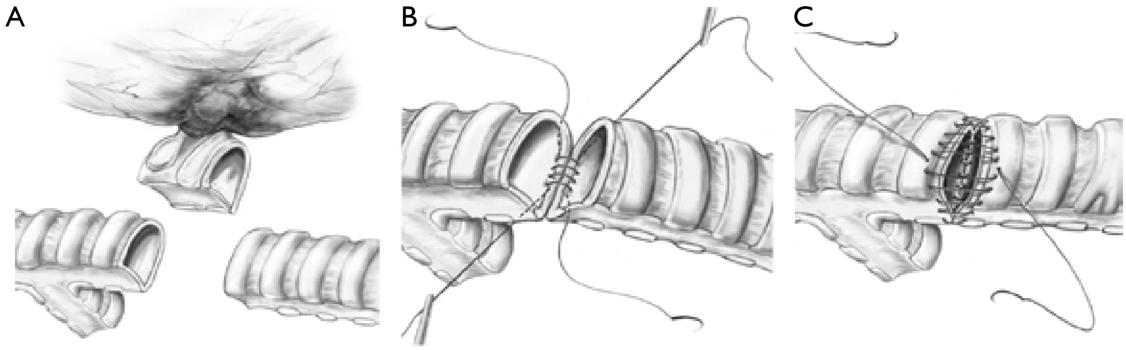


Figure 3 A schematic drawing of sleeve bronchial resection and reconstruction of the right upper bronchus. (A) After isolation of the right bronchial tree, the right mainstem bronchus and the intermedius bronchus are cut; (B,C) the two bronchial stumps are approached and two separated non-absorbable monofilament are used for the anastomosis.

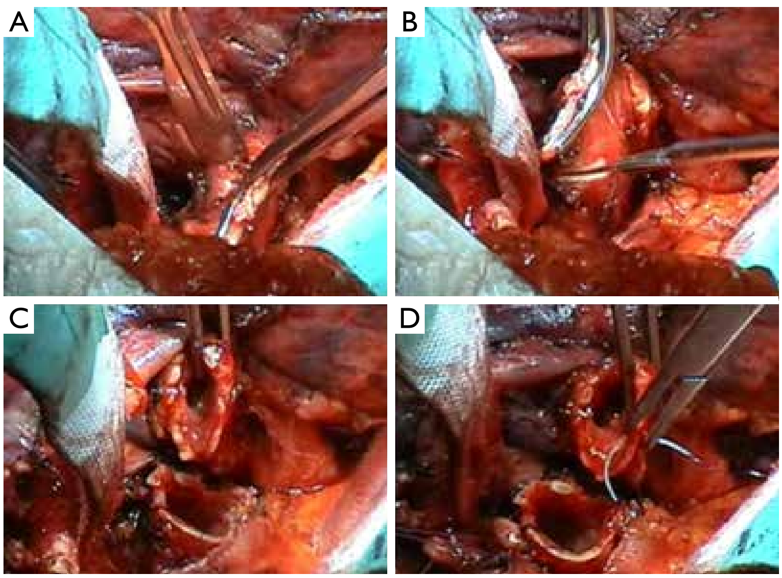


Figure 4 Intraoperative view of the right main stem bronchial transection (A) and the transection of the intermedius bronchus (B). The two bronchial stumps are approximated (C) and the first monofilament stitch is placed at the cartilaginous edge (D).

transection of the proximal artery and vein, the posterior recurrent branch of the PA is readily exposed and divided. The PA should be fully mobilized to the level of the superior segmental artery.

The division of the posterior recurrent branch of the PA facilitates complete mobilization of the right upper-lobe major fissure. Whether sharp dissection, electrocautery, or a stapler is used to complete the fissure, care must be taken to minimize any potential air leaks. The minor fissure is usually completed with a stapler.

The right upper lobe is fully mobilized before transecting the airway. First, the right mainstem bronchus is mobilized by passing umbilical tape around in the airway. Similarly, the bronchus intermedius is mobilized and encircled with umbilical tape. The proximal and distal tapes permit a careful inspection of the potential surgical margins before transecting the airway. The relative size mismatch of the airways can also be evaluated.

The bronchus is transected in a plane transverse to the axis of the airway. The perpendicular transection of the airway minimizes the size mismatch and facilitates the subsequent anastomosis. *Figure 3* represents a schematic drawing of a right upper slleve bronchial resection and anastomosis while *Figure 4A,B* shows the intraoperative

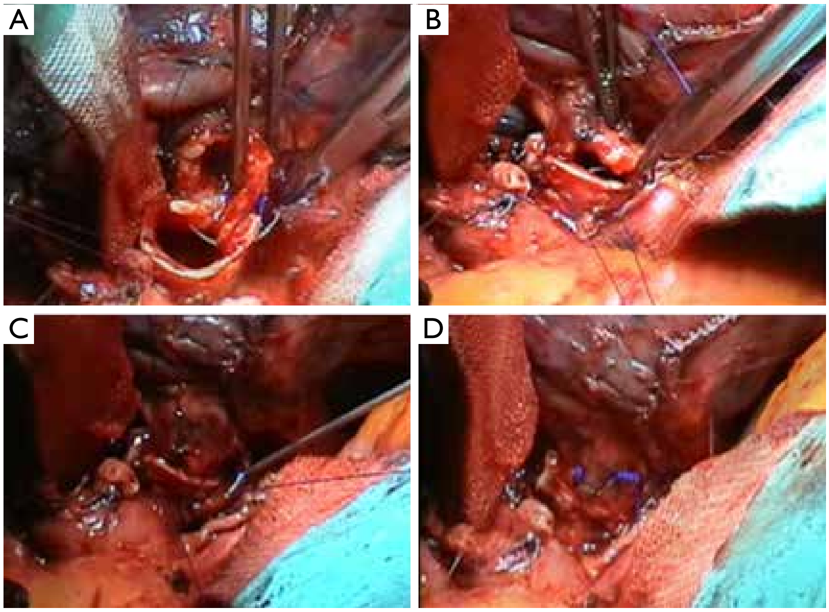


Figure 5 Intraoperative view of the bronchial reconstruction. (A) The second stitch is positioned at the cartilaginous edge; (B) anastomosis between the two bronchial edges is almost completed and the second running monofilament suture has been terminated; (C) before knotting, the stitches are well pull by means of a hook; (D) the bronchoplasty is concluded.

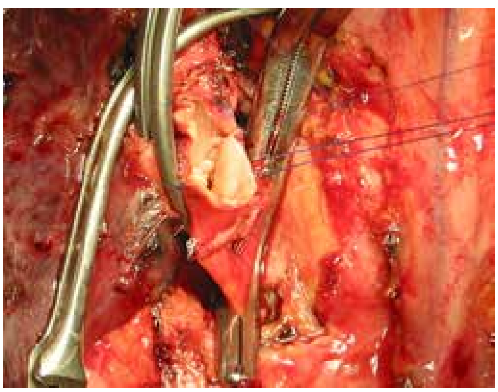


Figure 6 The main PA is proximally (extra-pericardically) and distally clamped by atraumatic vascular clamp. Distal control of the PA is obtained with another vascular clamp. In the reported case a direct suture of the arterial was performed using 6/0 polypropylene suture.

view of the bronchial transection. The oblique orientation of the airway cartilage can be misleading. The use of a needle-nose clamp to crush the cartilage in the appropriate orientation may be helpful in a teaching setting. When both the proximal and distal airways have been transected, the specimen is submitted to the pathology laboratory for frozen section evaluation of both the proximal and distal margins.

The orientation of the proximal and distal airways can be maintained with traction sutures. Although the orientation is more problematic in other sleeve lobectomies, we routinely place 3-0 monofilament traction sutures at the cartilaginous membranous junction. The sutures are placed in the cartilage to allow rotational traction in the airway and facilitate exposure for the anastomosis.

The cartilaginous portion of the anastomosis is constructed using two 3-0 monofilament (polypropylene) sutures. Stitches are anchored and knotted at the level of the cartilaginous wall (*Figure 4C,D*). Then, two running sutures are performed and a telescopic anastomosis is obtained (*Figure 5A,B*). At the end of the suture, stiches are well pulled by means of a hook (*Figure 5C,D*). Monofilament sutures provide additional strength for the first several months after airway reconstruction. The persistence of these sutures may help minimize the rotational deformation of the airway that can be bronchoscopically observed several years after sleeve resection. In addition, monofilament sutures are more convenient to use with a running technique.

In some exceptionally cases, a right angioplasty is needed (*Figure 6*). The technical aspects of PA reconstruction have

Figure 7 An endobronchial tumor located at the origin of the middle bronchus. (A) Endobronchial view of the neoplasm. CT axial (B) and sagittal (C) scans showing the endobronchial lesion.

Figure 8 Anatomic specimen with the middle lobe and the endobronchial resected tumor originating at the ostium of the middle bronchus.

been largely reported in the Chapter of Left Side Sleeves.

After completion of the anastomosis, the remaining right lung is ventilated. The anastomosis can be tested for an air leak using saline irrigation. The care taken to prevent an air leak in the major and minor fissures is rewarded by the absence of air bubbles near the bronchial reconstruction. Because the completed major and minor fissures rotate toward the anastomosis with reinflation, the evaluation of the source of the air leak can be ambiguous. The remaining middle and lower lobes should reinflate easily. Intraoperative bronchoscopy can be useful to evaluate the anastomosis and remove any retained secretions.

Although uncomplicated anastomotic healing is the rule, any airway separation or perianastomotic infection can lead to a catastrophic bronchovascular fistula. Normal tissue can be interposed between the bronchial anastomosis and the PA to prevent this complication. We typically mobilize the right lobe of the thymus gland and wrap the thymic fat between the artery and airway.

On rare occasions, a middle lobectomy with sleeve resection of the bronchus intermedius may be indicated (*Figures 7,8*). In this case an angled transection of the bronchus intermedius is performed resecting the origin of the middle bronchus and sparing the origin of the superior segment of the lower lobe (*Figures 9,10*). In this maneuver great attention should be taken in preserving the PA which is located posteriorly to the bronchus.

In case of endoluminal lesion in the bronchus intermedius, a sleeve bilobectomy may be required. The bronchial transection of the mainstem bronchus should be performed at the level of the upper bronchial origin while the resection of the bronchus intermedius should be performed just beneath the orifice of the upper bronchus. The bronchoplasty between mainstem bronchus and the upper right bronchus is then performed. In this case, due to the particular angle of the anastomosis and re-orientation of the bronchial axis, particular attention should be taken to avoid bronchial torsion (*Figure 11*).

Postoperative management of patients receiving bronchoplasty has been described in the Chapter of Left Side Sleeves.

Comments

Bronchial sleeve resection of the right upper lobe is the most common bronchoplastic procedure. The procedure should be considered in any patient with a proximal right upper-lobe tumor. Staging of the patient should include a bronchoscopic evaluation of the potential resection margin. Potential nodal metastases need to be carefully evaluated by endobronchial ultrasound. At the time of thoracotomy, additional nodal

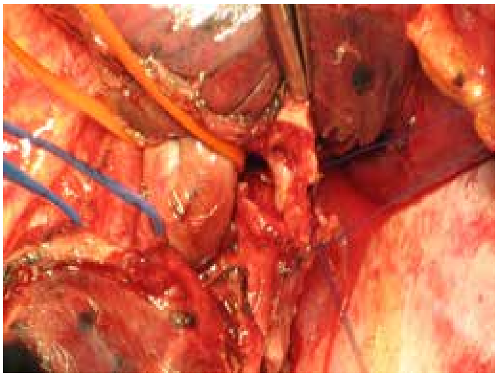


Figure 9 Intraoperative view of the bronchoplasty between the intermedius bronchus and the right lower bronchus.

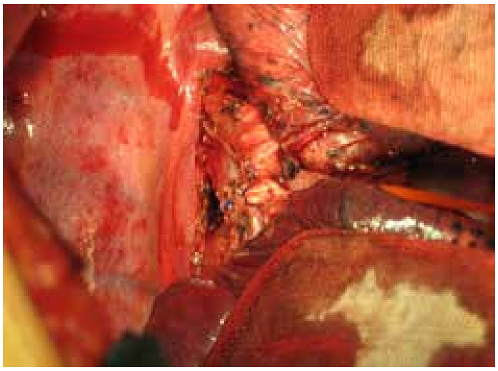


Figure 10 Intraoperative view of the completed anastomosis between the intermedius bronchus and the right lower bronchus.

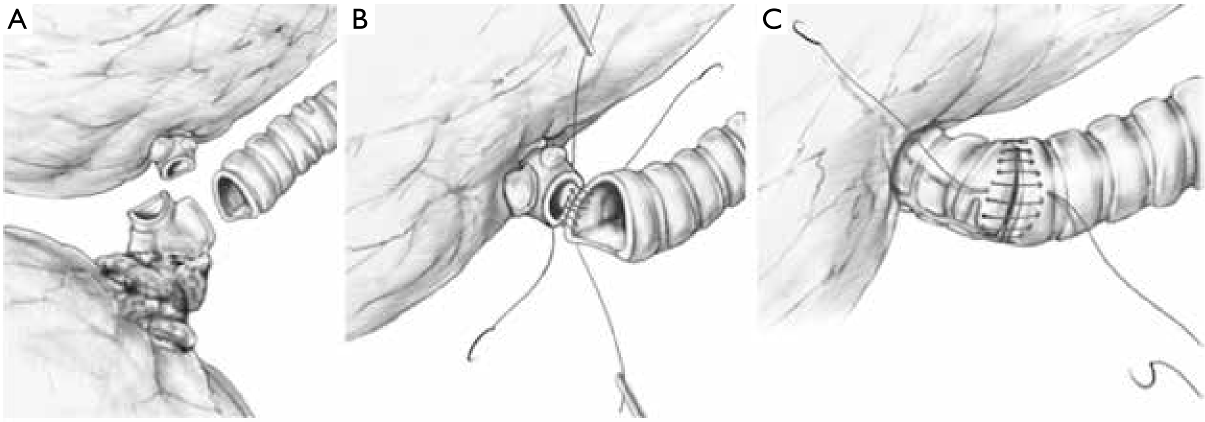


Figure 11 A schematic drawing of sleeve bronchial bilobectomy for tumor arising in the intermedius bronchus and extended to the origin of the upper bronchus. (A) The right upper bronchus and the right mainstem bronchus are cut and (B,C) the two bronchial stumps are approached and the anastomosis is performed by separated non-absorbable monofilaments.

sampling is required to assess the feasibility of sleeve resection. The surgeon who methodically evaluates each patient for possible sleeve resection will often be rewarded with an operation that produces an acceptable oncological result while preserving lung tissue and improving the quality of their patients' postoperative survival.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Deslauriers J, Gaulin P, Beaulieu M, et al. Long-term clinical and functional results of sleeve lobectomy for primary lung cancer. J Thorac Cardiovasc Surg 1986;92:871-9.
2. Ludwig C, Stoelben E, Olschewski M, et al. Comparison of morbidity, 30-day mortality, and long-term survival after pneumonectomy and sleeve lobectomy for non-small cell lung carcinoma. Ann Thorac Surg 2005;79:968-73.
3. Takeda S, Maeda H, Koma M, et al. Comparison of surgical results after pneumonectomy and sleeve lobectomy for non-small cell lung cancer: trends over time and 20-year institutional experience. Eur J Cardiothorac Surg 2006;29:276-80.
4. Price Thomas C. Conservative resection of the bronchial

tree. J R Coll Surg (Edinb) 1956:1:169-86.
5. Johnston JB, Jones PH. The treatment of bronchial carcinoma by lobectomy and sleeve resection of the main bronchus. Thorax 1959;14:48-54.
6. Vogt-Moykopf I, Frits TH, Meyer G, et al. Bronchoplastic and angioplastic operation in bronchial carcinoma: long-term results of a retrospective analysis from 1973 to 1983. Int Surg 1986;71:211-20.
7. Vogt-Moykopf I, Fritz T, Bülzebruck H, et al. Bronchoplastic and angioplastic operation in bronchial carcinoma. Langenbecks Arch Chir 1987;371:85-101.

doi: 10.21037/shc.2017.09.01
Cite this article as: Galetta D, Spaggiari L. Right side sleeves. Shanghai Chest 2017;1:33.

Mediastinal lymph node dissection in open thoracic surgery

Nikolaos Kostoulas, Kostas Papagiannopoulos

Department of Thoracic Surgery, St. James's University Hospital, Leeds, UK

Correspondence to: Kostas Papagiannopoulos, MMED THORAX, MD, CTH. Department of Thoracic Surgery, St. James's University Hospital, Bexley Wing, Level 3, Beckett St, LS9 7TF, Leeds, UK. Email: k.papagiannopoulos@nhs.net.

Received: 04 August 2017; Accepted: 16 August 2017; Published: 22 August 2017.
doi: 10.21037/shc.2017.08.09
View this article at: http://dx.doi.org/10.21037/shc.2017.08.09

Introduction

The importance of mediastinal lymph nodal involvement in lung cancer patients has been identified since 1978, when the first anatomic map for lymph node stations was published by Naruke. In 1997 an updated and detailed map was suggested by Mountain and Dresler and is the one that still remains in use, showing that there is a worldwide consensus on the nomenclature and the fact that they are an important descriptor in the staging process of lung cancer (1-3).

However, such consensus is not evident on the procedure that should be employed during lung resections, in order to obtain the most possible information of lymph node involvement and provide an accurate, final, postoperative, pathological N stage for non-small cell lung cancer. There is an evident long term dispute in the literature between the supporters of complete lymphadenectomy versus sampling (4,5). Equally, discussions remain whether a surgeon should perform lymphadenectomy in every mediastinal station or should follow a lobe-depended approach, in order to decrease the internal operative trauma (6). At the moment, the gold standard for the treatment of non-small cell lung cancer is lung resection combined with complete lymph node dissection of at least 3 mediastinal (N2) stations (7,8).

Operative technique

The traditional thoracotomy provides excellent access for an extensive lymph node dissection. The timing is a subject of discussion but we advocate lymphadenectomy prior to lung resection for the following reasons:

(I) Suspected lymph nodes can be subjected to intra operative frozen section and alter the surgical management in certain Institutions (9);
(II) Prior lymphadenectomy offers a superb dissection of the hilum with identification and separation of all hilar structures;
(III) Provision of a 'clean' operating field for safe ligation and transection of hilar structures;
(IV) Safeguards margins and eliminates disputes between surgeons and pathologists;
(V) Allows *en bloc*, clean resection of nodes and fat pads providing the best specimens for pathological examination.

Lymphadenectomy

General aspects

The preparation of the patient, incision and access to hilum and mediastinum have already been described in other chapters.

For the sake of completeness, the following safety features apply to each patient undergoing lymphadenectomy:

(I) Appropriate exposure with good lung isolation;
(II) Prior complete adhesiolysis with exposure of hilum and mediastinum;
(III) A 'dry' field with good prior hemostasis as blood pools in the most dependent areas which are peri hilar and mediastinal;
(IV) A sound knowledge of anatomy of mediastinum.

Technique description

Station 2

This station is also called "upper paratracheal" and it is usually dissected at the same time with Station 4 or by extending the dissection planes from Station 4 superiorly (*Figure 1*). For right sided resections the access is easier following the groove between the trachea and the superior

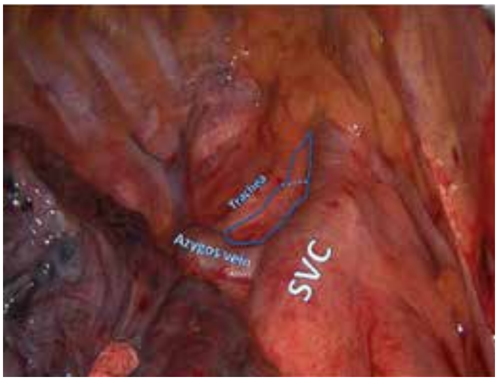


Figure 1 The dissection triangle containing the right paratracheal nodes is marked with the blue line. The dotted line defines arbitrary division between R2 and R4. Please note that the trachea, the SVC and the azygos vein are the boundaries of the nodal packet. The dissection should be cautious at SVC to avoid bleeding of tributaries and superiorly to avoid injury to the innominate artery. SVC, superior vena cava.

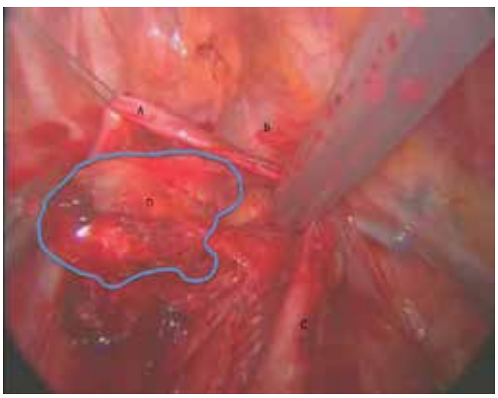


Figure 2 Another technique of retrieving right paratracheal nodes is dissection below the azygos vein. In this picture, the azygos has been retracted with a stitch through the chest wall to provide extra assistance and un obstructed view. (A) Azygos vein; (B) SVC; (C) phrenic nerve; (D) right paratracheal nodal tissue.

vena cava (SVC), although on the left side the aortic arch obscures the surgeon's view and special maneuvers need to be employed.

The assistant retracts the lung inferiorly. The pleura is incised lateral to the phrenic nerve and at the superior border of the azygos vein or aortic arch for right or left approach respectively. The fat tissue is grasped elegantly with fenestrated forceps or plain forceps and is dissected bluntly from the tracheal wall and surrounding structures. Diathermy is discouraged in this area as right sided dissection comes close to the right recurrent laryngeal nerve. Bleeding is avoided by clipping small arterial branches to the lymph nodal pad and avoiding injury to small draining veins that connect directly to the SVC on the right side. Small bleeds should be treated with simple gauze packing while other jobs are done in the chest. In the majority of cases no further action is required and hemostatic agents are available but rarely necessary.

Station 4

This station is also called "lower paratracheal". For a right approach the access is easy, but on the left the exposure is obstructed completely by the aortic arch and dissection on the left side is not routinely performed.

The lung is retracted inferiorly. The pleura is incised around the anterior and superior hilum, so that the azygous vein is separated from the pulmonary artery, lying inferiorly. The lower margin of Station 4 is identified below the proximal segment of the azygous vein resting posterolaterally to the SVC. The lymph nodes are dissected bluntly with a peanut or the suction catheter away from the azygous vein and SVC and away from the right main pulmonary artery (*Figure 2*).

The detachment from the artery may be facilitated by opening the arterial sheath, so at the same time the surgeon can assess any possible involvement of the pulmonary artery. The use of diathermy is not encouraged in this area, because of close proximity to major vascular structures. However, an energy device can facilitate the dissection without blood loss, maintaining clear dissection planes. This part of the station can be either removed at this stage or left aside and retracted from above the azygous vein for the next stage of dissection.

Hemostasis follows the same principles as described for station 2. Quite often these 2 stations are taken *en bloc* and an arbitrary division is performed by scissors. The specimens are placed in separate pots to be examined by a pathologist.

We generally advocate the use of clips and high energy devices to avoid injury to major vessels and the right recurrent nerve. Additionally, a clean dissection reduces the risk of an 'annoying' chyle leak, experienced when aberrant thoracic duct branches are disrupted but not ligated.

Station 5

We find this station only in the left chest cavity. It is also called "subaortic" and is located between the aortic arch

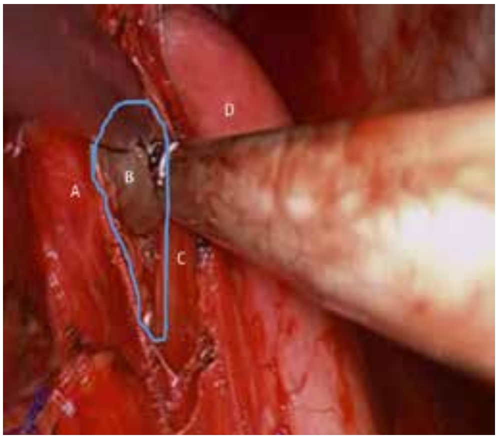


Figure 3 In this figure, the reader can appreciate the dissection for the subcarinal nodes from the left side. Please note that diathermy should be used with caution next to the esophagus to avoid injury. Large bronchial vessels directly from the descending aorta might cause significant bleeding and they should be clipped before the subcarinal nodes are detached from the surrounding tissues. Minor bleeding is best attended with initial packing and patience. (A) Bronchial stump; (B) subcarinal node; (C) esophagus; (D) descending aorta.

and the left main pulmonary artery, just laterally to the ligamentum arteriosum (aortopulmonary window).

The assistant retracts the lung inferiorly while the surgeon opens the pleural reflection at the superior border of the hilum. It is advisable to commence dissection by staying in close proximity of the left main pulmonary artery and identify the vagus nerve. The fat pad is gradually detached, vagal branches are clipped and no diathermy is used to avoid injury to the left recurrent laryngeal nerve. The dissection always keeps the roof of the vagus nerve as a pivot point and ascends as it comes to close proximity of the aortic arch. Quite often a 'button' of parietal pleura is sacrificed in order to perform a complete undisrupted dissection of the nodal fat pad.

Any minor bleeding is attended by gauze packing.

Station 6

It is also called "para-aortic" and is located adjacent to the lateral wall of the ascending aorta and aortic arch and its dissection is usually performed at the same time with the Station 5.

The dissection is a true continuation of the Station 5 lymph nodal pad. Injury to the left vagus should be avoided as it lies on the aortic arch and anterior dissection should protect the left phrenic nerve as well.

Station 7

This station is also called "subcarinal".

Station 7 is deeply embedded in the posterior mediastinum and access is impossible or challenging without prior appropriate homework from the surgeon.

Regardless of side of operation the pleural reflection on the posterior hilum needs to be dissected. The vagus nerve is identified and all hilar branches are individually identified and ligated. This maneuver offers two advantages:

(I) Prevents any bleeding from bronchial tributaries;
(II) Allows the ligatures to retract the vagus with the posterior mediastinum offering a good exposure.

On the left side, the proximal descending aorta reduces further the operating field and at times it needs to be retracted.

The main bronchus remains the pivot point on both sides. As soon as the nodes are identified the dissection concentrates on the inferior aspect of the main bronchus. The retraction of the nodes should be gentle and they should not be disrupted. Anteriorly the nodal pad is dissected from the posterior pericardium. There are generally no vessels of concern in that territory.

At the posterior aspect, the nodal pad needs to be dissected from the esophagus (*Figure 3*). We advocate the use of clips and no diathermy as the esophagus is an elegant structure and thermal injuries should be avoided with the generous use of diathermy. If in doubt, the surgeon should ask the anesthetist to introduce a large bore nasogastric tube or an esophageal bougie. Such maneuver will stent and state better the esophagus in the operating field. Identification is then easier in case of significant fibrosis and difficulty in identifying the correct dissection planes.

As soon as the true subcarinal area is reached care should be taken to clip the subcarinal bronchial vessels. For dissections performed on the background of inflammatory disease or bulky lymphadenopathy such vessels can be large and significant bleed might be encountered which is difficult to control at times due to the proximity of the vessels to the carina.

The reader should remember that the subcarinal dissection exposes the membranous part of the airways. This is subject to injuries as pressure is also applied endobronchially with the double lumen tube.

In case of a wet field, gauze packing is the answer again. The worst mistake is to control bleeding in a confined space with limited dissection and visibility.

In extreme circumstances, a period of apnoea with the bronchial cuff deflated might offer the extra volume required in the operating field to take care of the bleeding.

Figure 4 It is essential that the underlying mediastinum following dissection of the inferior pulmonary ligament should be checked for any bleeding prior to closing the thoracotomy. (A) Dissected inferior pulmonary ligament; (B) descending aorta; (C) left 9 lymph nodes.

The subcarinal space should be routinely packed for a few minutes while other jobs are done. The use of haemostatic agents is rarely necessary.

Station 8

This station is also called "paraoesophageal" and is including the lymph nodes that lie adjacent to the esophagus in each side, between the level of the bronchus and the diaphragm.

This is again a continuation of the previously described dissection of the posterior mediastinum and subcarinal nodes. This time the dissection identifies the paraoesophageal nodal pad just inferior to the subcarinal nodes and simply follows the esophagus until the pad is lifted off with gentle dissection and use if clips.

Again, the protection of the esophagus is of paramount importance. Additionally, the dissection should remain on the boundaries of the nodal pad to avoid injury to the thoracic duct leading to a chyle leak. For this reason, the separation of this nodal station from the mediastinum should ideally be performed mainly with blunt dissection and use of clips or ligation.

Station 9

This station is also called "inferior pulmonary ligament node", as it is lying inside the attachment of the pulmonary ligament to the mediastinum, between the inferior pulmonary vein (IPV) and the diaphragm on each side.

The lung is retracted superiorly and the ligament is transected initially with diathermy or a high energy device. Blunt dissection will then reveal the nodes within the pleural reflection and these should be dissected with the fat pad and part of the inferior pulmonary ligament until the floor of the IPV is identified (*Figure 4*).

This area has limited blood supply and bleeds are rarely encountered except the posterior attachments with the mediastinum and the close proximity to the IPV. The reader should remember that clips at the floor of the IPV should be avoided as subsequent stapling of the vein during lung resection can lead to stapler failure and catastrophic bleed.

General comments and advice

A meticulous lymph node dissection does not cure cancer but streamlines cancer treatment by offering accurate staging. Evidence shows that there is significant upstaging in patients who underwent total lymphadenectomy in comparison to those who had lymph node sampling. Hence, these patients can be offered adjuvant treatment with potential improvement in their long-term prognosis. Taking this into consideration, surgeons should be capable of offering their patients a safe, complete lymph node dissection without compromising patient safety.

The reader should keep in mind the following tips:

- ❖ In any nodal station, the surgeon should follow the landmarks surrounding the nodes, to facilitate a dry dissection;
- ❖ The technique of ligation instead of diathermy dissection keeps the field dry, protects surrounding tissues from potential thermal injuries and reduces the incidence of postoperative chyle leak from lymphatic vessels;
- ❖ The recurrent laryngeal nerve should be protected in lymphadenectomy of Stations 2 in the right side and 5 in the left side, especially in cases that there are no preoperative findings suggestive of involvement in these stations, so that a potential injury can justify the final disability;
- ❖ In patients with mediastinal lymphadenopathy and neoadjuvant treatment, the operating field might be hostile. The dissection should follow natural reflections and the soft flat structures, i.e., esophagus will need to be identified with special maneuvers to avoid injury (use of bougie or large nasogastric tube);
- ❖ Metal clips are a good choice for ligating small feeding vessels at surgery. They assist in an accurate dissection but are future markers if adjuvant radiotherapy is required.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Harisinghani MG. Atlas of Lymph Node Anatomy. New York: Springer, 2013:31-56.
2. Watanabe S. Lymph node dissection for lung cancer: past, present, and future. Gen Thorac Cardiovasc Surg 2014;62:407-14.
3. El-Sherief AH, Lau CT, Wu CC, et al. International association for the study of lung cancer (IASLC) lymph node map: radiologic review with CT illustration. Radiographics 2014;34:1680-91.
4. Dong S, Du J, Li W, et al. Systematic mediastinal lymphadenectomy or mediastinal lymph node sampling in patients with pathological stage I NSCLC: a meta-analysis. World J Surg 2015;39:410-6.
5. Doddoli C, Aragon A, Barlesi F, et al. Does the extent of lymph node dissection influence outcome in patients with stage I non-small-cell lung cancer? Eur J Cardiothorac Surg 2005;27:680-5.
6. Adachi H, Sakamaki K, Nishii T, et al. Lobe-Specific Lymph Node Dissection as a Standard Procedure in Surgery for Non-Small Cell Lung Cancer: A Propensity Score Matching Study. J Thorac Oncol 2017;12:85-93.
7. Lardinois D, De Leyn P, Van Schil P, et al. ESTS guidelines for intraoperative lymph node staging in non-small cell lung cancer. Eur J Cardiothorac Surg 2006;30:787-92.
8. Whitson BA, Groth SS, Maddaus MA. Surgical assessment and intraoperative management of mediastinal lymph nodes in non-small cell lung cancer. Ann Thorac Surg 2007;84:1059-65.
9. Li W, Yang XN, Liao RQ, et al. Intraoperative frozen sections of the regional lymph nodes contribute to surgical decision-making in non-small cell lung cancer patients. J Thorac Dis 2016;8:1974-80.

doi: 10.21037/shc.2017.08.09
Cite this article as: Kostoulas N, Papagiannopoulos K. Mediastinal lymph node dissection in open thoracic surgery. Shanghai Chest 2017;1:22.

Segmentectomies

Anna E. Frick[1], Dirk Van Raemdonck[1,2]

[1]Department of Thoracic Surgery, University Hospitals Leuven, Leuven, Belgium; [2]Department of Clinical and Experimental Medicine, KU Leuven University, Leuven, Belgium

Correspondence to: Prof. Dr. Dirk Van Raemdonck. Department of Thoracic Surgery, University Hospital Gasthuisberg, Herestraat 49, B-3000 Leuven, Belgium. Email: dirk.vanraemdonck@uzleuven.be.

Received: 31 July 2017; Accepted: 04 August 2017; Published: 29 August 2017.
doi: 10.21037/shc.2017.08.07
View this article at: http://dx.doi.org/10.21037/shc.2017.08.07

Introduction

Definition

The word segment is derived from the Latin noun segmentum ("a piece cut off") meaning part of larger structure. Bronchopulmonary segments are anatomical and functional units of lung parenchyma formed from subdivisions of each lobe. Each segment has a pyramidal structure with its apex at the hilum and its base on the surface of the lung supplied by (I) a segmental bronchus as tertiary branch of the bronchial tree; (II) a segmental branch of the pulmonary artery (as well as a bronchial artery); and (III) a segmental (± intersegmental) branch of the pulmonary vein together with lymphatics.

Segmental resection, or "segmentectomy", describes a technique whereby part of the lung is excised along its anatomical landmarks based on bronchovascular anatomy. It involves division and closure of all individual bronchovascular segmental structures followed by dissection and removal of the lung parenchyma along the intersegmental planes. A thorough knowledge of the human lung anatomy is mandatory for any surgeon before embarking on resection of individual segments. There are 10 segments in the right lung (3 in upper lobe, 2 in middle lobe, and 5 in lower lobe) and 9 segments in the left lung (5 in upper lobe and 4 in lower lobe) (*Figure 1*).

Indications

Churchill and Belsey first described the technique of segmentectomy in 1939 in a patient with bronchiectasis (1). This type of resection was originally limited to patients with infectious diseases like bronchiectasis or tuberculosis as pneumonectomy was still the standard surgical resection for patients with lung cancer before 1950. This resection type should be preferred for benign conditions limited to a segment of the lung, but too centrally located for simple wedge excision; examples are bronchiectasis, pulmonary abscess, pulmonary sequestration, benign tumors (hamartoma), or centrally located metastatic lesions. In the modern era of lung surgery with widespread availability of antibiotics and antituberculous drugs, the number of segmentectomies performed for infectious lung processes has significantly decreased.

In 1973, Jensik and Faber published on a series of patients who underwent segmental resection for lung cancer questioning the standard of lobectomy already at that time (2). With the introduction of spiral and later on helical computed tomographic (CT) screening, more small-sized tumors and precancerous lesions are being found. This has led many surgeons to question the appropriateness of lobectomy for all cases of non-small cell lung cancer (NSCLC). In the last 2 decades, limited resection for early lung cancer, ranging from ground glass opacities (GGO), adenocarcinoma *in situ* (AIS), and minimally invasive adenocarcinoma (MIA), has continued to be an area of controversy with conflicting reports from non-randomized studies that compare survival after segmentectomy with those after standard lobectomy (3-5). In an effort to increase the level of evidence to support limited resection for small (≤2.0 cm) tumors, two prospective randomized studies were set up, one in the USA & Canada with an expected enrollment of 1,258 patients in 5 years (CALGB-140503) (6) and one in Japan with an accrual of 1,100 patients in 3 years

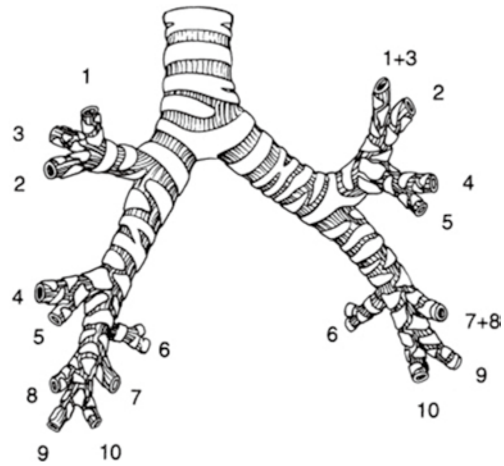


Figure 1 A schematic drawing of the different segments in the lung. Note the right lung has ten anatomical segments while the left lung has nine segments only. Anterior view of the distal trachea, carina, right and left bronchial trees. Right upper lobe segments: [1] apical; [2] anterior; [3] posterior. Right middle lobe segments: [4] lateral; [5] medial. Right lower lobe segments: [6] superior; [7] medial basal; [8] anterior basal; [9] lateral basal; [10] posterior basal. Left upper lobe segments: [1, 3] apical posterior; [2] anterior; [4] superior lingular; [5] inferior lingular. Left lower lobe segments: [6] superior; [7, 8] anteromedial basal; [9] lateral basal; [10] posterior basal. There are some variations in the nomenclature and in numbers of segment; for example: in the upper lobe of left lung, some authors merge the apical and posterior segments (S1+3), with only 4 segments in this lobe or number segments 2 and 3 in the upper lobe in a reversed order. (Picture courtesy of Dr. Thomas W. Rice, Cleveland Clinic, Ohio, USA.)

(JCOG0802/WJOG4607L) (7).

There are two patient groups with early stage NSCLC that may benefit from segmentectomy as a surgical approach. The first group includes patients who can not tolerate a lobectomy because of poor pulmonary function test [forced expiratory volume in 1 second (FEV_1) less than 50% of predicted] or have other lesions that will need to be resected. A lesser resection constitutes an alternative local cancer treatment now competing with other less invasive methods such as stereotactic body radiation therapy or radiofrequency ablation. The second group consists of patients who would tolerate a lobectomy, but in whom a curative resection is likely with a sublobar resection because of a small tumor size with negative lymph nodes. Until further evidence coming from the ongoing randomized trials, it is recommended that anatomical segmentectomy is currently reserved for fit patients with pure GGO lesions or partly (<25%) solid lesions (AIS, MIA) below 2 cm located in the peripheral third of the lung. These lesions are known to be non-invasive without malignant nodal spread (3-5). In case of segmentectomy, the tumor should be situated in the central aspect of a typical pulmonary segment and intraoperative frozen section of N1 and N2 nodes should have confirmed the T1aN0M0 status. In addition, the surgeon should always resect all intersegmental lymph nodes and check its tumor-free status. Otherwise the procedure should be converted into a lobectomy. Segmentectomy should not be performed when the tumor is close (<1.0 cm) to the intersegmental plane. Frozen section of the resection margin is therefore also recommended.

Approach

The original segmentectomy operation included an open approach as will be discussed further in this paper. As experience with video-assisted thoracic surgery (VATS) and robotic thoracic surgery (RATS) increases, more segmentectomies nowadays are being performed by these less invasive techniques, especially for easily resectable segments (S4–5 and S6) with reported reduced morbidity and 30-day mortality, and shorter hospital stay (8-11).

Terminology

It is important to understand the nomenclature that is being used in the literature to describe the number and the location of segments to be removed. The classical example and technically easiest surgical procedure is the removal of a single segment (monosegmentectomy) such as the apical segment of the lower lobe (S6), also called the Nelson or the Fowler segment. Another example is the removal of the two basal segments in the left upper lobe, equivalent to the right middle lobe. This procedure is not called lobectomy because of the absence (or incompleteness) of the horizontal fissure in the left lung, but rather bisegmentectomy (S4–S5), better known as lingulectomy. The above-described operations are more commonly performed, especially for T1aN0M0 NSCLC. Removal of the upper lobe, but sparing the lingula (the equivalent of the right upper lobe) is called trisegmentectomy (S1–S2–S3) or sometimes lingula-sparing upper lobectomy or culmenectomy. Finally, removal of 4 segments in the right lower lobe (S7–S8–S9–S10) or 3 segments in the left lower lobe (S7 & 8–S9–S10) sparing the apical segment (S6) is called basal segmentectomy.

Different terms are also being used in the literature to describe the extent of parenchymal resection, but they do not all match the same surgical procedure. A wedge resection sometimes referred to as an atypical segmentectomy because of its sublobar resection status, is not an anatomical resection and should not be confused with a typical, anatomical segmentectomy. This is an important distinction as a non-anatomical segmentectomy may have a negative impact on tumor-free resection margin, extent of lymph node sampling and excision, local recurrence, and overall survival in patients with early stage lung cancer. This mixture of atypical and typical segmentectomies has tainted the data in series used to recommend segmental resection as an adequate cancer operation. Extended segmentectomy describes a technique whereby the parenchyma is divided lateral to the intersegmental plane in order to have a wider resection margin in patients with a limited margin-to-tumor diameter ratio.

Preoperative assessment

The same principles of preoperative cardiopulmonary workup and evaluation to assess medical operability apply for segmentectomy as compared to more extended pulmonary resections like lobectomy or pneumonectomy. Cardiologic evaluation and lung function testing including carbon monoxide lung diffusion capacity (DLCO) are recommended in every patient undergoing pulmonary resection. Further exercise testing with oxygen consumption (VO_2) should be performed in patients with FEV_1 and/or DLCO <80% (12).

With regards to staging of suspicious or proven malignant lesions, combined positron emission tomography (PET)/CT scan nowadays has become the best radiographic and metabolic test to rule out extrapulmonary disease, to assess mediastinal and hilar lymph nodes, and to exclude other suspicious nodules in the lung. Endobronchial ultrasound (EBUS) and esophageal ultrasound (EUS) have become accurate and less-invasive tools for mediastinal staging that can be followed by video-mediastinoscopy to rule out false negative results in case of suspicious lymph nodes on imaging (13). CT or magnetic resonance imaging scan of the brain and CT or ultrasonography of the abdomen, especially in patients with proven adenocarcinoma are useful to complete a preoperative staging of NSCLC.

Operative techniques

Preparation

We favor an epidural catheter for postoperative pain control for all thoracotomy patients. An indwelling subpleural catheter for intercostal nerve block can also be recommended. This form of non-sedating analgesia is very important to decrease the risk of postoperative respiratory complications, especially in patients with poor pulmonary reserve scheduled for limited resection. A double lumen endotracheal tube or bronchial blocker is used for selective one-lung ventilation. The use of a pediatric bronchoscope introduced through the open lumen of the isolated lung may help to identify the correct bronchial anatomy by transilluminating the segmental airway to be divided whenever doubt.

Patient

The patient described in this paper is a 66-year-old male with recent diagnosis of prostate cancer following rise in his prostate-specific antigen tumor marker. An incidental mass was discovered in the right kidney on abdominal CT scan during further oncologic screening of his prostate cancer. Simultaneously, chest CT scan revealed a nodular mass in the posterior segment (S3) of the right upper lobe (*Figure 2*), proven to be a synchronous metastasis from a clear cell carcinoma on EBUS-guided needle biopsy. Six weeks following a laparoscopic right nephrectomy for a clear cell carcinoma (pT3N1M1), an anatomical posterior segmentectomy (S3) in the right upper lobe was performed via open thoracotomy. Pathologic examination revealed a metastasis (2.2×2×2 cm) from a clear cell carcinoma with negative margins and negative hilar and mediastinal lymph nodes. Patient had an uneventful recovery and was discharged home on the 6^{th} postoperative day with a clear chest-X ray (*Figure 3*).

Exposition

The authors favor an anterior approach as is currently the standard access for all our open and VATS pulmonary resections and for double-lung transplantations. Pulmonary structures will need to be divided working from anteriorly towards the posterior aspect of the lung. Once the targeted lung part is being removed, the larger airways and the posterior mediastinum become exposed allowing additional

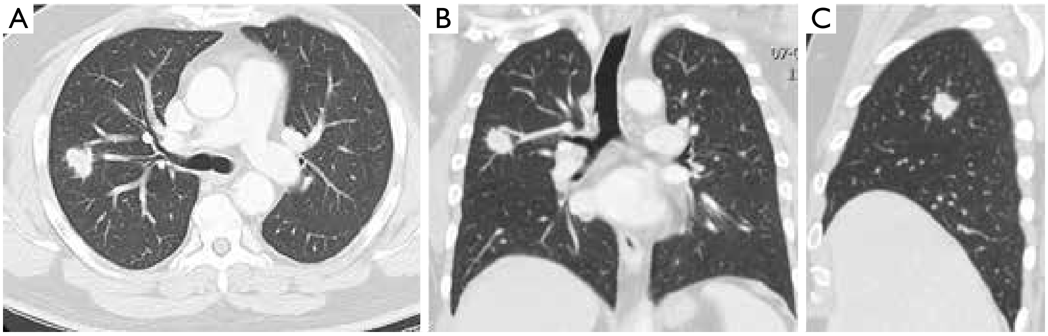


Figure 2 CT scan of the chest reveals a nodular mass in the posterior segment of the right upper lobe. The nodular mass was proven on EBUS guided biopsy to be a synchronous metastasis originating from a clear cell carcinoma of the right kidney. (A) Axial view; (B) coronal view; (C) sagittal view. EBUS, endobronchial ultrasound.

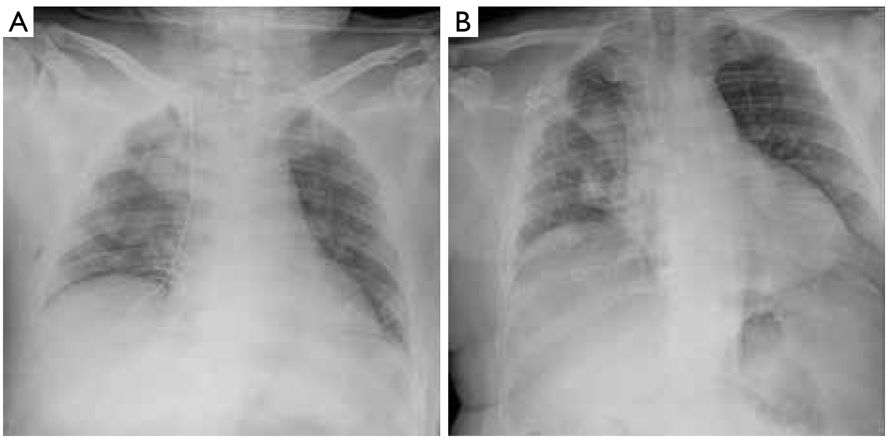


Figure 3 Chest-X ray after posterior segmentectomy in the upper lobe. (A) On the first postoperative day; and (B) on the sixth postoperative day. The two drains (one basal and one apical) have now been removed.

airway or arterial sleeve resection as well as mediastinal lymph node dissection whenever indicated.

The patient is placed in semilateral (45°) decubitus position. The body is fixed on the table using a vacuum matrass with the ipsilateral arm supported and protected on an arm rest and the contralateral arm positioned on an arm rest 90° to the body (*Figure 4*). The table is tilted slightly in an anti-Trendelenburg position with both legs lifted up for better venous return. During the operation, the table can always be turned towards the surgeon or the first assistant as needed. Medical images of the lesion(s) to be resected are projected on a large computer screen for intraoperative consultation. Patient's intraoperative parameters are projected on the video screens for cardiopulmonary monitoring by the surgeon whenever needed during one-lung ventilation or clamping of the ipsilateral main pulmonary artery.

The chest is entered via a submammary incision through the fourth intercostal space. This incision results in a muscle-sparing thoracotomy as the pectoralis major and the anterior portion of the serratus anterior are the only muscles that need to be divided. The remaining extrathoracic muscles can be lifted with a Richardson retractor while the intercostal muscles are incised from anteriorly (sparing the mammary vessels whenever possible) all the way down towards the level of the sympathetic chain posteriorly. By doing so, the ribs can be sufficiently spread for intercostal access as needed. We prefer to use the Price-Thomas rib spreader rather than the classical Finochietto retractor as this instrument stabilizes the ribs much better while opening the chest in a V-shape. The valves of the spreader can be adjusted according the thickness of the subcutaneous fatty and muscular layers avoiding the use of other soft tissue spreaders (*Figure 5*). Occasionally, a second Price-Thomas spreader is needed to better open the incision anteriorly by luxating the cartilaginous bone at its junction with the sternum.

The next and most important step is to place a heavy pericardial suture anteriorly to the phrenic nerve and through the subcuticular skin layer. By tying this suture, the heart protected by the pericardium will be lifted up substantially giving a superb exposure to the hilar vessels while facilitating access to the posterior mediastinum. Meanwhile the heart remains in a stable position avoiding need for further traction and compression intraoperatively (*Figure 6*).

On entrance of the chest, careful inspection of the pleural cavity and palpation of the lung is conducted to rule out other, unexpected pathology. If no tissue diagnosis is known preoperatively and if the lesion is located peripherally and clearly within a segment, a wedge excision can be performed first for intraoperative frozen section. In case of a more central lesion within the segment, a tru-cut needle biopsy can be done first or directly a segmentectomy in a fit patient in case of high tumor suspicion. As previously stated, adequate hilar and intersegmental lymph node sampling and evaluation of the resection margin are needed to ensure the procedure is correctly executed from an oncologic standpoint. Mediastinal and hilar nodal dissection can be done as needed after the segment has been removed.

Figure 4 Positioning of the patient in semilateral (45°) decubitus position. The body is fixed on the table using a vacuum matras with the ipsilateral right arm supported and protected on an arm rest and the contralateral left arm positioned on an arm rest 90° to the body.

Operation

The initial step is to identify the intrathoracic anatomy and the hilar structures (*Figure 7*) (14). In our patient, the upper lobe vein was identified first. After cleaning the hilar fad, three major venous branches showed up. One small branch drained venous blood coming from the middle lobe; the two other branches came from the upper lobe (*Figure 8*). To identify the individual segmental anatomy, opening of the fissure is needed prior to transection of any vessels. First, the interlobar pulmonary artery is identified in the fissure and a tunnel is created connecting with the hilar area anteriorly.

The horizontal fissure is then divided using a linear cutter (*Figure 9*) (15). We prefer to use the ILA^{TM} 100 re-usable stapler (Medtronic, Jette, Belgium) as this device is the cheapest stapler available with usually only one cartridge needed to transect the parenchymal bridge (*Figure 10*). Occasionally, a second cartridge on the ILA^{TM} 52 is used to complete parenchymal transection. In theory, for posterior segmentectomy in the upper lobe, the horizontal fissure can remain intact. However, interlobar anatomy with the individual venous and arterial branches to the three lobes becomes clearer after parenchymal division avoiding

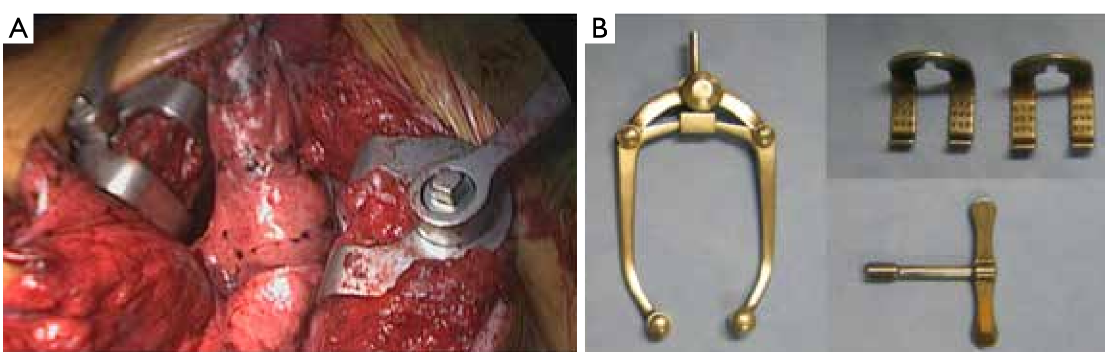


Figure 5 Rib spreading during anterior thoracotomy. (A) A Price-Thomas retractor is used to spread the ribs in a V-shape through an anterior thoracotomy; (B) different valves can be mounted on the rib spreader to retract the soft tissues.

Figure 6 A pericardial suspension stitch (white arrow) is placed anteriorly to the phrenic nerve lifting up the heart and keeping it in a stable position during the entire operation. This manoeuvre will largely facilitate exposure of the hilum of the right lung with little need to use other valves for retraction of the heart.

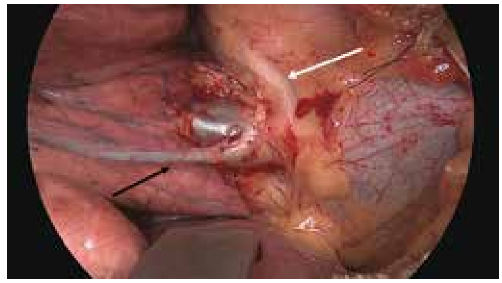


Figure 8 Vision on the hilum of the right upper lobe. After cleaning the hilar fat, three major venous branches showed up. One small branch drained venous blood coming from the middle lobe; the two other branches came from the upper lobe. Note the course of the phrenic nerve (white arrow).

Figure 7 This video shows the hilar anatomy after opening the chest. The right phrenic nerve runs anteriorly to the hilum of the lung. The upper lobe vein is still covered by the hilar fat pad. A small venous branch is draining blood from the middle lobe (14).
Available online: http://www.asvide.com/articles/1669

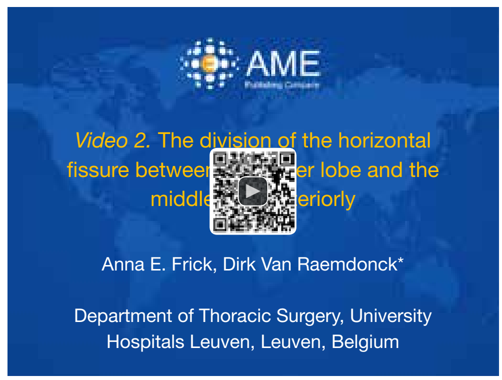


Figure 9 This video shows the division of the horizontal fissure between the upper lobe and the middle lobe anteriorly. A linear stapling device (ILA™ 100; Medtronic, Jette, Belgium) is being used to cut the parenchyma (15).
Available online: http://www.asvide.com/articles/1670

erroneous transection. Attention is needed not to damage the middle lobe artery when dividing the horizontal fissure. The next step is to divide the oblique fissure between the apical segment of the lower lobe and the basis of the upper lobe posteriorly. A second tunnel is therefore created from the interlobar space between the upper lobe bronchus and the intermediate bronchus posteriorly towards the pulmonary artery in the fissure. Sharp dissection with a scissor immediately beyond the interlobar artery guided by the finger coming from posteriorly is helpful to safely create this tunnel. The oblique fissure is then divided with the same stapler (one cartridge on the ILA™ 100 usually suffices). Careful attention should be given not to damage the vascular supply going to the apical segment of the lower lobe (S6) as this arterial branch may come off from the interlobar pulmonary artery rather high!

With both fissures now completely divided, identification of the segmental vasculature becomes clearer (*Figure 11*). The vein draining blood from the posterior segment crosses the artery in the fissure. It should be divided with suture or ligature distal to any other side veins draining the middle lobe or other segments of the upper lobe. Usually, the segmental artery to the posterior segment (S3) takes off from the interlobar artery in the fissure, also known as the posterior ascending artery (*Figure 12*). Depending on its size, this artery can be ligated and clipped or sutured (*Figure 13*) (16). Proximal control by encircling the pulmonary artery with a tape can be useful in case vascular

Figure 10 The horizontal fissure is being divided using a re-usable linear cutting and stapling device (ILA™100; Medtronic, Jette, Belgium).

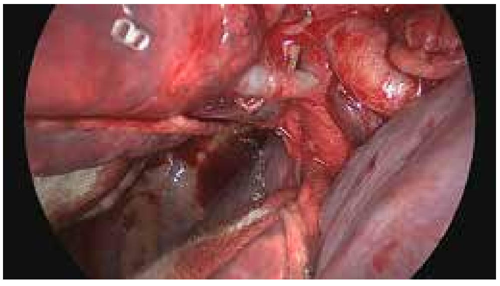


Figure 11 The oblique fissure has now also been divided giving great exposure to the segmental bronchovascular structures.

anatomy is unclear or when fissure planes are inflamed or scared, but this is not our routine practice. After division of the vasculature, the take off of the upper lobe bronchus becomes clear (*Figure 14*). The three segmental bronchi going to the individual upper lobe segments can then be identified by dissecting the upper lobe bronchus more distally (*Figure 15*) (17). Gentle traction on the segment to be resected with an atraumatic clamp may help to expose the bifurcation of segmental bronchi as these may be hidden more deeply into the lung parenchyma. The segmental bronchus (S3) to the posterior segment usually runs behind and parallel to its segmental artery.

Prior to transecting the airway, the lung should be reventilated with the segmental bronchus clamped in order to verify the correct anatomy (*Figure 16*) (18). The virtual fissure running between the posterior segment and the two remaining (anterior and apical) segments will then become more clear as the atelectatic parenchyma will no longer ventilate or will be aerated more slowly through collateral ventilation across the intersegmental plane (*Figure 17*) (19). The segmental bronchus is then divided with a stapler or a bistouri (*Figure 18*). Gentle traction on the distal bronchial stump will open up the hilum of the segment giving better exposure to the excluded parenchyma.

The final step is transection of the intersegmental plane to exclude the involved segment (S3) from the remaining segments (S1 and S2) (*Figure 19*) (20). This can be done with the same linear stapler or with electrocautery while the remaining part of the lung is being ventilated with the bronchial stump clamped. Finally, in case no stapler was used for airway closure, the bronchus has to be sutured (*Figure 20*) (21). We prefer a manual closure using two over-and-over running polydioxanone 4/0 absorbable monofilament sutures after folding the membranous part inside the lumen of the bronchus and bringing the cartilaginous rings together according to the technique previously described by the Dutch surgeon Klinkenberg (*Figure 21*).

Completion

The remaining lobe is then tested under water while ventilated to identify any remaining air leak from the bronchus or the parenchyma. The small bronchial stump can be covered with any fatty or pleural tissue flap surrounding the bronchus or even with the remaining stapler line after parenchymal division. In order to avoid hilar torsion, the remaining segment(s) in the upper lobe can be approximated to the middle and/or lower lobes using a parenchymal suture on a vascular clamp or by approximating and fixing both staple lines left over after transection of the horizontal or oblique fissures.

After careful check for any bleeding, the chest is being closed. We prefer to insert two large drains size CH 28; one curved basal on the diaphragm and one straight apical with the tip in the remaining cavity. The ribs can be approximated with one or two heavy pericostal sutures of absorbable material (polyglyconate 2 or polydioxanone 2). The remaining wound is closed in layers in the usual manner (*Figure 22*). The resected specimen is then sent to the pathology department for further histological and immunological examination (*Figure 23*).

Comments

Postoperative care

Postoperative care after segmentectomy is comparable to other patients undergoing pulmonary resection. We do not put the drains on suction routinely unless there is an increasing pneumothorax or subcutaneous emphysema as a

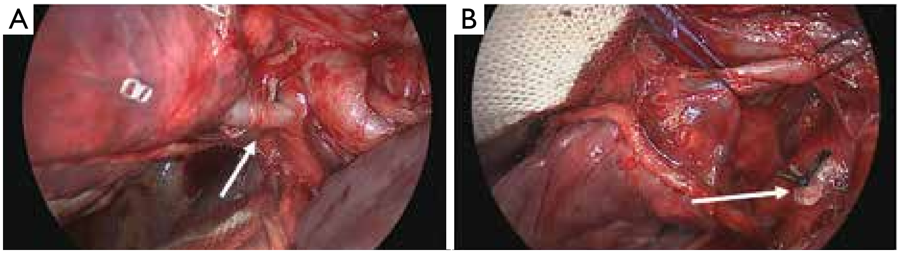


Figure 12 The posterior ascending artery (S3) to the posterior segment of the upper lobe (white arrow) (A) before; and (B) after ligation and clipping.

Figure 13 This video shows the posterior ascending artery and vein (S3) ligated and divided (16).
Available online: http://www.asvide.com/articles/1671

Figure 14 After division of the vasculature, the take off of the upper lobe bronchus becomes more clear. Please note (from left to right) the right main bronchus, the upper lobe bronchus running upwards and the intermediate bronchus continuing down to the right. The interlobar lymph node (position 11) is clearly visible sitting in the bifurcation between upper lobe bronchus and intermediate bronchus.

result of a large airleak. The focus of postoperative care is directed towards adequate analgesia and pulmonary toilet. A dedicated pain team is visiting our patients on the ward daily to check the patient-controlled analgesia pumps. Dedicated physiotherapy, early ambulation, regular portable chest X-rays, and a low threshold for bronchoscopy and antibiotics are all helpful to minimize the risk of pulmonary complications.

Specific complications

The morbidity and mortality after segmentectomy is comparable with patients after lobectomy in most reported series. After segmentectomy, residual space problem is less frequently seen compared to lobectomy. However, the postoperative course can be complicated by atelectasis of remaining segments as a result of sputum impaction or disturbed bronchial anatomy or by persistent air leaks, especially if no stapling devices were used to divide the intersegmental plane in an attempt to preserve maximum volume of the remaining lung. A residual pseudotumor can sometimes be seen on chest X-ray as a result of a local hematoma filling the remaining cavity of the removed segment or developing in adjacent lung parenchyma. A progressive lobar infiltrate unique to the remaining lobe in a septic patient may be the first sign of a lobar infarct. Re-exploring the patient may be indicated after computer tomographic and bronchoscopic work-up.

Caveats

The spatial approach and the order of dividing the individual bronchovascular structures may well vary according to the individual segment(s) to be removed, but the overall principles remain the same. The easiest procedures are the removal of the superior segment of the lower lobe (S6), the lingular segments (S4 + S5), and the basilar segments of the lower lobe (S7–S10), while the individual segments in the upper lobe (S1, S2, S3) and lower

Figure 15 This video shows the bronchial anatomy after complete division of the oblique fissure between upper and lower lobe. Please note (from left to right) the right main bronchus, the upper lobe bronchus running upwards and the intermediate bronchus continuing down to the right. The interlobar lymph node (position 11) is clearly visible sitting in the bifurcation between upper lobe bronchus and intermediate bronchus (17).
Available online: http://www.asvide.com/articles/1672

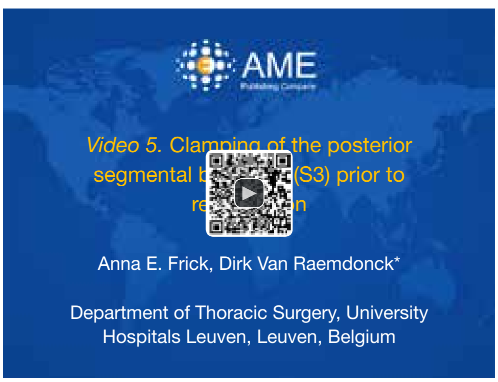


Figure 16 This video shows clamping of the posterior segmental bronchus (S3) prior to reventilation (18).
Available online: http://www.asvide.com/articles/1673

lobe (S7, S8, S9, S10) are more challenging (*Figure 1*).

Specific segments (S4–S5–S6) have an individual central vein that can be ligated or clipped while the other segments have veins that run closer to the periphery of the segment and can not be identified until after dissection of the intersegmental plane has started and drainage into the superior or inferior venous trunks become visible. Sometimes, these veins will not become identifiable until after stapling of the parenchyma. It is however important to identify the anatomy of the venous trunks carefully before dividing segmental vessels to avoid inadvertent ligation of

Figure 17 This video shows reventilation of the remaining upper lobe after clamping the posterior segmental bronchus. The intersegmental plane between the anterior and posterior segment becomes more clear as the parenchyma in segment 3 becomes atelectactic when no longer ventilated (19).
Available online: http://www.asvide.com/articles/1674

Figure 18 The segmental bronchus has been divided after cutting with a bistouri.

veins draining blood from adjacent segments. This may result in venous thrombosis, lobar infarct, and potentially disastrous complications postoperatively.

Identifying the appropriate plane for parenchymal division can be challenging, especially when doing VATS segmentectomy. Differential ventilation of the individual segments by clamping the segmental bronchus before (or after) full inflation can help to better delineate the intersegmental plane. In patients with severe COPD, collateral ventilation between adjacent segments through the pores of Kohn may trouble the identification of the intersegmental plane.

Two techniques have been described for parenchymal division: the open and stapled division.

In the open technique, the intersegmental plane is teared by traction on the stump of the transected segmental

Figure 19 The virtual fissure between the anterior and posterior segment is transected using a re-usable linear stapler (ILA™00; Medtronic, Jette, Belgium) (20).
Available online: http://www.asvide.com/articles/1675

Figure 20 This posterior segmental bronchus prior to suturing (21).
Available online: http://www.asvide.com/articles/1676

bronchus with a clamp while the rest of the lung is well ventilated. Sharp and blunt finger dissection may help to open the intersegmental plane. Diathermy, harmonic scalpel, or small vascular clips are used to ensure hemostasis as more blood loss may be expected. Small air leaks can be over sewn with fine sutures. In addition, the raw surface of the adjacent segment denuded from its visceral pleura can be covered with pleural or pericardial fat flaps for additional hemostasis and aerostasis. Care has to be taken to avoid compression or kinking of remaining bronchovascular structures caused by the flap. This might end up in a non-functional lobe eliminating the benefit of segmentectomy versus lobectomy. The advantage of the non-stapled technique is that re-expansion of the adjacent parenchyma is maximally filling the empty segmental space, but it carries a higher risk of prolonged air leaks from unidentified

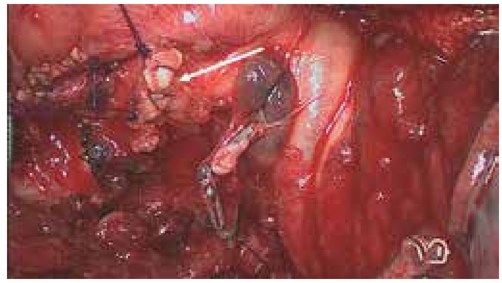


Figure 21 The segmental bronchial stump (white arrow) after closure according to the Klinkenberg technique.

Figure 22 The anterior thoracotomy wound has now been closed with an intra-cuticular suture (3/0 poliglecaprone) and covered with self adhesive wound strips. Two intrathoracic drains are in place (one basal and one apical).

bronchioli not sutured or clipped resulting in a small broncho-pleural fistula.

In the closed technique the virtual fissure is compressed and cut with the aid of a linear stapler. We prefer a re-usable linear cutting device with a stapling length of 10.0 cm. Usually more than 1 cartridge is needed. This technique results in a better pneumostatic control in the remaining lung, but it comes at the expense of volume loss as the visceral pleural layers are stapled together when closing the device. The remaining parenchyma is then somewhat trapped by the individual staplers blocking re-expansion of the lobe until its maximum volume.

Summary

Segmentectomy has been part of the thoracic surgeon's armamentarium by nearly 80 years. In the last 4 decades, the indication for segmentectomy has shifted from a procedure to remove a destroyed segment after infection towards a surgical option for patients with very early, peripheral

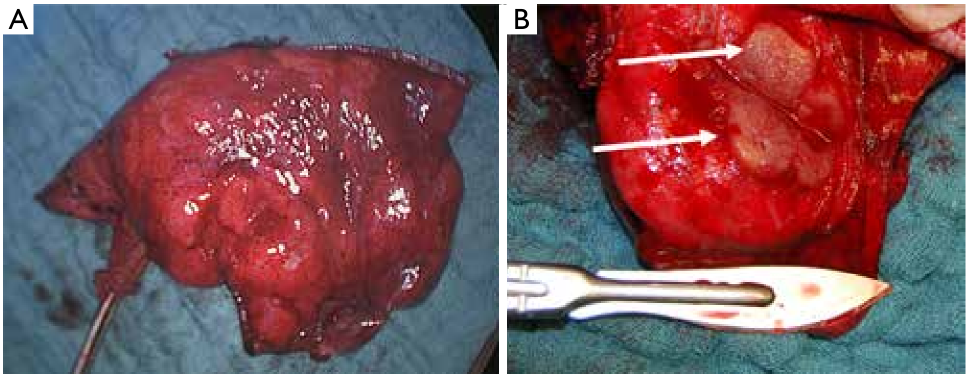


Figure 23 Resected specimen. (A) The posterior segment (S3) of the upper lobe with its triangular shape; (B) the parenchymal nodule (white arrow) in the resected specimen is incised showing a suspicious tumor. Pathologic examination confirmed the presence of a metastasis from a clear cell carcinoma originating from the right kidney.

(Stage IA ≤2.0 cm) NSCLC or for patients with limited cardiopulmonary reserve with a favorable sized and located NSCLC without lymph node involvement. Retrospective and single-institutional reports suggest that the outcome in carefully selected patients with small (≤2.0 cm) peripheral tumors (mainly adenocarcinoma) is excellent after anatomic segmentectomy and comparable to lobectomy. Nevertheless, before segmentectomy can become the standard resectional procedure for early NSCLC, we need to await the results of two ongoing randomized controlled trials. VATS or RATS approach for sublobar resection has proven to be feasible achieving excellent survival results comparable to open segmentectomy, but with shorter hospital stay and lower pulmonary morbidity. Proponents of this approach believe it may well become the future of surgery for lung cancer (22).

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Churchill ED, Belsey R. Segmental pneumonectomy in bronchiectasis: the lingula segment of the left upper lobe. Ann Surg 1939;109:481-99.
2. Jensik RJ, Faber LP, Milloy FJ, et al. Segmental resection for lung cancer. A fifteen-year experience. J Thorac Cardiovasc Surg 1973;66:563-72.
3. Hennon M, Landreneau RJ. Role of Segmentectomy in Treatment of Early-Stage Non-Small Cell Lung Cancer. Ann Surg Oncol 2017. [Epub ahead of print].
4. Sesti J, Donington JS. Sublobar Resection: Ongoing Controversy for Treatment for Stage I Non-Small Cell Lung Cancer. Thorac Surg Clin 2016;26:251-9.
5. Landreneau RJ, D'Amico TA, Schuchert MJ, et al. Segmentectomy and Lung Cancer: Why, When, How, and How Good? Semin Thorac Cardiovasc Surg 2017;29:119-28.
6. Comparison of Different Types of Surgery in Treating Patients With Stage IA Non-Small Cell Lung Cancer. Available online: https://clinicaltrials.gov/ct2/show/record/NCT00499330
7. Nakamura K, Saji H, Nakajima R, et al. A phase III randomized trial of lobectomy versus limited resection for small-sized peripheral non-small cell lung cancer (JCOG0802/WJOG4607L). Jpn J Clin Oncol 2010;40:271-4.
8. Yang CF, D'Amico TA. Open, thoracoscopic and robotic segmentectomy for lung cancer. Ann Cardiothorac Surg 2014;3:142-52.
9. Atkins BZ, Harpole DH Jr, Mangum JH, et al. Pulmonary segmentectomy by thoracotomy or thoracoscopy: reduced hospital length of stay with a minimally-invasive approach. Ann Thorac Surg 2007;84:1107-12; discussion 1112-3.
10. Schuchert MJ, Pettiford BL, Pennathur A, et al. Anatomic segmentectomy for stage I non-small-cell lung cancer: comparison of video-assisted thoracic surgery versus open approach. J Thorac Cardiovasc Surg 2009;138:1318-25.e1.
11. Ghaly G, Kamel M, Nasar A, et al. Video-Assisted Thoracoscopic Surgery Is a Safe and Effective Alternative

to Thoracotomy for Anatomical Segmentectomy in Patients With Clinical Stage I Non-Small Cell Lung Cancer. Ann Thorac Surg 2016;101:465-72; discussion 472.
12. Brunelli A, Charloux A, Bolliger CT, et al. ERS/ESTS clinical guidelines on fitness for radical therapy in lung cancer patients (surgery and chemoradiotherapy). Eur Respir J 2009;34:17-41.
13. De Leyn P, Dooms C, Kuzdzal J, et al. Revised ESTS guidelines for preoperative mediastinal lymph node staging for non-small-cell lung cancer. Eur J Cardiothorac Surg 2014;45:787-98.
14. Frick AE, Van Raemdonck D. The hilar anatomy after opening the chest. Asvide 2017;4:355. Available online: http://www.asvide.com/articles/1669
15. Frick AE, Van Raemdonck D. The division of the horizontal fissure between the upper lobe and the middle lobe anteriorly. Asvide 2017;4:356. Available online: http://www.asvide.com/articles/1670
16. Frick AE, Van Raemdonck D. The posterior ascending artery and vein (S3) ligated and divided. Asvide 2017;4:357. Available online: http://www.asvide.com/articles/1671
17. Frick AE, Van Raemdonck D. The bronchial anatomy after complete division of the oblique fissure between upper and lower lobe. Asvide 2017;4:358. Available online: http://www.asvide.com/articles/1672
18. Frick AE, Van Raemdonck D. Clamping of the posterior segmental bronchus (S3) prior to reventilation. Asvide 2017;4:359. Available online: http://www.asvide.com/articles/1673
19. Frick AE, Van Raemdonck D. Reventilation of the remaining upper lobe after clamping the posterior segmental bronchus. Asvide 2017;4:360. Available online: http://www.asvide.com/articles/1674
20. Frick AE, Van Raemdonck D. The virtual fissure between the anterior and posterior segment is transected using a re-usable linear stapler. Asvide 2017;4:361. Available online: http://www.asvide.com/articles/1675
21. Frick AE, Van Raemdonck D. This posterior segmental bronchus prior to suturing. Asvide 2017;4:362. Available online: http://www.asvide.com/articles/1676
22. Swanson SJ. Video-assisted thoracic surgery segmentectomy: the future of surgery for lung cancer? Ann Thorac Surg 2010;89:S2096-7.

doi: 10.21037/shc.2017.08.07
Cite this article as: Frick AE, Van Raemdonck D. Segmentectomies. Shanghai Chest 2017;1:28.

Lung

Resection of superior sulcus cancers (anterior approach)

Antonio Bobbio, Salvatore Strano, Marco Alifano

Thoracic Department, Paris Center University Hospital, Paris, France

Correspondence to: Marco Alifano. Thoracic Department, Paris Center University Hospital, 27, rue du Faubourg Saint Jacques, 75014 Paris, France. Email : marco.alifano@aphp.fr.

Received: 25 January 2017; Accepted: 22 February 2017; Published: 14 June 2017.
doi: 10.21037/shc.2017.05.06
View this article at: http://dx.doi.org/10.21037/shc.2017.05.06

Introduction

Tumors of superior sulcus are defined as primary lung cancers involving one or more structures of the apex of the thoracic cavity. They are frequently referred in the eponymous of Pancoast HK who described in 1932 the clinical and radiological findings associated with tumors arising in the region. Invasion of one or more of the following structures is frequent: lower roots of brachial plexus, stellate ganglion and sympathetic trunk, upper thoracic ribs or vertebrae, subclavian vessels. Since the work of Tobias J. W. the constellation of symptoms related to these tumors is also referred as the Pancoast-Tobias syndrome.

Up to Fifties these tumors deemed as inoperable, but thanks to the work of Shaw R. R. irradiation followed by resection became the standard treatment for a long while, whereas multimodality approach including radiotherapy, surgery and chemotherapy, pre and/or post-operatively has been variously explored in recent years (1).

Surgical access to apical tumors has been classically achieved in the rules of Paulson D. L. and Shaw R. R. through a posterior thoracic incision (1). This access is fully satisfactory when dealing with posteriorly located tumors, but may be inadequate in the presence of involvement of anterior structures. For this reason, several anterior approaches have been developed, including the cervico-sterno-thoracotomy, the hemiclamshell, and the transcervical-transthoracic approach with resection of the clavicle.

During last twenty years, however, the transmanubrial approach (2), which will be described in details in the present chapter, has gain large favor as the first-choice approach for anterior forms of the superior sulcus tumors. In our opinion (3), main indications for an anterior approach are represented by proven or suspected infiltration of cervico-mediastinal vascular structures or infiltration of anterior arch of first/second ribs. More infrequent indications include: presence of a palpable supraclavicular mass, clinical involvement of C7 and/or C8 root, Horner syndrome. In these last three cases, first-line surgery is rarely indicated and patient is generally operated after induction.

Operative techniques

Single lung ventilation is mandatory for this operation, especially if lung resection is performed through the anterior approach. Thus, general anesthesia and double-lumen intubation are necessary. For anterior approach, supine position is adopted, with patient positioned on the operative table with the arms are abducted at 90° and the neck hyperextended with the head turned toward non-operated side to expose the homolateral sterno-cleido-mastoid region and the sternal notch. We use to put a vertical roll under the spine to allow shoulder gentle fall of the shoulder of the operated side. The whole homolateral neck and thorax are included in the operative field and skin preparation and draping is extended some centimeters away from the midline.

The skin incision includes a vertical presternocleidomastoid incision which is prolonged over the upper the sternal manubrium and then horizontally two transverse fingers below the clavicle up to the delto-pectoral groove (*Figure 1*).

The anterior margin of the sternomastoid muscle is freed and the lower portion of the internal jugular vein is dissected, manubrium and upper portion of the second rib are exposed. The first intercostal space is opened, thus allowing finger exploration of the pleural cavity and anticipation of further technical aspects of the operation

Figure 1 Skin incision. The vertical mark goes from the anterior margin of the sterno-cleido muscle downward to the midline of the sternal manubrium and stop at the level of the Louis' notch. The horizontal mark follows the upper margin of the second costal cartilage.

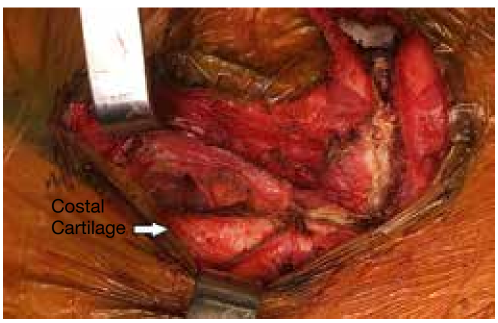


Figure 2 Opening of the pleural cavity in the first intercostal space.

(*Figure 2*).

Internal thoracic vessels are subsequently dissected and sectioned at the first intercostal space level (*Figure 3*). This allows exposition of the lateral aspect of the sternal manubrium which can be now sectioned by an oscillating saw in an L-shaped (dextro or laevorotatory) fashion: midline vertical, and horizontal from the lateral aspect to the midline (*Figure 4*). This allows preservation of the sterno-clavicular joint. The sternoclavicular flap may be elevated only after division of the first rib cartilage at its sternal insertion and provided that no tumour invasion

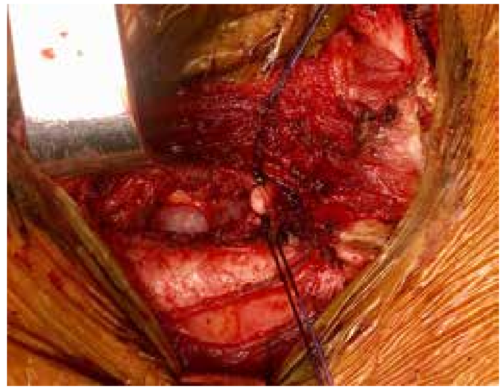


Figure 3 Ligature of the internal mammary artery.

Figure 4 Division of the sternal manubrium (4).
Available online: http://www.asvide.com/articles/1559

is present at this level (*Figure 5*). The upper portion of the major pectoral muscle is now elevated to expose the cartilage of the first rib that could be sectioned with a costotome (*Figure 6*), a hand manoeuvred (Gigli), or an electrical saw (*Figure 7*).

In parallel with flap elevation, section of the costo-clavicular ligament is carried out (*Figure 8*), thus providing increasing amplitude to the operative field (*Figure 9*). Exposure of the whole cervico-thoracic junction is now achieved. Further dissection depends on the extent of tumours and infiltration of different structures: upper ribs, especially in their anterior portion, subclavian vessels, apical pleura, sympathetic chain, and/or brachial plexus. The section of the internal jugular vein may be seldom necessary in order to allow a better access to posterior plans. Subclavian vein is dissected and spared if free, or easily resected without need of subsequent revascularization (contralateral venous axis can be preserved in almost all the

Figure 5 Elevation of the major pectoral muscle to expose the first cartilage.

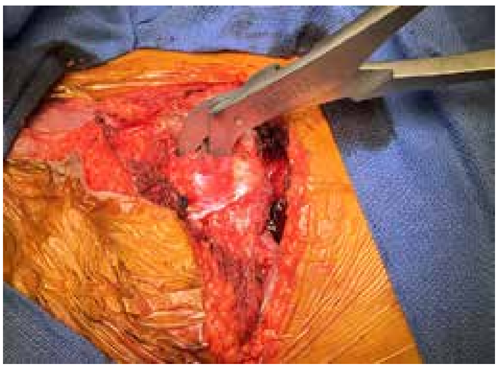


Figure 6 Division of the first cartilage with costotome. Note that in this case the thoracotomy is performed in the second intercostal space.

Figure 7 Division of the first cartilage with electric saw (5). Available online: http://www.asvide.com/articles/1560

Figure 8 Division of the costoclavicular ligament (6). Available online: http://www.asvide.com/articles/1561

instances). Dissection of the subclavian vein encompasses the visualization of the phrenic nerve which in cervical region lies anteriorly to anterior scalene muscle and behind the subclavian vein, whereas in its thoracic portion is placed on the antero-lateral aspect of the venous axis.

Thus anterior scalene muscle can be safely freed from its insertion on the first rib tubercle, allowing exposition of the subclavian artery. Sacrifice of its branches may be required and care should be taken to spare, if possible, the vertebral artery. In case of tumors infiltrating the wall of the artery a dissection in the subadventitial plane should be attempted and is generally successful; deeper infiltration requires resection and reconstruction. End to end anastomosis or interposition of a (6-8 mm in diameter) polytetrafluoroethylene graft can be performed, depending on the extent of resection. Behind the arterial plane, vertebral bodies and the nerves root coming from the intervertebral foramina are accessible. Of note anteriorly to nerve roots of brachial plexus lay the stellate ganglion and sympathetic chain.

In case of tumours invading the chest wall *en bloc* resection is to be planned. As previously described (*Figure 2*) the invasion of the parietal wall is first explored when performing the thoracotomy at the first intercostal space. In case of involvement of first intercostal space or of the second rib a lower anterior thoracotomy at the second or third intercostal space must be performed. Once L-shaped section of the manubrium is performed the inspection of its posterior aspect is performed and especially of the cartilage of the first rib which is sectioned to finally elevate the osteomuscolar flap. Posterior control of the parietal wall infiltration through the anterior approach is possible for the first rib. When parietal involvement concerns the ribs posteriorly, below the second or the third one, the transmanubrial approach is carried out as described, and posterior rib resection is performed through an associated

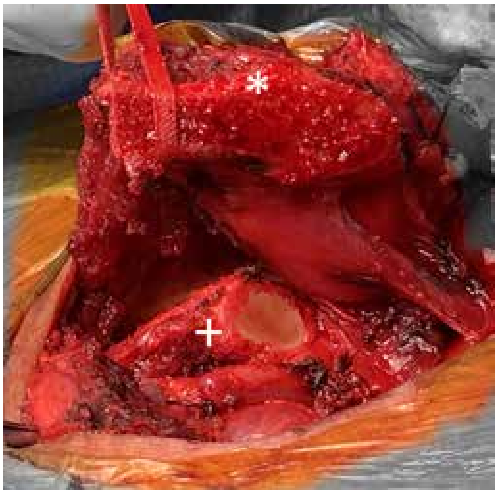


Figure 9 Elevation of the sterno-clavicular junction (*), after section of the first costal cartilage (+).

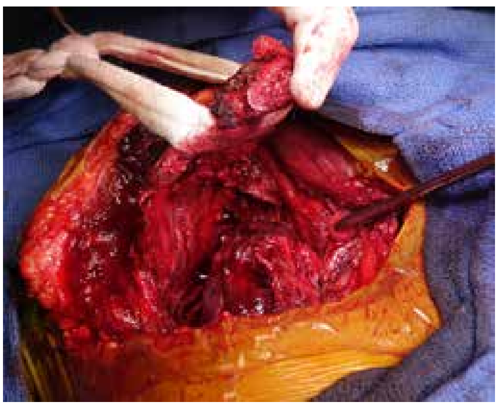


Figure 10 "Modified" hemiclamshell in the second intercostal space. Note the wide rotation of osteomuscolar flap in spite of the integrity of the second rib.

posterior approach. After dissection and/or resection of chest wall and remaining structures of cervico-thoracic junction (apical pleura, sympathetic chain, brachial plexus), the osteomuscular flap is returned in its position, sternal manubrium is sutured by two metallic stitches and soft tissues are closed as usually. Motility of shoulder is thus completely preserved.

Comments

In case of surgery for primary lung cancer lobectomy should constitute the standard pulmonary resection and it has to be associated to mediastinal lymph nodes dissection. Obviously the access to the hilar pulmonary structures is restraint through the thoracic inlet even in case of a wide elevation of the manubrium-clavicular flap. Unless in some cases (thin patients with limited tumours not involving hilar structures nor posterior chest wall) lobectomy can be carried out through the anterior approach, in the most cases, after completion of the surgical manoeuvres through the anterior approach, the patient should be turned in the full lateral position to perform a second incision, generally a postero-lateral thoracotomy, which allows standard lung resection, mediastinal lymph nodes dissection and eventually the completion of posterior chest wall resection. In order to avoid a second installation and a second incision, the use of a "modified hemi-clamshell" approach can be planned. In this technique a standard hemiclamshell approach in the third or fourth intercostal space is associated to the section of the first cartilage and opening of the costoclavicular ligament (7). Thanks to the lower anterior thoracotomy and to the possibility to rotate the osteomuscolar flap, a full mediastinal vascular control is possible, as well as an easy access to the structure of the pulmonary hilum (*Figure 10*).

Our experience on surgical management of superior sulcus tumor has been previously reported (3). We employed an isolated posterior approach in 49% of cases, whereas in the remaining patients (with the exception of a single case who had an isolated anterior approach) a combined anterior and posterior approach was carried out. Complete resection was achieved in 82% of cases. Operative mortality was 8.9%. This percentage is relatively high but probably explained by the extent of resection in a subset of lung cancer patients presenting frequently important associated illness. Overall survival rates (including non-cancer-related deaths) were 54% and 36.2 at 2 and 5 years, respectively. Study of prognostic factors showed, at multivariate analysis, that T status, R0 resection, and the presence of associated comorbidities, were independent prognostic factors. Patients with T3N0 tumors experienced a 5-year survival as high as 47.7%.

Surgery of the thoracic inlet is challenging because of the presence of several leading vascular and nervous structures, in any case a precise knowledge of the anatomy of the first rib is crucial. A list of tips and trick is in *Table 1*. After elevation of the osteomuscular flap, the mediastinal venous net is first encountered (*Figure 11*). A smart tip is to not hesitate to divide the internal jugular vein which facilitates mobilization of the innominate vein and raises visualization of the surrounding structures. It should be noted that right or left interruption of the innominate vein can be performed

Table 1 Tips and tricks

Start dissection of the vascular plane from internal jugular vein cranially and innominate vein far from the tumour, caudally
Division of the internal jugular vein facilitates venous vascular control and access to adjacent structures
Recognition and eventually ligature of thoracic duct
The anterior scalene muscle can be safely freed from its insertion on the first rib by subperiosteal dissection
Arterial sub adventitial dissection is effective in almost all cases
"Modified" hemiclamshell approach may allow lobectomy and vascular control through a single surgical incision
Infiltration of the vertebral body and of vertebral pedicle requires a posterior approach with instrumentation and laminectomy

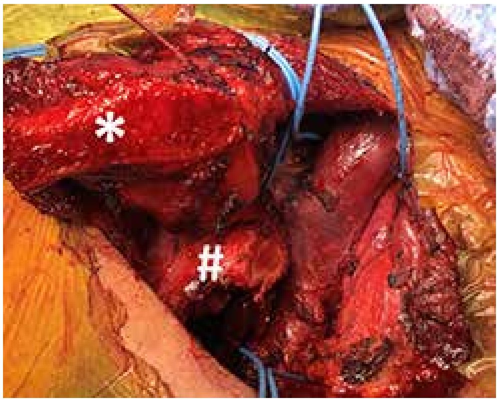


Figure 11 Isolation of the mediastinal venous axis: manubrium (*), first cartilage (#).

without the need of vascular continuity reconstruction, unless the occurrence of a temporary (1-2 months) arm oedema in the postoperative period. During the dissection of the venous axis, we recommend the recognition of the lymphatic thoracic duct on the left side but also detection of either a right-sided thoracic duct, or the right cervico-thoracic lymphatic duct (*Figure 12*), in order to avoid post-operative leaks. It should be reminded that the phrenic nerve originates from the 4th cervical nerve and receives contributions from the 5th and 3rd cervical nerves (C3-C5). In the cervical region the nerve lies behind the venous axis in front of the anterior scalene muscle. The anterior scalene muscle can be safely freed from its insertion on the first rib by subperiosteal dissection, if not directly infiltrated by the tumor allowing extrathoracic control of the subclavian artery.

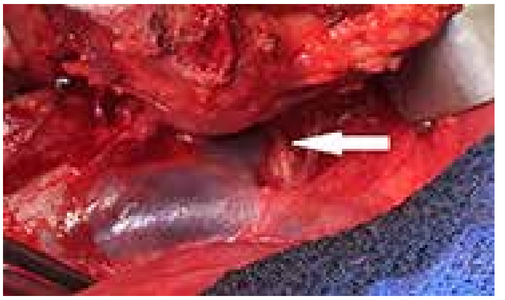


Figure 12 Accessory right lymphatic duct crossing the venous axis.

In case of arterial infiltration proximal and distal control of subclavian artery is performed, and, in this objective, ligature of one or several of its branches (vertebral artery, internal thoracic artery, thyreocervical artery, costocervical trunk, dorsal scapular artery) may be necessary. We generally attempt dissection of subclavian artery itself in the sub-adventitial plane and this maneuver is often successful; otherwise resection and reconstruction is performed by end to end anastomosis or by prosthesis interposition.

In case of tumors infiltrating the posterior mediastinum, the dorsal sympathetic chain and the stellate ganglion can be involved as well as the lower nerve root of the brachial plexus. These structures can be resected by the anterior approach. This is generally done after dissection of the vascular structures. In case of deeper infiltration involving the spine, anterior approach is in most cases unsatisfactory and a second step by posterior approach is generally necessary. Infiltration of prevertebral fascia may be resected by the anterior approach as well as limited infiltration of the periosteum of vertebral body, but more extensive infiltration of the vertebral body and, *a fortiori*, of vertebral pedicle requires a posterior approach with instrumentation and laminectomy. In these cases after a dissection as complete as possible, the anterior approach is closed, the patient repositioned either in Paulson or ventral decubitus (according to the team experience) and the operation continued by the posterior approach allowing en –bloc vertebral resection.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Shaw RR, Paulson DL, Lee JL. Treatment of Superior Sulcus Tumor by Irradiation Followed by Resection. Ann Surg 1961;154:29-40.
2. Grunenwald D, Spaggiari L. Transmanubrial osteomuscular sparing approach for apical chest tumors. Ann Thorac Surg 1997;63:563-6.
3. Alifano M, D'Aiuto M, Magdeleinat P, et al. Surgical treatment of superior sulcus tumors: results and prognostic factors. Chest 2003;124:996-1003.
4. Bobbio A, Strano S, Alifano M. Division of the sternal manubrium. Asvide 2017;4:250. Available online: http://www.asvide.com/articles/1559
5. Bobbio A, Strano S, Alifano M. Division of the first cartilage with electric saw. Asvide 2017;4:251. Available online: http://www.asvide.com/articles/1560
6. Bobbio A, Strano S, Alifano M. Division of the costoclavicular ligament. Asvide 2017;4:252. Available online: http://www.asvide.com/articles/1561
7. Rusca M, Carbognani P, Bobbio P. The modified "hemi-clamshell" approach for tumors of the cervicothoracic junction. Ann Thorac Surg 2000;69:1961-3.

doi: 10.21037/shc.2017.05.06

Cite this article as: Bobbio A, Strano S, Alifano M. Resection of superior sulcus cancers (anterior approach). Shanghai Chest 2017;1:12.

Posterior thoracic approach for Pancoast tumour resection

Marc Boada, David Sánchez-Lorente, Laureano Molins

General Thoracic Surgery Department, Hospital Clínic de Barcelona, Spain

Correspondence to: Marc Boada. General Thoracic Surgery Department, Hospital Clínic de Barcelona, Spain. Email: MBOADA@clinic.cat.

Received: 21 May 2017; Accepted: 04 July 2017; Published: 22 August 2017.

doi: 10.21037/shc.2017.07.04

View this article at: http://dx.doi.org/10.21037/shc.2017.07.04

Introduction

Pancoast tumour is an uncommon lung cancer presentation, it represents only 3–5% of all lung cancer. Located at the superior pulmonary sulcus with direct spread to the para-apical structures makes its clinical presentation atypical and usually delays the diagnosis and the further treatment. Clinical presentation usually consists in Pancoast's Syndrome. Radicular arm affection caused by brachial plexus infiltration, shoulder pain because of rib tumour invasions and Horner's syndrome (miosis, ptosis and anhidrosis) in relation to sympathetic nerve involvement (1-3).

Small apical tumours could remain hide behind the clavicle and first ribs and be missed on plain chest X-rays in early stages. In consequence when clinical presentation suggests the presence of this pathology CT scan becomes the gold standard for diagnosis and staging as well as to define the size of the process and reveal bone, spinal, mediastinal or brachial plexus invasion, detect peripheral or satellite lesions and assess the presence of enlarged lymph nodes. Magnetic resonance imaging proportionates a more accurate local extension preoperative evaluation. In our opinion, CT guided biopsy for histological diagnostic is mandatory—especially in locally extended tumours—previous to continue the operability assessment and therapy strategy planning. PET-CT is useful for preoperative detection of lymph nodes involvement and occult metastatic disease. Because of high rate of false negatives reported on PET-CT, cervical mediastinoscopy is still considered mandatory (2).

Non-hiliar lymph node metastases (N2 or N3) are associated with lower 5-year survival. However, ipsilateral supraclavicular lymph node involvement (N3) demands a special mention. As a result of better survival in these cases compared to N2 affection, supraclavicular lymph node involvement may be considered as a first lymphatic drainage (N1) and do not contraindicate surgery (4).

Globally less than 50% of patients with Pancoast tumours are considered resectable at diagnosis. Induction chemo-radiotherapy has been proposed with the intention to increase resectability options, particularly in doubtful cases (1,4). Surgical resection is most commonly accomplished with either posterior or anterior approach. Posterior thoracotomy described by Shaw-Paulson as a classical postero-lateral thoracotomy extended around the scapula to the base of the neck, has certain advantages over the anterior approach. It is ideal for posterior tumours, particularly those that invade the vertebral bodies and the brachial plexus. Also if invasion of the subclavian artery is found, this approach can still be used (1,4).

Surgical technique

Under general anesthesia a double lumen tube is placed—preferably a contralateral specific bronchus tube. Arterial line for gas analyses and blood pressure continuous monitoring is place at contralateral arm. A deep venous line—subclavian or jugular—is placed at the same side of the tumor. Epidural catheter is mandatory for analgesia and postoperative pain management. It is preferable to place it before surgery to start analgesia as soon as possible to reduce chronic pain. Thereafter the patient is positioned and secured in lateral decubitus. Inferior leg is flexed and superior stays extended placing a pillow between both legs. The ipsilateral arm is fixed at double 90º positions using an arm holder or a pillow. Table is broken at the level of xifoid to widen the intercostal space. Especial care must be taken in protecting the brachial plexus and cubital nerve as well as in cushion the decubitus areas (*Figure 1*).

Sterile draping is done exposing spine and nipple

Figure 1 Patient preparation and operating room distribution.

Figure 2 Operating room distribution and draping.

Figure 3 Posterolateral Paulson's skin incision.

to be used as antero-posterior landmarks. Scapula and costal borders are the supero-basal landmarks. Sterile skin adhesive protection is placed to prevent cutaneous contamination (*Figure 2*). After security checklist is done, a postero-lateral thoracotomy is undergone extending it following the interescapulo-vertebral space (*Figure 3*).

First, Latissimus Dorsi is exposed and completely divided. Both sides of the muscles are desinserted for a better exposure and to facilitate closure at the end—this is easily done everting the muscle. Second, the Serratus muscle is preserved and the inter-scapulo-romboid fascia is opened. Posteriorly the trapezium and rhomboids muscles are divided to expose de paravertebral muscles and costovertebral junction. Finally, 4th intercostal muscle is desinserted from the 5th rib to enter to pleural cavity.
Once the pleural cavity is opened a small retractor is placed anteriorly to spread the ribs. For easier exposure and to avoid an accidental rib fracture we recommend an internal further division of the intercostal space. Some times if exposition is not good enough posterior costectomy of the 6th rib could be necessary.

Before chest wall resection the pleural cavity has to be thoroughly explored. Attachments must be released and the tumor borders precisely identified to ensure that resectability is still possible. In addition exploration for intracavitary unexpected metastases is important before start resection.

Recently, some groups advocated for VATS approach of chest wall-involving tumors. In those situations the lobectomy is performed prior to the wall resection. However, in our opinion, in posterior tumors with required costal desarticulation VATS surgery is not recommendable. In our experience, good short-term pain management and survival results were obtained using an open approach.

Before resection, complete exposition of the upper thoracic inlet and costo-vertebral junction is mandatory. Rib spreader is used to elevate the scapula placing one blade to the 5th rib border and the other one on the tip of the scapula—Finochietto retractor's fenestrated blade is useful to fix the tip of the scapula through it (*Figure 4*). Adherences between chest wall and thoracic muscles must be released. Serratus muscle insertions are released anteriorly to facilitate exposure.

Once the chest wall is well exposed and all the adherences are completely free the 1st rib and the scalene muscles are visualized in upper thoracic outlet. It is important to be oriented at that point because of the lateral position of the patient. Posterior scalene muscle inserts to the posterior portion of the 2nd rib and is divided initially using a straight angle dissector (*Figure 5*). Secondly exposed muscle, inserted to the 1st rib, is the Middle Scalene and just beneath it runs the brachial plexus and subclavian artery. The middle scalene muscle needs to be carefully sectioned too.

Once the mid scalene muscle is identified the brachial plexus (posterior) and the subclavian artery (anterior) are exposed (*Figure 6*). Vascular affectation must be carefully

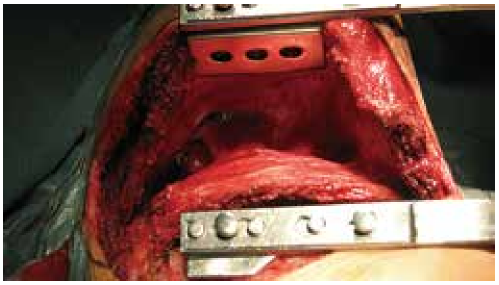


Figure 4 External chest wall exposure.

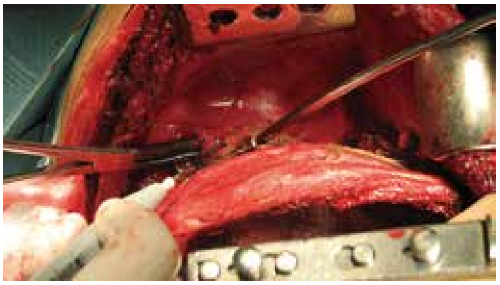


Figure 5 Dissection and division of the scalene muscles.

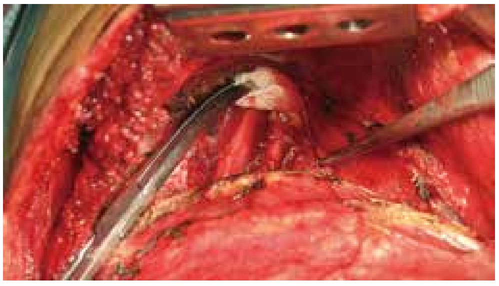


Figure 6 First rib, vascular structures and brachial plexus.

checked although subclavian vessels are normally not involved in posterior Pancoast's tumors. Despite it is technically more demanding, resection and reconstruction of unexpected subclavian vessels invasion may be necessary. Anterior Pancoast's tumors are further treated in a specific chapter.

Chest wall resection is started anteriorly leaving a macroscopic wide margin—bigger than 1 cm (*Figure 7*). It is important to be sure about the margins because frozen section is not possible for bone invasion. Subcostal dissection is performed to surround and ligate the whole intercostal muscle. Distal ligature or clip is recommended to avoid infrequent but possible venous retrograde bleeding. After division of the intercostal muscle the superior border of the rib is exposed, then the rib is divided using a costotome. Resection of a 1 cm piece of rib is helpful to easily mobilize and resect the upper anterior borders of the chest wall.

1st rib is normally divided posterior to the subclavian artery and brachial plexus. In this step is when there is higher chance of unadvertised vascular lesion—*we strongly recommend spending some time to dissect and secure the vessels for patient's safety*.

Using a dissector the first rib is completely surrounded ensuring sufficient oncologic margins. To divide the anterior border of the rib we prefer to use a Gigli saw instead of 1st rib costotome because it can be placed easily using the dissector and use it under direct vision assessment. The assistant has to protect vascular structures using a peanut while the surgeon saws the rib (*Figure 8*). After division the upper posterior border of the rib is cautiously divided while protecting brachial plexus from electrocoagulation.

Paraspinous muscles are desinsherted and mobilized laterally to expose the costovertebral junction. Costotransverse ligaments are divided with electrocautery to expose vertebral transverse process and its junction with the rib (*Figure 9*). A straight periostotome is used to dislodge the ribs from inferior to superior. Pressure must be applied to anterior at the same time the assistant rotates the anterior rib border down to widen the space. It is important to avoid lever movement to posterior because it could damage the vertebra apophysis.

Once the vertebral facets are exposed the intercostal arteries and nerve roots are ligated or clipped to prevent bleeding or cerebrospinal fluid leakage. Transfixion non-absorbable stich may be necessary if there is no space for clips.

Disarticulation of the 1st rib is the most challenging one. Just beneath it arises the lower root of the brachial plexus-T1 and joins C8 just over the rib. Ligation and section of T1 could be done with no motor affection of the hand. However, all efforts must be focused to preserve C8 to avoid hand mobility impairment.

After tumor involved chest wall is completely released standard lobectomy is carried out through the wall defect. It is recommendable not to spread the remaining ribs to avoid added damage to the wall. Systematic mediastinal lymphadenectomy is done once the tumor is out the chest (*Figure 10*).

Meticulous hemostasis must be performed at the end of the surgery—specially revising arterial stumps and chest wall border—to prevent postoperative bleeding.

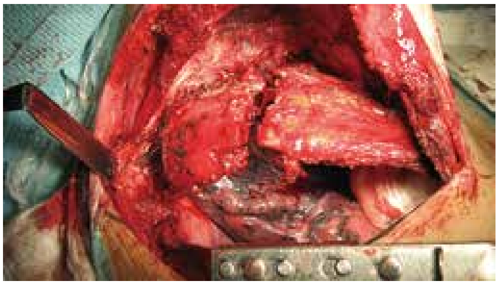


Figure 7 Section of the anterior chest wall border.

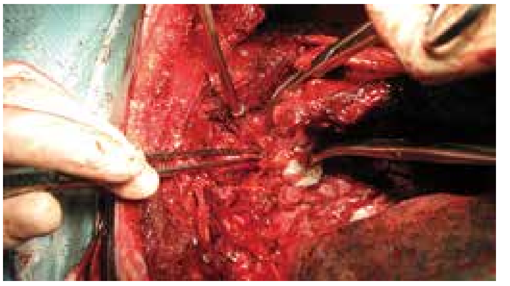


Figure 9 Desarticulation of the costovertebral junction.

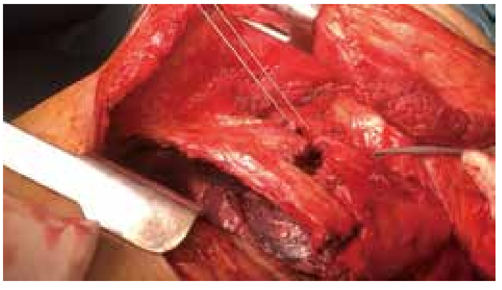


Figure 8 Section of the first rib.

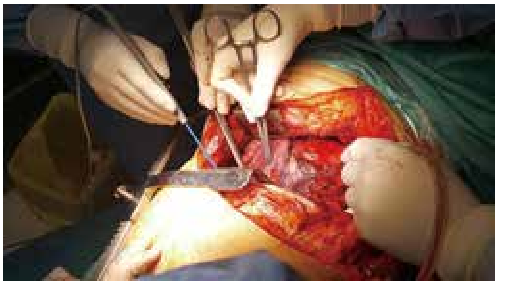


Figure 10 Upper lobectomy and lymphadenectomy through the chest wall defect.

Direct closure of the chest wall is preferred in these surgeries because two main reasons. First, chest wall muscles and scapula disposition maintain the continuity in high-posterior chest wall defects. In consequence ventilation mechanics are not compromised. Second, synthetic exogenous materials are a risk factor for infection and colonization. In occasions, absorbable crossed stitches may be useful to maintain anterior rib borders in position. Nevertheless, when the 5th rib has been resected chest wall continuity could be compromised. Scapula and posterior thoracic muscles give rigidity enough to allow normal respiratory movements and in consequence rigid reconstruction is not strictly necessary. In the other hand the discontinuity could affected scapular movement trapping it during abduction. Scapula compromise might lead to acute respiratory failure and contribute to chronic pain. In consequence we recommend chest wall reconstruction using a mesh fixed with interrupted stitches to the surrounding tissue when 5th rib is removed.

Tips and tricks

- ❖ Starting with the anterior border of the chest wall makes easier to perform the posterior disarticulation while applying pression/rotation.
- ❖ Dissection and control of the subclavian vessels is strongly recommended for patient's safety in case of accident.
- ❖ It is easier and safer to cut the first rib using a Giggli saw than using the 1st rib costotome.
- ❖ Electrocoagulations should be avoided as much possible at the posterior and superior borders to prevent neuronal injury.

Complications

Trapped scapula

Chest wall reconstruction is recommended if costal resection under the 5th rib is necessary to avoid impaired scapula movement. Trapped scapula could compromise respiration and lead to severe respiratory failure.

Dehiscence of the thoracotomy

Individualized closure of all layers is mandatory to avoid chest wall dehiscence. Although this is essential after any surgery, this demanding and long procedure added to surgeon's fatigue makes the closure even more important.

Cerebrospinal fluid leakage

It is important to identify and ligate the intercostal nerve during the disarticulation to avoid in adverted lesions. In case of CLF leakage reparation using materials that could migrate to the medullar canal must be avoided.

Vertebral artery injury

Preoperative assessment is important to know if Willis' polygon is permeable in case the vertebral artery needs to be sacrificed for oncological or technical reasons.

Chilothorax

At the end of the surgery it is important to check for thoracic duct leakage. This is especially important in left sided resections because of anatomical disposition of the thoracic duct.

Acknowledgements

None.

doi: 10.21037/shc.2017.07.04
Cite this article as: Boada M, Sánchez-Lorente D, Molins L. Posterior thoracic approach for Pancoast tumour resection. Shanghai Chest 2017;1:24.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

Informed Consent: Written informed consent was obtained from the patient for publication of this case report and any accompanying images.

References

1. Rusch VW. Management of Pancoast tumours. Lancet Oncol 2006;7:997-1005.
2. Panagopoulos N, Leivaditis V, Koletsis E, et al. Pancoast tumors: characteristics and preoperative assessment. J Thorac Dis 2014;6 Suppl 1:S108-15.
3. Rusch VW, Parekh KR, Leon L, et al. Factors determining outcome after surgical resection of T3 and T4 lung cancers of the superior sulcus. J Thorac Cardiovasc Surg 2000;119:1147-53.
4. Detterbeck FC. Changes in the treatment of Pancoast tumors. Ann Thorac Surg 2003;75:1990-7.

Surgical approaches for bronchopleural fistula

Guilherme Dal Agnol[1], Arthur Vieira[2], Ricardo Oliveira[2], Paula Antonia Ugalde Figueroa[2]

[1]Department of Thoracic Surgery, Americas Medical Center, Rio de Janeiro, Brazil; [2]Department of Thoracic Surgery, Research Centre, Institut universitaire de cardiologie et de pneumologie de Québec, Université Laval, (IUCPQ-UL), Chemin Sainte-Foy, Quebec City, Canada

Correspondence to: Guilherme Dal Agnol, MD. Av. Henrique Dumont, 68/203, Rio de Janeiro, 22410-060, Brazil. Email: gdalagnol@yahoo.com.br.

Received: 11 June 2017; Accepted: 18 June 2017; Published: 13 July 2017.
doi: 10.21037/shc.2017.06.01
View this article at: http://dx.doi.org/10.21037/shc.2017.06.01

Introduction

Bronchopleural fistula (BPF) is defined as a direct communication between the bronchus and the pleural space. BPF can be classified as central, which are fistulous connections between the trachea or a lobar bronchus and the pleural space, or peripheral, which are fistulous connections between the distal airway (segmental bronchi or lung parenchyma) and the pleural space.

In the mid 1950s to early 1960s, the vast majority of BPFs were secondary to pulmonary tuberculosis infection. As drug therapy for tuberculosis has improved, this complication has considerably decreased (1). Currently, complications during bronchopulmonary procedures are the leading cause of BPF despite refinements in surgical techniques and surgical equipment (2-4). Postpneumonectomy BPF is a severe postoperative complication with high rates of morbidity and mortality (5,6). Postlobectomy BPF, however, occurs in less than 1% of patients and has a much lower mortality rate (1,7,8). More rarely, benign pathologies, such as necrotizing pneumonia, empyema, tuberculosis, aspergillosis, granulomatosis with polyangiitis, rheumatologic conditions and pulmonary sarcoidosis, can cause BPF (9).

The clinical suspicion of BPF obligates an urgent and objective investigation that allows proper decision-making for the management of this highly morbid complication. Despite all medical and technical advances, BPF remains a challenge to the thoracic surgeon. In this chapter we will discuss the management of central BPF.

Presentation

Modern lung surgery relies on staplers to transect and seal the bronchus. This strategy has decreased the likelihood of an early postoperative BPF as compared with the hand-sewn techniques used previously. Bronchial fistulas are detected most frequently between the 1st week and 3rd month postoperatively (10) with a peak in incidence between the 8th and 12th postoperative days (8,11). The diagnosis of BPF can be a clinical challenge, but a combination of imaging techniques and invasive procedures, such as bronchoscopy with or without surgical exploration, are used to define the location and the clinical presentation of BPF.

The clinical presentation of a BPF can be acute, subacute, or chronic depending on the timing of surgery (*Table 1*). This differentiation is important in selecting the proper treatment. In an acute case due to a massive air leak, the patient will present with a tension pneumothorax and subcutaneous emphysema. If the chest tube still in place, an important air leak will be seen at the water seal (12). Sudden expectoration of purulent sputum, acute cough, dyspnea, and mediastinal and tracheal shifts are also common findings. In postpneumonectomy patients, an acute decrease in the pleural liquid level is the common presentation (13). The subacute and chronic clinical presentations of BPF are usually associated with an infected pleural space (empyema) and present with more insidious symptoms with productive cough, fever, leukocytosis, and progressive clinical deterioration with varying levels of respiratory compromise (13).

Risk factors

There are several known clinical risk factors for postoperative BPF including the patient's clinical condition preoperatively and the technical features of the surgical procedure performed (*Table 2*). Diabetes mellitus and chronic obstructive pulmonary disease (COPD) are independent risk factors for postoperative BPF (14,15). Age (>70 years), anemia, adult respiratory distress syndrome, poor nutrition,

Table 1 Symptoms and signs of BPF according to clinical presentation

Acute
Tension pneumothorax
Subcutaneous emphysema
Sudden expectoration of purulent sputum
Acute cough
Dyspnea
Mediastinal and tracheal shifts
Acute decrease of the pleural liquid level
Subacute and chronic
Empyema
Productive cough
Fever
Leukocytosis
Progressive clinical deterioration

BPF, bronchopleural fistula.

hypoalbuminemia, systemic use of steroids, empyema, neoadjuvant therapy with chemotherapy or radiation, and tracheostomy have also been described as risk factors for BPF (8,16-23).

Technical mistakes that can ultimately result in a BPF include a long bronchial stump, disrupted bronchial blood supply, inadequate stump closure, and extended bronchial resection (24). Residual carcinoma at the bronchial stump also increases the chances of BPF (25). BPF is 4 to 5 times more likely after right pneumonectomy as compared with left pneumonectomy (20,26). It is not clear why postpneumonectomy fistulas are more common on the right side than on the left. However, the decreased mediastinal tissue coverage of the right bronchial stump and lack of a dual blood supply to the right main bronchus may contribute to the increased incidence of BPF after right pneumonectomy. Therefore, coverage of the bronchial stump with a well-vascularized flap is strongly suggested (27). Additionally, postoperative ventilator assistance can affect stump healing and the incidence of dehiscence (17,18,20).

Investigation

When investigating a possible BPF, the objective is to estimate the size and precise location of the BPF, understand its relationship to adjacent mediastinal structures, and identify any secondary complications.

Table 2 Risk factors for BPF

Systemic
Poor nutrition
Sepsis
Immunosuppression
Diabetes mellitus
COPD
Anemia
Local
Neoadjuvant therapy
Poor blood supply
Active infection
Long bronchial stump
Extended lymph node dissection
Residual or recurrent cancer at the bronchial stump
Devascularization of bronchial stump
Other
Postoperative mechanical ventilation
Steroid use
Right pneumonectomy
Bronchial stump by hand-sewn
Tracheostomy
Smoking

BPF, bronchopleural fistula; COPD, chronic obstructive pulmonary disease.

Bronchoscopy

Bronchoscopy is essential for BFP diagnosis and therapeutic planning and can establish the location and size of a BPF with precision (*Figure 1*). Definitive treatment can sometimes be administered through an endobronchial approach.

Chest radiography

A chest X-ray is the simplest and easiest test to investigate a BPF. The presence of increased intrapleural air space, the appearance of an air-fluid level, and the development of a tension pneumothorax are classical findings of BPF (10,28). A new or larger pneumothorax—commonly noted as a decrease in the air-fluid level, a shift of the mediastinum contralateral to the surgical side, and subcutaneous

Figure 1 A small BPF identified by bronchoscopy after a right lower lobectomy. BPF, bronchopleural fistula.

Figure 2 BPF after lung resection. BPF, bronchopleural fistula.

emphysema—is suggestive of a BPF and warrants a thorough investigation (29). The diagnosis of BPF is an exclusion diagnosis related to postoperative pleural fluid shifts (30). Rarely, a decrease in the air-fluid level in the postpneumonectomy cavity will not be associated with BPF.

Chest computed tomography (CT)

A chest CT scan should be acquired with intravenous contrast to define the anatomic relationship of the fistula with adjacent vasculature, mediastinal structures, pleural space, and the diaphragm (*Figure 2*). A chest CT can also identify peripheral rind enhancement and air-fluid levels suggestive of localized or multi-loculated empyema (9) (*Figure 3*).

Virtual bronchoscopy

Virtual bronchoscopy is a 3-dimensional reconstruction of 2-dimensional, helical CT images that provides a simulated, noninvasive, intraluminal tracheo-bronchial evaluation (9). This test essentially allows a complete view of the airway beyond any obstruction. Virtual bronchoscopy can be used prior to endobronchial procedures such as bronchial stent placement. Acute angles in the tracheo-bronchial tree can be studied extensively when planning stent deployment and when evaluating airway complications after stent placement (31,32). Virtual bronchoscopy can also be a useful method for monitoring the healing process (33,34) and evaluating the internal diameter of the bronchial stump prior to the application of sealants.

Nuclear medicine

Nuclear medicine can be considered when CT scans and bronchoscopy cannot identify or sufficiently characterize a fistula (35,36). In one study of ventilation scintigraphy in 28 postpneumonectomy patients, this nuclear medicine technique using 99 m Tc-diethylenetriamine penta-acetate aerosol had a sensitivity of 78% and a specificity of 100% for the detection of BPF, with 86% accuracy (35).

Management

Preventative steps

To reduce the risk of BPF development, the majority of the studies recommend prophylactic bronchial stump coverage in patients with known preoperative risk factors for fistula. The benefit of prophylactic bronchial stump coverage has not been proved by randomized trials, and some of the data in the literature is controversial. In a recent meta-analysis, the incidence of BPF in patients considered at high risk for BPF who received bronchial stump coverage was only slightly higher as compared with patients considered at low risk for BPF who did not undergo prophylactic stump coverage (6.3% *vs.* 4.0%) (37). In another study, Sfyridis and colleagues randomized patients with diabetes mellitus who underwent pneumonectomy to either resection with reinforcement of the bronchial stump with an intercostal muscle flap or to a conventional resection. The patients who received an intercostal muscle flap had a lower incidence of BPF as compared with the patients who underwent conventional resection (0% *vs.* 17.1%) (38).

Figure 3 BPF and empyema after wedge resection in patient with lung cancer. BPF, bronchopleural fistula.

Initial management

Patients with BPF are at high risk of bronchial aspiration, aspiration pneumonia, acute respiratory distress syndrome, and mortality (3,23,39). Protecting the contralateral lung from spillage of pleural fluid is the single most important action when BPF is suspected (9). It is then imperative to rapidly diagnose and manage the BPF.

Appropriate management of a BPF depends on the type of fistula and the clinical condition of the patient. In undernourished patients with chronic BPF and empyema, nutritional rehabilitation has to start before planning a definitive fistula repair (40). Conversely, in patients with acute fistulas, rapid intervention to close the bronchial stump and obliterate the residual pleural space should be performed (1,41,42). Independent of the timing of the BPF, broad-spectrum antibiotics, aggressive nutritional supplementation, and adequate pleural drainage are key to recovery, because almost 80% of patients with BPF have pleural empyema (43).

Noninvasive treatment

On occasion, conservative treatment with antibiotics, nutritional support and proper pleural drainage may allow spontaneous closure of BPF. This noninvasive option is simple; however, the safety of the patent must be ensured. It is particularly useful in patients with postlobectomy fistulas when there is minimal residual pleural space and the air leak progressively decreases (1).

Patching a BPF

BPF are frequently patched with a muscle flap. The principles for a complete closure include (I) antibiotics for pleural sterilization; (II) completed drainage of the pleural space before reoperation; (III) preserving the integrity of the blood supply to the chest wall muscles; (VI) wide debridement and removal of all granulation tissue; (V) identification and closure of the fistula; and (VI) filling the residual space with a vascularized flap (44-47). Several anatomic structures have been used to patch BPFs (*Table 3*). The serratus anterior and the latissimus dorsi muscles have been described in the treatment of infected residual spaces (1,61-66), with or without BPF (52) without significant addition of morbidity (67). However, use of these muscles as a patch is contraindicated if the muscle was previously divided (15,68).

Management of the pleural space

When caring for patients with BPF or attempting to avoid BPF in high-risk patients, reduction of the pleural space enables resolution of any empyema and facilitates the closure of small peripheral BPFs. Several procedures have been described to manage the pleural space including pleural tenting, pneumoperitoneum, phrenic nerve block, the Clagett procedure, and open-window thoracotomy (69,70).

Pleural tenting

During the history of general thoracic surgery, many methods have been tried to prevent residual air spaces after thoracic surgery, especially after lung resection for inflammatory lung disease. Pleural tenting is an old method, first described by Miscall and colleagues (71) and Hansen (72), that has recently regained popularity (73-75). This technique is used to reduce the apical pleural space and requires dissection of the parietal pleura off the endothoracic fascia, from the thoracotomy incision towards the apex of the chest cavity. The mobilized parietal pleura are then tented over the residual lung by suturing the border of the pleura to the lower edge of the thoracotomy (72).

Table 3 Anatomic structures used to patch BPF

Anatomic structure	Comments
Azygous vein	Used in rare cases
Diaphragm	A diaphragmatic flap can be used to reduce the pleural cavity by elevating the remaining diaphragm (48-50)
	Used in rare cases
Epicardial fat	Used in rare cases
Intercostal muscle	One of the most used muscle grafts due to its wide availability, simplicity to harvest, good vascularization, and length
	A single intercostal flap or multiple intercostal flaps may be used to reinforce a fistula suture and fill the residual space (51)
Latissimus dorsi	Excellent option
	A bulky muscle that is easy to harvest
	Blood supply is from the thoracodorsal artery
	One of the most frequently used flaps due to its ability to protect the stump and fill the residual space (52,53)
Omentum	A good choice for the obliteration of the fistula and the pleural space due to its bulkiness and optimal vascular supply
	The omentum is passed through the substernal space. Due to its singular vascular supply, great care must be taken not to twist the omentum when entering the pleural cavity (54-59)
Parietal pleura	Used in rare cases
Pectoralis major	A particularly good option
	Dual vascularization from the internal mammary and the thoracoabdominal artery (60)
Rectus abdominis	Excellent vascular muscle flap
	Bilateral option
	Vascularization from the inferior epigastric artery
Serratus anterior	Small and thin muscle
	Vascularization from the lateral thoracic artery
	Easy utilization and insertion in the pleural cavity (61)

Importantly, chest tubes should to be placed under the tent. A recent meta-analysis defined pleural tenting as simple and easy to perform. Also, tenting did not prolong the duration of the operation and was not associated with greater morbidity as compared with upper lobectomy without tenting (76).

Pneumoperitoneum

Pneumoperitoneum is the injection of air into the abdominal cavity, causing an elevation of the hemi-diaphragm and thus reducing the residual pleural space postoperatively. In 1924, Reich and colleagues first described the use of pneumoperitoneum for patients with emphysema (77); Carter and colleagues later confirmed the safety of the procedure (78). The main indications for institution of pneumoperitoneum are postoperative residual pleural space, incomplete lung re-expansion after empyema decortication, and severe pleural space problems in adult patients (79). It is also indicated as an adjunct to block major air leaks. Pneumoperitoneum is a safe and effective procedure (79,80) performed with the aid of imaging exams to guide the introduction of air. A catheter is left in place to progressively inject air in the abdomen (79-81).

Phrenic nerve block

Phrenic nerve block is a simple technique that allows temporary reduction of the pleural cavity by raising the dome of the diaphragm. The phrenic nerve block is performed with bupivacaine (0.5%) without epinephrine at the neurovascular pedicle at the level of the pericardium (82).

Figure 4 Open-window thoracotomy.

The effect usually lasts 24 hours. This procedure is contraindicated in patients with limited lung function (82).

Clagett procedure

In 1963, Clagett and Geraci (61) described a technique for the management of postpneumonectomy empyema. The technique was a 2-stage procedure: open pleural drainage for control of the septic cavity and closure of BPF and then obliteration of the pleural cavity with antibiotic solution. The Clagett procedure has been reported to be effective in 88% of patients, with failures resulting from persistent or recurrent BPF (83). In an attempt to address these failures, Pairolero and Arnold (84) described the transposition of a well-vascularized extrathoracic muscle as an intermediate step. This modification of the "Clagett" procedure was designed to further reinforce the bronchial stump and to decrease the size of the pleural cavity.

Open-window thoracotomy

The open-window thoracostomy (*Figure 4*) is an ideal method for draining the septic pleural cavity in patients with empyema after a pulmonary resection (61,85,86), especially in patients with a postpneumonectomy BPF with empyema (87). Open-window thoracostomy was first described by Robinson in 1916 (88) in patients with nontuberculous empyema, and was subsequently revised in 1935 by Eloesser (89) for patients with tuberculous empyema. The Eloesser procedure added the resection of 2-to-3 rib segments and the creation of a skin flap used to epithelialize the entryway in the pleural space. The window should be placed, low and anterior in the chest to facilitate drainage (89).

The timing of attempting to close the window created during open-window thoracostomy is usually dictated by the condition of the pleural cavity and the prognosis of the patient (90). When the pleural space is clean, as characterized by the presence of healthy granulation tissue, it can be closed (66). There is some controversy on the timing for closing the window, but in most cases closure is warranted ~6 months after thoracostomy (90).

Endoscopic treatment

History and indications

Although it is primarily used for diagnostic purposes, flexible bronchoscopy has been gaining ground as a therapeutic modality in patients with BPF and has evolved to treat central BPF, primarily after lobectomy and less frequently after pneumonectomy. In 1983, Roksvaag and colleagues (91) reported two cases of postpneumonectomy BPF closure with synthetic tissue glue applied endoscopically. Several other cases have been reported since then, and endoscopic techniques are considered a safe and feasible alternative to open surgery for management of BPF (92,93).

Despite the fact that surgery is the standard of care for a central BPF when properly indicated, a less invasive approach can be a bridge to a definitive treatment in fragile patients. The primary objective of endoscopic BPF closure is to reduce a potentially life-threatening air leak, prevent aspiration of pleural fluid, and decrease secondary pleural contamination. Once the patient's clinical condition and nutritional status improve definitive surgical treatment can be attempted (13). Eventually endoscopic treatment can potentially result in long-term BPF closure and complete empyema resolution without requiring permanent-tube thoracostomy or open pleural drainage (92).

Different techniques through flexible or rigid bronchoscopes are available and can be performed under conscious sedation or general anesthesia. These approaches mainly differ in

Figure 5 Use of bioglue in small BPF. BPF, bronchopleural fistula.

the material used to close the fistula. Success rates reported in retrospective series range widely—from 22.5% to 96.9% (94). This might indirectly represent the lack of standard practices in the endoscopic management of BPF.

Fistula size

Fistula size is one factor that determines whether an endoscopic approach is an appropriate treatment. Smaller fistulas are more suitable for endoscopic closure (92,94,95). In a retrospective series of 35 patients who underwent bronchoscopic repair of BPFs after pneumonectomy, repair was successful in 92.3% of patients with BPFs ≤2 mm in size, 71.4% for BPF >2 and <3 mm, 80% for BPF >3 and <6 mm, and only 33.3% in patients with BPF >6 mm (96). The BPFs ≤2 mm in size were treated with mechanical abrasion causing local inflammation. BPF >2 and <3 mm were treated with submucosal injection of polidocanol; BPF >3 and <6 mm were treated with n-butyl-2-cyanoacrylate glue (Histoacryl) instillation. BPF >6 mm were treated via insertion of an expandable substance filled with fluid n-butyl-2-cyanoacrylate glue to occlude the fistula (94). Before applying any endoscopic therapy, it is advisable to clear secretions and debris from the bronchial stump (97). Mucosa necrosis has been described as an indication for surgical treatment (94).

Biological glues

Several types of biological glues with different components have been used for endoscopic BPF closure including fibrin-based glues, cyanoacrylate-based glues (e.g., Histoacryl, TissueSeal, Ann Arbor MI), and albumin-glutaraldehyde tissue adhesive (BioGlue, BioLife Inc., Kennesaw, GA) (96,98-100). Regardless of the glue type, the application technique is very similar. A catheter (e.g., Fogarty n°5) is inserted through the working channel of a flexible bronchoscope and placed just above the fistula. The glue is then injected into the fistula, and after a few seconds, it creates a plug that occludes the fistula (*Figure 5*). Alternatively, some authors (96) have injected the glue in the submucosa with a 21G needle in favor of a theoretically more effective closure due to less glue displacement. An air-leak interruption through the chest tube should be immediately observed. Close clinical and endoscopic surveillance is important for identification of failure to plug the fistula. The need for repeated endoscopic glue applications for successful closure is not uncommon (91). Following mechanical occlusion, the glue induces scar tissue formation, which helps achieve long-term BPF closure (101).

The application of biological glues has some positive aspects, such as (I) potentially providing an instantaneous closure of the BPF, which plays a key role in preventing the development of pleural space infection or treating an empyema that is already onset and (II) using a tool (biological glue) that is already widely applied on humans in a variety of procedures with low risks of complications.

Sclerosing agents

Endoscopic submucosal injection of sclerosing substances or direct application of these agents over the mucosa of the bronchial stump can be used to close BPF by promoting local edema and tissue-healing processes (93,102). Silver nitrate causes cellular damage, because it burns the superficial layer and induces local inflammation and scar tissue formation. The application of sclerosing agents requires the expertise of a skilled endoscopist to avoid injury to surrounding tissues. It can be applied through rigid or flexible bronchoscopy (103). Stratakos and colleagues (104) reported an 81.8% success rate using this technique in a small series of 11 patients with postpneumonectomy or postlobectomy BPF ≤5 mm in size. They applied melted silver nitrate through a flexible bronchoscope until blanching and edema of the mucosa appeared around the fistula. The procedure was repeated up to 10 times at 5- to 7-day intervals until effective sealing was achieved. Boudaya and colleagues (102) successfully treated 16 of 17 patients with postoperative BPFs, mostly ≤5 mm (a success rate of 94.1%). Liquid silver nitrate (1%) was applied around the stump mucosa under direct vision with a catheter through the working channel of a flexible bronchoscope. A solution of 100% carbolic acid has also been used with similar technique, mechanism of action and results for BPF with a median diameter of 4.5 mm (105).

Video-assisted thoracic surgery (VATS)

Several reports have described video-assisted surgery for the closure of BPF. The main benefits of VATS are better visualization, which allows more secure fixation of the vascularized grafts, and a decreased need for intervention as compared with the open approaches discussed below.

Open surgical treatment of BPF

Dehiscence of the bronchial stump after anatomic resection remains the most common cause of BPF (9). Therefore, prevention through complete preoperative evaluation and safe decision-making during surgery is the best way to avoid this complication (11). Standard procedures to reduce the likelihood of BPF in patients at risk include ensuring an appropriate vascular supply to the stump, creating a bronchial stump <1 cm long, and prophylactically covering the bronchial stump with a vascularized flap (1).

Treatment principles

Only a small percentage of BPF will spontaneously close, typically BPF that occur after anatomic segmentectomy or lobectomy where the residual pleural space is small in patients who are healthy otherwise (1). BPF is habitually accompanied by empyema, which can range from exudative pleural effusion to a more chronic fibrinopurulent effusion. So ideally, the repair of the fistula should be performed once the pleural cavity is clean. Ignoring this rule will most certainly result in poor outcome (61,65).

Early BPF

Initial management of a BPF that occurs early after surgery (within 2 weeks) is dependent on drainage of the pleural space with a large chest tube (32F or higher) and positioning the patient in the reverse Trendelenburg position with the affected side down to prevent compromising the contralateral lung. Fluid cultures must be requested, and broad-spectrum antibiotics should be started immediately and continued until culture results are available to dictate a more specific antibiotic range (84).

Early postoperative stump leaks require urgent intervention. After initial bedside management is initiated, an individualized strategy must be planned, and a surgical procedure must take place after the infection is under control (106). Classical surgical management consists of thoracotomy (opening of the previous incision), inspection and searching for the leaking site, debridement of fibrin and infected pleural residue, irrigation of the cavity with antibiotic solution, resection of necrotic tissue around the stump, reclosure with non-absorbable sutures , and reinforcement of the suture with a vascularized pedicle patch (1,82). The most commonly used vascularized patches are derived from the intercostal muscles, serratus anterior, latissimus dorsi, pectoralis major, omental flap, or rectus abdominalis. If a long stump is noticed, it must be resected to its origin and restapled, if possible. Pleurostomy may be performed depending on the size of the fistula, state of infection of the cavity or in poor surgical candidates.

Late BPF

Late postoperative BPF (2 weeks and more after surgery) may require a longer course of treatment. After initial drainage, definitive treatment should be delayed until the infection is under control and the nutritional status of the patient is optimal. Several techniques have been described for the treatment of a BPF occurring late after surgery, ranging from open thoracostomy (Eloesser Flap) to the Clagett or modified Clagett procedure (61,65).

The Clagett procedure, a two-step procedure, begins with open pleural drainage (through an open-window thoracostomy) and resuturing of the bronchial stump followed by packing the space one or two times a day with dressings imbibed with quarter-strength Dakin's solution or povidone-iodine solution diluted 20:1. After the cavity is judged clean, a second stage takes place that consists of the filling the pleural space with an antiseptic solution (Dab's solution—0.5 g of neomycin, 0.1 g of polymyxin B sulfate and 80 mg of gentamicin per liter of saline) followed by water-tight wound shutting (61). Zaheer and colleagues demonstrated a rate of success of over 80% with this technique (6).

A transsternal transpericardial approach for BPF repair was initially described by Abruzzini in 1961 and is an option that avoids entering a previous manipulated cavity (107).

A full sternotomy is used to access the anterior pericardium, which is then opened. The pulmonary artery is mobilized, allowing opening of the posterior pericardium, and finally, exposure of the carina. The bronchial stump is identified, divided, and closed. A vascularized patch of pericardium is then used to reinforce the suture. Ginsberg and collaborators reported successful management in 77% of patients in their series using this approach (108).

Conclusions

In modern thoracic surgery, the incidence of BPF has substantially decreased due to improvements in preoperative evaluation and surgical techniques. However, BPF still represents a major complication in thoracic surgery that demands proper and accurate management.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Cooper WA, Miller JI Jr. Management of bronchopleural fistula after lobectomy. Semin Thorac Cardiovasc Surg 2001;13:8-12.
2. Asamura H, Kondo H, Tsuchiya R. Management of the bronchial stump in pulmonary resections: a review of 533 consecutive recent bronchial closures. Eur J Cardiothorac Surg 2000;17:106-10.
3. Asamura H, Naruke T, Tsuchiya R, et al. Bronchopleural fistulas associated with lung cancer operations. Univariate and multivariate analysis of risk factors, management, and outcome. J Thorac Cardiovasc Surg 1992;104:1456-64.
4. al-Kattan K, Cattalani L, Goldstraw P. Bronchopleural fistula after pneumonectomy with a hand suture technique. Ann Thorac Surg 1994;58:1433-6.
5. Schneiter D, Grodzki T, Lardinois D, et al. Accelerated treatment of postpneumonectomy empyema: a binational long-term study. J Thorac Cardiovasc Surg 2008;136:179-85.
6. Zaheer S, Allen MS, Cassivi SD, et al. Postpneumonectomy empyema: results after the Clagett procedure. Ann Thorac Surg 2006;82:279-86; discussion 286-7.
7. Nagahiro I, Aoe M, Sano Y, et al. Bronchopleural fistula after lobectomy for lung cancer. Asian Cardiovasc Thorac Ann 2007;15:45-8.
8. Sirbu H, Busch T, Aleksic I, et al. Bronchopleural fistula in the surgery of non-small cell lung cancer: incidence, risk factors, and management. Ann Thorac Cardiovasc Surg 2001;7:330-6.
9. Gaur P, Dunne R, Colson YL, et al. Bronchopleural fistula and the role of contemporary imaging. J Thorac Cardiovasc Surg 2014;148:341-7.
10. Kirsh MM, Rotman H, Behrendt DM, et al. Complications of pulmonary resection. Ann Thorac Surg 1975;20:215-36.
11. Cerfolio RJ. The incidence, etiology, and prevention of postresectional bronchopleural fistula. Semin Thorac Cardiovasc Surg 2001;13:3-7.
12. McManigle JE, Fletcher GL, Tenholder MF. Bronchoscopy in the management of bronchopleural fistula. Chest 1990;97:1235-8.
13. Lois M, Noppen M. Bronchopleural fistulas: an overview of the problem with special focus on endoscopic management. Chest 2005;128:3955-65.
14. Li SJ, Fan J, Zhou J, et al. Diabetes Mellitus and Risk of Bronchopleural Fistula After Pulmonary Resections: A Meta-Analysis. Ann Thorac Surg 2016;102:328-39.
15. Li SJ, Zhou XD, Huang J, et al. A systematic review and meta-analysis-does chronic obstructive pulmonary disease predispose to bronchopleural fistula formation in patients undergoing lung cancer surgery? J Thorac Dis 2016;8:1625-38.
16. Hu XF, Duan L, Jiang GN, et al. A clinical risk model for the evaluation of bronchopleural fistula in non-small cell lung cancer after pneumonectomy. Ann Thorac Surg 2013;96:419-24.
17. Algar FJ, Alvarez A, Aranda JL, et al. Prediction of early bronchopleural fistula after pneumonectomy: a multivariate analysis. Ann Thorac Surg 2001;72:1662-7.
18. Panagopoulos ND, Apostolakis E, Koletsis E, et al. Low incidence of bronchopleural fistula after pneumonectomy for lung cancer. Interact Cardiovasc Thorac Surg 2009;9:571-5.
19. Khan JH, Rahman SB, McEihinney DB, et al. Management strategies for complex bronchopleural fistula. Asian Cardiovasc Thorax Ann 2000;8:78-84.
20. Darling GE, Abdurahman A, Yi QL, et al. Risk of a right pneumonectomy: role of bronchopleural fistula. Ann Thorac Surg 2005;79:433-7.
21. Hubaut JJ, Baron O, Al Habash O, et al. Closure of

the bronchial stump by manual suture and incidence of bronchopleural fistula in a series of 209 pneumonectomies for lung cancer. Eur J Cardiothorac Surg 1999;16:418-23.
22. Deschamps C, Bernard A, Nichols FC 3rd, et al. Empyema and bronchopleural fistula after pneumonectomy: factors affecting incidence. Ann Thorac Surg 2001;72:243-7; discussion 248.
23. Wright CD, Wain JC, Mathisen DJ, et al. Postpneumonectomy bronchopleural fistula after sutured bronchial closure: incidence, risk factors, and management. J Thorac Cardiovasc Surg 1996;112:1367-71.
24. Smith GH. Complications of cardiopulmonary surgery. 1 edition. London, UK: Bailliere Tindall, 1984:18-20.
25. Li S, Fan J, Zhou J, et al. Residual disease at the bronchial stump is positively associated with the risk of bronchoplerual fistula in patients undergoing lung cancer surgery: a meta-analysis. Interact Cardiovasc Thorac Surg 2016;22:327-35.
26. Gudbjartsson T, Gyllstedt E, Pikwer A, et al. Early surgical results after pneumonectomy for non-small cell lung cancer are not affected by preoperative radiotherapy and chemotherapy. Ann Thorac Surg 2008;86:376-82.
27. Taghavi S, Marta GM, Lang G, et al. Bronchial stump coverage with a pedicled pericardial flap: an effective method for prevention of postpneumonectomy bronchopleural fistula. Ann Thorac Surg 2005;79:284-8.
28. Piccione W, Faber LP. Management of complications related to pulmonary resection. In: Waldhausen JA, Orringer MB. editors. Complications in Cardiothoracic Surgery. St. Louis, MO: Mosby Year-Book, 1991:336-53.
29. Lauckner ME, Beggs I, Armstrong RF. The radiological characteristics of bronchopleural fistula following pneumonectomy. Anaesthesia 1983;38:452-6.
30. Merritt RE, Reznik SI, DaSilva MC, et al. Benign emptying of the postpneumonectomy space. Ann Thorac Surg 2011;92:1076-81; discussion 1081-2.
31. Dialani V, Ernst A, Sun M, et al. MDCT detection of airway stent complications: comparison with bronchoscopy. AJR Am J Roentgenol 2008;191:1576-80.
32. Nair A, Godoy MC, Holden EL, et al. Multidetector CT and postprocessing in planning and assisting in minimally invasive bronchoscopic airway interventions. Radiographics 2012;32:E201-32.
33. McAdams HP, Palmer SM, Erasmus JJ, et al. Bronchial anastomotic complications in lung transplant recipients: virtual bronchoscopy for noninvasive assessment. Radiology 1998;209:689-95.
34. Shitrit D, Valdsislav P, Grubstein A, et al. Accuracy of virtual bronchoscopy for grading tracheobronchial stenosis: correlation with pulmonary function test and fiberoptic bronchoscopy. Chest 2005;128:3545-50.
35. Mark JB, McDougall IR. Diagnosis and localization of bronchopulmonary air leaks using ventilation scintigraphy. Chest 1997;111:286-9.
36. Nielsen KR, Blake LM, Mark JB, et al. Localization of bronchopleural fistula using ventilation scintigraphy. J Nucl Med 1994;35:867-9.
37. Di Maio M, Perrone F, Deschamps C, et al. A meta-analysis of the impact of bronchial stump coverage on the risk of bronchopleural fistula after pneumonectomy. Eur J Cardiothorac Surg 2015;48:196-200.
38. Sfyridis PG, Kapetanakis EI, Baltayiannis NE, et al. Bronchial stump buttressing with an intercostal muscle flap in diabetic patients. Ann Thorac Surg 2007;84:967-71.
39. Hollaus PH, Lax F, el-Nashef BB, et al. Natural history of bronchopleural fistula after pneumonectomy: a review of 96 cases. Ann Thorac Surg 1997;63:1391-6; discussion 1396-7.
40. Puskas JD, Mathisen DJ, Grillo HC, et al. Treatment strategies for bronchopleural fistula. J Thorac Cardiovasc Surg 1995;109:989-95; discussion 995-6.
41. Allen MS, Deschamps C, Trastek VF, et al. Bronchopleural fistula. Chest Surg Clin 1992;823.
42. Westcott JL, Volpe JP. Peripheral bronchopleural fistula: CT evaluation in 20 patients with pneumonia, empyema, or postoperative air leak. Radiology 1995;196:175-81.
43. Wain JC. Management of late postpneumonectomy empyema and bronchopleural fistula. Chest Surg Clin N Am 1996;6:529-41.
44. Anderson TM, Miller JI Jr. Use of pleura, azygos vein, pericardium, and muscle flaps in tracheobronchial surgery. Ann Thorac Surg 1995;60:729-33.
45. Pairolero PC, Arnold PG. Intrathoracic transfer of flaps for fistulas, exposed prosthetic devices, and reinforcement of suture lines. Surg Clin North Am 1989;69:1047-59.
46. Pairolero PC, Trastek VF, Allen MS. Empyema and bronchopleural fistula. Ann Thorac Surg 1991;51:157-8.
47. Petrovsky BV. The use of diaphragm grafts for plastic operations in thoracic surgery. J Thorac Cardiovasc Surg 1961;41:348-55.
48. Westaby S, Shepherd MP, Nohl-Oser HC. The use of diaphragmatic pedicle grafts for reconstructive procedures in the esophagus and tracheobronchial tree. Ann Thorac Surg 1982;33:486-90.
49. Mineo TC, Ambrogi V. Early closure of the postpneumonectomy bronchopleural fistula by pedicled diaphragmatic flaps. Ann Thorac Surg 1995;60:714-5.
50. Hollaus PH, Huber M, Lax F, et al. Closure of

bronchopleural fistula after pneumonectomy with a pedicled intercostal muscle flap. Eur J Cardiothorac Surg 1999;16:181-6.
51. Chan EC, Lee TW, Ng CS, et al. Closure of postpneumonectomy bronchopleural fistula by means of single, perforator-based, latissimus dorsi muscle flap. J Thorac Cardiovasc Surg 2002;124:1235-6.
52. Abolhoda A, Wirth GA, Bui TD, et al. Harvest technique for pedicled transposition of latissimus dorsi muscle: an old trade revisited. Eur J Cardiothorac Surg 2008;33:928-30.
53. Yokomise H, Takahashi Y, Inui K, et al. Omentoplasty for postpneumonectomy bronchopleural fistulas. Eur J Cardiothorac Surg 1994;8:122-4.
54. D'Andrilli A, Ibrahim M, Andreetti C, et al. Transdiaphragmatic harvesting of the omentum through thoracotomy for bronchial stump reinforcement. Ann Thorac Surg 2009;88:212-5.
55. Shrager JB, Wain JC, Wright CD, et al. Omentum is highly effective in the management of complex cardiothoracic surgical problems. J Thorac Cardiovasc Surg 2003;125:526-32.
56. Levashev YN, Akopov AL, Mosin IV. The possibilities of greater omentum usage in thoracic surgery. Eur J Cardiothorac Surg 1999;15:465-8.
57. Mathisen DJ, Grillo HC, Vlahakes GJ, et al. The omentum in the management of complicated cardiothoracic problems. J Thorac Cardiovasc Surg 1988;95:677-84.
58. Miller JD, DeHoyos A. An evaluation of the role of omentopexy and of early perioperative corticosteroid administration in clinical lung transplantation. The University of Toronto and Washington University Lung Transplant Programs. J Thorac Cardiovasc Surg 1993;105:247-52.
59. Kalweit G, Feindt P, Huwer H, et al. The pectoral muscle flaps in the treatment of bronchial stump fistula following pneumonectomy. Eur J Cardiothorac Surg 1994;8:358-62.
60. Park JS, Eom JS, Choi SH, et al. Use of a serratus anterior musculocutaneous flap for surgical obliteration of a bronchopleural fistula. Interact Cardiovasc Thorac Surg 2015;20:569-74.
61. Clagett OT, Geraci JE. A procedure for the management of postpneumonectomy empyema. J Thorac Cardiovasc Surg 1963;45:141-5.
62. Abrashanoff X. Plastische Methode des Schliessung von Fistelga¨ngen, welche von inneren Organen kommen. Zentralbl Chir 1911;38:186-91.
63. Robinson S. The treatment of chronic non-tuberculous empyema. Collected Papers Mayo Clin 1915;7:618-44.
64. Arnold PG, Pairolero PC. Intrathoracic muscle flaps. An account of their use in the management of 100 consecutive patients. Ann Surg 1990;211:656-60; discussion 660-2.
65. Pairolero PC, Arnold PG, Trastek VF, et al. Postpneumonectomy empyema. The role of intrathoracic muscle transposition. J Thorac Cardiovasc Surg 1990;99:958-66; discussion 966-8.
66. Deschamps C, Pairolero PC, Allen MS, et al. Management of postpneumonectomy empyema and bronchopleural fistula. Chest Surg Clin N Am 1996;6:519-27.
67. Widmer MK, Krueger T, Lardinois D, et al. A comparative evaluation of intrathoracic latissimus dorsi and serratus anterior muscle transposition. Eur J Cardiothorac Surg 2000;18:435-9.
68. Regnard JF, Alifano M, Puyo P, et al. Open window thoracostomy followed by intrathoracic flap transposition in the treatment of empyema complicating pulmonary resection. J Thorac Cardiovasc Surg 2000;120:270-5.
69. Miller JI Jr. Acute and delayed space problems following pulmonary resection. Chest Surg Clin N Am 1996;6:615-21.
70. Rice TW, Kirby TJ. Prolonged air leak. Chest Surg Clin North Am 1992;2:803–11.
71. Miscall L, Duffy RW, Nolan RB, et al. The pleural tent as a simultaneous tailoring procedure in combination with pulmonary resection. Am Rev Tuberc 1956;73:831-52.
72. Hansen JL. Parietal pleurolysis (the pleural tent) as a simultaneous space-reducing procedure in combination with pulmonary resection. Acta Chir Scand 1957;112:485-8.
73. Robinson LA, Preksto D. Pleural tenting during upper lobectomy decreases chest tube time and total hospitalization days. J Thorac Cardiovasc Surg 1998;115:319-26; discussion 326-7.
74. Okur E, Kir A, Halezeroglu S, et al. Pleural tenting following upper lobectomies or bilobectomies of the lung to prevent residual air space and prolonged air leak. Eur J Cardiothorac Surg 2001;20:1012-5.
75. Brunelli A, Al Refai M, Monteverde M, et al. Pleural tent after upper lobectomy: a randomized study of efficacy and duration of effect. Ann Thorac Surg 2002;74:1958-62.
76. Uzzaman MM, Daniel Robb J, Mhandu PC, et al. A meta-analysis assessing the benefits of concomitant pleural tent procedure after upper lobectomy. Ann Thorac Surg 2014;97:365-72.
77. Reich L. Der Einfluss des Pneumoperitoneums auf das Lungen-emphysem. Wien Arch Finn Med 1924;8:245-60.
78. Carter MG, Gaensler EA, Kyllonen A. Pneumoperitoneum in the treatment of pulmonary emphysema. N Engl J Med

1950;243:549-58.
79. Podgaetz E, Berger J, Small J, et al. Therapeutic Pneumoperitoneum: Relevant or Obsolete in 2015? Thorac Cardiovasc Surg 2016. [Epub ahead of print].
80. Cerfolio RJ, Holman WL, Katholi CR. Pneumoperitoneum after concomitant resection of the right middle and lower lobes (bilobectomy). Ann Thorac Surg 2000;70:942-6; discussion 946-7.
81. Nielsen KT, Lund L, Larsen LP, et al. Duration of postoperative pneumoperitoneum. Eur J Surg 1997;163:501-3.
82. Murthy SC. Air leak and pleural space management. Thorac Surg Clin 2006;16:261-5.
83. Clagett OT. Changing aspects of the etiology and treatment of pleural empyema. Surg Clin North Am 1973;53:863-6.
84. Pairolero PC, Arnold PG. Bronchopleural fistula: treatment by transposition of pectoralis major muscle. J Thorac Cardiovasc Surg 1980;79:142-5.
85. Lemmer JH, Botham MJ, Orringer MB. Modern management of adult thoracic empyema. J Thorac Cardiovasc Surg 1985;90:849-55.
86. Shamji FM, Ginsberg RJ, Cooper JD, et al. Open window thoracostomy in the management of postpneumonectomy empyema with or without bronchopleural fistula. J Thorac Cardiovasc Surg 1983;86:818-22.
87. Goldstraw P. Treatment of postpneumonectomy empyema: the case for fenestration. Thorax 1979;34:740-5.
88. Robinson S. The Treatment of chronic non-tuberculous chronic emyeme. Surg Gynecol Obstet 1912;22:257.
89. Eloesser L. Of an operation for tuberculous empyema. Ann Thorac Surg 1969;8:355-7.
90. García-Yuste M, Ramos G, Duque JL, et al. Open-window thoracostomy and thoracomyoplasty to manage chronic pleural empyema. Ann Thorac Surg 1998;65:818-22.
91. Roksvaag H, Skalleberg L, Nordberg C, et al. Endoscopic closure of bronchial fistula. Thorax 1983;38:696-7.
92. Hollaus PH, Lax F, Janakiev D, et al. Endoscopic treatment of postoperative bronchopleural fistula: experience with 45 cases. Ann Thorac Surg 1998;66:923-7.
93. Varoli F, Roviaro G, Grignani F, et al. Endoscopic treatment of bronchopleural fistulas. Ann Thorac Surg 1998;65:807-9.
94. Cardillo G, Carbone L, Carleo F, et al. The Rationale for Treatment of Postresectional Bronchopleural Fistula: Analysis of 52 Patients. Ann Thorac Surg 2015;100:251-7.
95. Scappaticci E, Ardissone F, Ruffini E, et al. As originally published in 1994: Postoperative bronchopleural fistula: endoscopic closure in 12 patients. Updated in 2000. Ann Thorac Surg 2000;69:1629-30.
96. Hamid UI, Jones JM. Closure of a bronchopleural fistula using glue. Interact Cardiovasc Thorac Surg 2011;13:117-8.
97. Sippel JM, Chesnutt MS. Bronchoscopic therapy for bronchopleural fistula. J Bronchol 1998;5:61-9.
98. Fuso L, Varone F, Nachira D, et al. Incidence and Management of Post-Lobectomy and Pneumonectomy Bronchopleural Fistula. Lung 2016;194:299-305.
99. Lang-Lazdunski L. Closure of a bronchopleural fistula after extended right pneumonectomy after induction chemotherapy with BioGlue surgical adhesive. J Thorac Cardiovasc Surg 2006;132:1497-8.
100. Ranu H, Gatheral T, Sheth A, et al. Successful endobronchial seal of surgical bronchopleural fistulas using BioGlue. Ann Thorac Surg 2009;88:1691-2.
101. Menard JW, Prejean CA, Tucker WY. Endoscopic closure of bronchopleural fistulas using a tissue adhesive. Am J Surg 1988;155:415-6.
102. Boudaya MS, Smadhi H, Zribi H, et al. Conservative management of postoperative bronchopleural fistulas. J Thorac Cardiovasc Surg 2013;146:575-9.
103. Høier-Madsen K, Schulze S, Møller Pedersen V, et al. Management of bronchopleural fistula following pneumonectomy. Scand J Thorac Cardiovasc Surg 1984;18:263-6.
104. Stratakos G, Zuccatosta L, Porfyridis I, et al. Silver nitrate through flexible bronchoscope in the treatment of bronchopleural fistulae. J Thorac Cardiovasc Surg 2009;138:603-7.
105. Wang Z, Yu HB, Luo Q, et al. Treatment of Bronchopleural Fistula with Carbolic Acid instilled through Bronchofiberscope in post-pulmonectomy patients. J Cardiothorac Surg 2015;10:120.
106. Zanotti G, Mitchell JD. Bronchopleural Fistula and Empyema After Anatomic Lung Resection. Thorac Surg Clin 2015;25:421-7.
107. Abruzzini P. Tratamento chirurgico delle fistulae del broncho principale consecutive pneumonectomia tubercolosi. Chir Thorac 1961;14:165-71.
108. Ginsberg RJ, Pearson FG, Cooper JD, et al. Closure of chronic postpneumonectomy bronchopleural fistula using the transsternal transpericardial approach. Ann Thorac Surg 1989;47:231-5.

doi: 10.21037/shc.2017.06.01
Cite this article as: Dal Agnol G, Vieira A, Oliveira R, Ugalde Figueroa PA. Surgical approaches for bronchopleural fistula. Shanghai Chest 2017;1:14.

Lung decortication for pleural empyema

Marco Scarci[1], Federico Raveglia[2]

[1]Department of Thoracic Surgery, University College London Hospital, London, UK; [2]Department of thoracic Surgery, San Paolo Hospital, Milan, Italy

Correspondence to: Marco Scarci. Department of Thoracic Surgery, University College London Hospital, London, UK. Email: marco.scarci@mac.com.

Received: 03 August 2017; Accepted: 07 August 2017; Published: 14 August 2017.
doi: 10.21037/shc.2017.08.08
View this article at: http://dx.doi.org/10.21037/shc.2017.08.08

Empyema definition, etiology, pathogenesis

Thoracic empyema is an accumulation of infected fluid within the pleural space. The most common cause in the western world is parapneumonic followed by complications of surgery. Patients with advanced age, multiple comorbidities such as chronic obstructive pulmonary disease (COPD), diabetes and immunodeficiency are more likely to develop empyemas.

Empyemas are classified in three evolving stages:

(I) Exudative: accumulation of sterile fluid into the pleural space as the result of the initial inflammatory process, usually during the first week;

(II) Fibrinopurulent: the fluid tends to be colonized by bacteria migrating from the lung parenchima;

(III) Organized: if the fluid is not evacuated at this stage, the activation of fibroblasts produces a thick cortex over the surface of the lung. Whilst this process has a role in limiting the spread of the infection, on the other hand restricts lung expansion.

Pleural aspiration, often under ultrasound guidance to assess the presence of locations and drain pockets of fluid, is mandatory in the management of empyemas. The gold standard to assess the need for open surgical intervention remains CT scan of the chest. The thickness of the cortex if often a reliable sign that the patient will require an open procedure.

Empyema treatment by stages

The treatment of empyemas varies according to the stages, but the main goal is twofold: (I) drainage of the fluid; (II) re-expansion of the lung.

In our experience and according to the most up to date guidelines, medical treatment with culture-targeted antibiotics is effective in stage one. In stage two we opt for uniportal video-assisted thoracoscopic surgery and finally we reserve open decortication to the more advanced cases.

Decortication is a surgical procedure aimed to remove a restrictive layer of fibrous membrane overlying the lung parenchyma, diaphragm, and chest wall. The ultimate goal is to allow parenchymal re-expansion. Most patients present to surgeons with fibrothorax, which is a production of fibrous tissue that pulls the ribs together and inhibits the re-expansion of the lung.

In order for a patent to be candidate for open surgery it is expected for him to have evidence of trapped lung that failed to respond to medical treatment and is not amenable of minimally invasive intervention. We do not believe there are absolute contraindications to surgery as the infective process is not going to resolve on his own. Ideally the patients should be medically optimized and then operated on promptly. It is surprising how very sick patients recover very rapidly once the infective process is resolved and adequate support (especially nutritional) is instituted. Of course the patient must be able to tolerate single lung ventilation, therefore large bilateral lung consolidations precludes immediate surgery.

In our experience, in the presence of thick cortex on CT scan, we prefer an open approach to adequately clear the pleural space and expand the lung. We start with a posterolateral thoracotomy and the chest is entered in the bed of the sixth rib. This is because, almost always, the largest amount of adhesions and cortex is at the bottom. In cases of severe loss of volume in the hemithorax due to rib crowding, we remove a segment of the sixth rib. This avoids to force open the ribs avoiding traumatic fractures. If the cortex if particularly thick, we dissect extra-pleurally for about 2–3 cm cranially and caudally in order to insert the branches of the spreader without tearing the underlying lung. Particular care must be paid, at the beginning of the operation, to identify correctly the different layers. Sometime it is easy to get confused and start stripping entirely the parietal pleura with potential for iatrogenic injuries to the surrounding structures or bleeding from small peri-spinal veins. We recommend to start the dissection with the lung inflated. Such approach allows easier visualisation of the anatomical planes. It is important to dissect on top of the lung and inside the parietal pleura. To identify the lung we incise the cortex with a number 11 blade until the lung start to become evident. At that point we use sharp dissection to define the correct plane. Most of the dissection is done with the lung inflated with a combination of sharp and blunt dissection. We recommend to swipe along the lung horizontally, rather than pushing the lung down. In this way it is easier to avoid injuring the lung. We also strongly recommend to identify the fissures. The reader as to image each lobe like a cubical structure in three-dimension. If the cube (lobe) is expanded only on one side it is impossible for the lung to fill the space. If accidental injury of the lung occurs, then we recommend to choose a different spot and stat again. Usually it is easier to identify the plane toward the upper part of the lung (the least affected part) then move caudally. It is also suggested to remove partially the parietal pleura to avoid a restrictive movement of the chest. We routinely leave an area of 4–5 cm just above the spine to insert a paravertebral catheter for analgesia. One or two drains are inserted and the chest closed in routine fashion. If we remove a segment of the rib, we bring together the intercostal muscles to avoid surgical emphysema. If there is a bothersome air leak with loss of capnography, the patient should not be closed and further manoeuvres must be done to reduce it, otherwise the patient will lose all the tidal volume down the drain and it won't be possible to ventilate him.

Tips and tricks

- ❖ Start the dissection from the least involve part of the lung, usually that is the top. It is possible to appreciate, in most of the cases, a transition area between relatively normal lung and the cortex. That is a useful area to gauge the depth of the cortex and to avoid to get too deep into the lung.
- ❖ Resist the temptation to rip everything apart with fingers. The only result you will achieve for sure is to cause a lot of bleeding and damage to the lung.
- ❖ Reassess anatomy continuously. The biggest mistake is to confuse the parietal pleura for the cortex and land into the oesophagus or rip small vessels perispinally or, worse, the hemiazygos vein. If that last eventuality occurs, the best way to control the bleeding is to push a sponge stick on the bleeding point and isolate the vessel proximally and distally. Do not try to repair the vessel directly as it is likely to tear more.
- ❖ Pay attention to always be intrapleurally at the top as there is a risk of damaging the subclavian vessels.
- ❖ Small patients, especially if emaciated because of chronic infection, might have a very thin diaphragm. That could be much thinner than the cortex. Pay attention to that to avoid entering into the abdomen. The best way to prevent this is to follow the contour of the lung with the lung inflated.
- ❖ If a lung abscess is encountered, then it should be drained and the raw area potentially treated with capitonnage.
- ❖ Be careful of the oesophagus. A good trick is to insert a large nasogastric tube to guide digital exploration of the area.
- ❖ Always re-expand all lobes removing the cortex. In very rare occasions, the underlying lung is so fragile that it is impossible to remove the cortex without significant iatrogenic injury. In that case a good re-expansion can be achieved by incising the cortex with a number 11 blade in a criss-cross fashion.
- ❖ Always perform a bronchoscopy before and after surgery. Before to avoid surgery problems with lung expansion during surgery and poor oxygenation due to mucous plugs. Moreover, occasionally, empyema and pneumonia can be caused by inhaled foreign-bodies. Preoperative bronchoscopy is a great way to ensure that is not the case and to retrieve them in case. The authors removed pills, vegetables and buttons from the airways. The presence of foreign body can be suspected in case of a prevalent lobar distribution of the pneumonic process. Endobronchial cancer can also cause empyema.
- ❖ Immediately after surgery to remove any phlegm in order to give the patients the best chances of keeping the lung expanded without the need for positive pressure ventilation.
- ❖ Analgesia is essential. There is no reason not to insert a paravertebral catheter in these patients for the fear of infection.

Further reading

- Scarci M, Abah U, Solli P, *et al.* EACTS expert consensus statement for surgical management of pleural empyema. Eur J Cardiothorac Surg 2015;48:642-53.
- Andrews NC, Parker EF, Shaw RR, *et al.* Management of nontuberculous empyema: a statement of the subcommittee on surgery. Am Rev Resp Dis 1962;85:935-6.
- Light RW. A new classification of parapneumonic effusions and empyema. Chest 1995;108:299-301.
- Muers MF. Streptokinase for empyema. Lancet 1997;349:1491-2.
- Nie W, Liu Y, Ye J, *et al.* Efficacy of intrapleural instillation of fibrinolytics for treating pleural empyema and parapneumonic effusion: a meta-analysis of randomized control trials. Clin Respir J 2014;8:281-91.
- Shen KR, Bribriesco A, Crabtree T, *et al.* The American Association for Thoracic Surgery consensus guidelines for the management of empyema. J Thorac Cardiovasc Surg 2017;153:e129-e146.
- Espinosa CM, Fallat ME, Woods CR, *et al.* An Approach to the Management of Pleural Empyema with Early Video-assisted Thoracoscopic Surgery and Early Transition to Oral Antibiotic Therapy. Am Surg 2016;82:295-301.
- Bagheri R, Haghi SZ, Dalouee MN, *et al.* Effect of decortication and pleurectomy in chronic empyema patients. Asian Cardiovasc Thorac Ann 2016;24:245-9.
- Chung JH, Lee SH, Kim KT, *et al.* Optimal timing of thoracoscopic drainage and decortication for empyema. Ann Thorac Surg 2014;97:224-9.
- Kotzé A, Hinton W, Crabbe DC, *et al.* Audit of epidural analgesia in children undergoing thoracotomy for decortication of empyema. Br J Anaesth 2007;98:662-6.
- Bertolaccini L, Lybéris P, Manno E. Lung sealant and morbidity after pleural decortication: a prospective randomized, blinded study. J Cardiothorac Surg 2010;5:45.
- Zahid I, Nagendran M, Routledge T, *et al.* Comparison of video-assisted thoracoscopic surgery and open surgery in the management of primary empyema. Curr Opin Pulm Med 2011;17:255-9.
- Bongiolatti S, Voltolini L, Borgianni S, *et al.* Uniportal thoracoscopic decortication for pleural empyema and the role of ultrasonographic preoperative staging. Interact Cardiovasc Thorac Surg 2017;24:560-6.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

doi: 10.21037/shc.2017.08.08
Cite this article as: Scarci M, Raveglia F. Lung decortication for pleural empyema. Shanghai Chest 2017;1:19.

Pleurectomy/decortication for malignant pleural mesothelioma

Mariano Di Martino, David A. Waller

Barts Thorax Centre, Barts Health NHS Trust, London, UK

Correspondence to: David A. Waller. Barts Thorax Centre, Barts Health NHS Trust, London, UK. Email: david.waller1@nhs.net.

Received: 08 June 2017; Accepted: 14 June 2017; Published: 29 June 2017.
doi: 10.21037/shc.2017.06.02
View this article at: http://dx.doi.org/10.21037/shc.2017.06.02

Introduction

Malignant pleural mesothelioma (MPM) is a relatively rare malignancy arising from the mesothelial cells lining the pleural cavity with an increasing annual incidence in UK of over 2,000 cases per year. There is a clear association between occupational or environmental asbestos exposure and the development of MPM. There are two distinct histological subtypes of MPM: epithelioid (50–70%) and sarcomatoid (10–20%), with an intermediate classification of biphasic which may be epithelioid or sarcomatoid predominant. The epithelioid cell type is the most common and has a better prognosis. The standard treatment is platinum-based/pemetrexed chemotherapy and in some patient additional surgery may have a survival benefit. MPM is associated. Additional hemithorax irradiation may be used for local control. Recent reports suggested that patients undergoing surgery experienced a longer median survival compared with those without surgery (1). Concerns over the application of extrapleural pneumonectomy to an ageing population with reduced cardiorespiratory reserve and high treatment associated morbidity and mortality have led to a shift in opinion towards lung sparing surgery (2). Extended pleurectomy/decortication (EPD) is an operation intended to achieve removal of all visible tumour (macroscopic complete resection of the disease) without sacrificing the lung. It involves the resection of all parietal and visceral pleural tumours with associated resection of the diaphragm and/or pericardium if necessary (3). The IASLC Mesothelioma Domain suggested using the term "extended" rather than "radical" because of inability to eradicate residual microscopic disease. Radical term implies a completeness of resection with added therapeutic benefit and there was insufficient evidence that resection of the pericardium and diaphragm provides either (4).

Clinical setting

In order to establish the role of EPD within multimodality therapy we encourage surgery as part of the MARS2 trial: a randomised trial comparing (extended) pleurectomy decortication versus no pleurectomy decortication in the multimodality management of patients with MPM. This phase III study, which is on-going, needs to recruit over 300 patients and will report in 3–5 years. In the trial protocol all patients receive induction chemotherapy but EPD can be performed in chemonaive patients and as a salvage procedure for disease progression after first line chemotherapy.

Preoperative requirements

Operability

The patient must have sufficient cardiorespiratory reserve to tolerate the loss of the diaphragm but this may be countered by release of an entrapped lobe. In general if the patient would be considered fit enough to tolerate a lobectomy then they can proceed to EPD (5). In cases of doubt a differential lung perfusion scan may be helpful particularly where accurate assessment of pulmonary function may be difficult due to pleural effusion or entrapment.

Preoperative imaging of the chest and upper abdomen with recent staging CT-scan is indicated to establish the suitability of the patient for the surgery and planning the surgical strategy. CT-scan is important to identify the entity of invasion of the diaphragmatic muscle which occurs relatively early in the natural history of this disease (6), and to exclude invasion of major vascular structures, vertebrae or multifocal chest wall (cT4) or extra-thoracic lymph node metastases (cN2) disease (8^{th} TNM revision). PET may be performed to exclude distant metastatic disease if there are equivocal appearances on CT-

Figure 1 Lateral decubitus position, double-lumen endotracheal tube, oesophageal bougie.

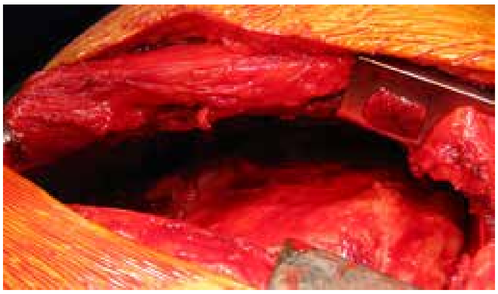


Figure 2 Extrapleural plane is progressively developed.

scan. If chest wall or neurovascular invasion is suspected, MRI may be helpful in preoperative planning, particularly in the apex of the pleural cavity.

Patients with clinical stage IV showing evidence of diffuse disease or metastatic disease should be excluded from surgery.

Operative technique

Preparation

Following placement of an epidural catheter and induction of general anaesthesia a double-lumen endotracheal tube is used to facilitate single-lung ventilation. An arterial line and central venous line are inserted for invasive pressure monitoring. A 28Fr oesophageal bougie is used to identify the oesophagus during surgery to facilitate dissection. The patient is placed in the lateral decubitus position and to help the exposure the operative table is placed in a break position or a bean bag is placed to expand the rib cage and elevate the mediastinum (*Figure 1*).

Exposure

The incision for an extended posterolateral thoracotomy starts in front of the anterior axillary line, extending down toward the costal margin over the 9^{th} rib and posteriorly beyond the tip of the scapula. The incision curves one or two finger breadths under the tip of the scapula and extends vertically on a line halfway between the posterior midline over the vertebral column and the medial edge of the scapula. The incision can be extended to widely excise all previous biopsy sites where there is potential for tumour progression. These biopsy sites are sent for histological examination since positive findings are a negative prognostic factor. Electrocautery is used for haemostasis and musculo-fascial dissection. The subcutaneous layer is divided down to the superior musculo-fascial plane. The dissection continues dividing, in the same plane, posteriorly the trapezius muscle and anteriorly the latissimus-dorsi muscle. Next, the inferior musculo-fascial plane is dissected dividing the lower portion of the rhomboid muscle and the fascia immediately posterior to the serratus muscle. The serratus muscle is spared and retracted anteriorly. The chest is entered via the 6^{th} intercostal space, but if there is suggestion of close tumour apposition to the subclavian vessels or the inferior vena cava then the chest is entered via a double level 4th and 8th intercostal space. The periosteum is elevated off the rib superiorly and inferiorly. A periosteal elevator is used to separate the ribs from the surrounding soft tissue. A rib cutter is used to divide the lower rib anteriorly to the costovertebral angle to improve exposure. A rib spreader is placed to gain the initial room to start the dissection between the endothoracic fascia and the parietal pleura. Once an area large enough for a finger is created, blunt dissection of the tumour in the extrapleural plane can be commenced by digital manipulation.

Dissection

The dissection of the extrapleural plane is progressively developed first toward the apex with a posterior and anterior direction (*Figure 2*) then inferiorly toward the diaphragmatic surface. Both blunt and sharp dissections are used with electrocautery reserved for areas of dense adhesions. As the dissection moves anteriorly, the internal mammary vessels should be freed using sharp dissection and the internal mammary lymph nodal chain with surrounding adipose tissue should be removed. As the area of dissection increases, previous areas of dissection are packed with laparotomy pads for haemostasis. As the dissection progresses toward the apex great care must be used dissecting around the subclavian vessels. Once the

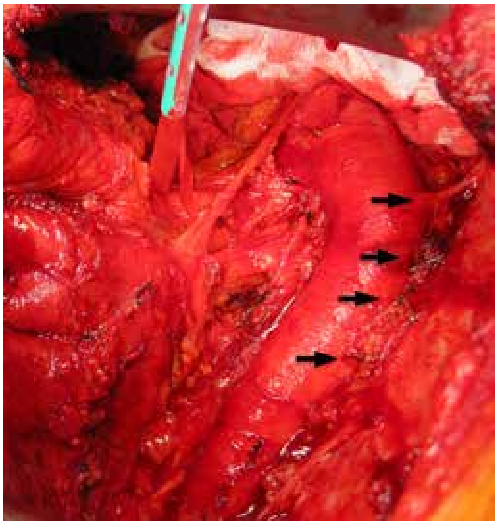


Figure 3 Intercostal arteries identified and tributary arteries ligated.

Figure 4 Once a layer has been developed, it can be incised with electrocautery, each side of the flap grasped and the visceral pleurectomy started.

superior portion of the lung is mobilised from the chest wall, intercostal arteries on both sides should be identified and tributary arteries may need to be ligated (*Figure 3*). From here blunt and sharp extrapleural plane dissection can be continued down towards the diaphragm to confirm resectability and assess diaphragmatic involvement before commencing dissection around the hilum and visceral surface.

Returning to the hilum, the dissection proceeds toward the mediastinum. On the right side: the azygos vein and superior vena cava must be approached and gently dissected with care; if the azygos vein is invaded and dissection is impossible, it may need to be divided. The right main stem bronchus is identified and exposed. The dissection of the oesophagus is begun at this level, then it is proceeded inferiorly along the oesophagus using sharp and blunt dissection; the bougie helps in palpating and identifying the oesophagus. It is important at this point is to identify and try to preserve the thoracic duct to avoid postoperative chylothorax. Then dissection continues on the posterior aspect of the pericardium where the vagus should be identified and protected and a subcarinal lymphadenectomy performed. On the left side: the dissection of the aorta starts using sharp and blunt dissection to enter the extrapleural plane over the vessel. Caution should be taken never to dissect behind the aorta. The dissection is continued medially along the aortic arch to the origin of the left subclavian and left carotid arteries, here the vagus nerve and the recurrent laryngeal branch should be identified and preserved. Then the dissection is continued distally along the descending aorta, the intercostal arteries are identified and tributary arteries may need to be ligated. Along the oesophagus superiorly to the aortic arch and inferiorly to hiatus is identified and exposed. Returning to hilum the left main bronchus is identified and exposed and subcarinal lymph node dissection is performed.

Once the parietal pleura have been freed in all areas attention is shifted toward the decortication of the lung by separating the visceral pleura from the underlying lung parenchyma. A sharp dissection is performed at the level of the visceral pleural reflection which is adherent to the tumor, on the main bronchus. The pleural reflection is undermined until a space between the visceral pleura and the lung parenchyma is created to allow digital insertion and blunt dissection. Where anatomical limitations do not allow using this approach; an alternative approach is to use a scalpel to make an incision in the tumour overlying the area of the oblique fissure down to lung parenchyma. The plane created between the visceral pleura, which is adherent to the tumour, and the lung is carefully developed with digital dissection by pushing along the rigid bronchus until a flap is raised. It is possible to mobilise a wide area of pleura from the underlying lung parenchyma working either side of the oblique fissure. Once a layer has been developed, it can be incised with electrocautery. At this point, each side of the flap is grasped (*Figure 4*) and the visceral pleurectomy continued using a gentle blunt dissection with a peanut sponge first and then with gentle digital sweeping motion of a small swab; sweeping should be exercised against the

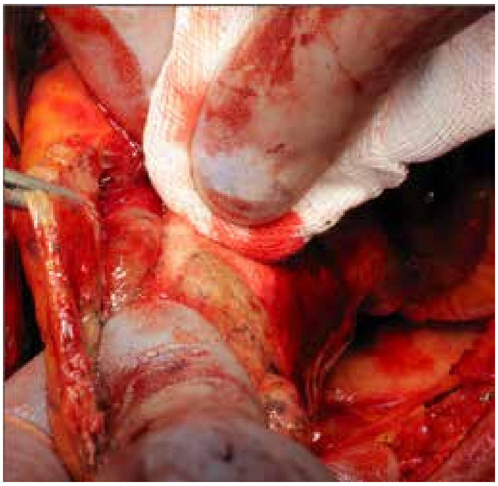


Figure 5 Digital sweeping with swab exercised against the pleural sheet.

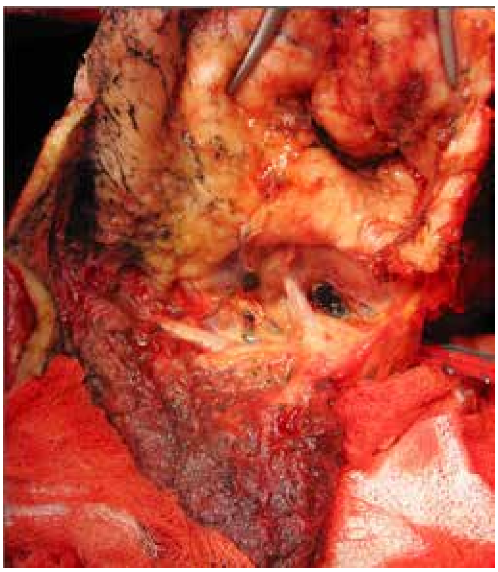


Figure 6 Clearance around the interlobar structures.

pleural sheet rather than the delicate underlying lung parenchyma (*Figure 5*). The plane of visceral dissection is continued superiorly towards the apex and across to the mediastinum then inferiorly to the interlobar fissure. It is important to achieve macroscopic tumour clearance around the interlobar structures by sharp dissection together with lymphadenectomy (*Figure 6*). Usually the upper lobe is cleared first then attention switches to the lower lobe. Visceral pleurectomy is continued down to the diaphragmatic surface. Direct parenchymal invasion by tumour may be encountered at the periphery of the lower lobe and less frequently in the upper and middle lobes. It is not necessary to perform more than a peripheral wedge resection using linear staplers. Once the lung parenchyma is completely decorticated with clear interlobar fissures and free from the hilar pleural reflection (*Figure 7*), the lung is pulled out of the tumour capsule and can be packed into the apex of the chest covered in laparotomy packs whilst attention switches to the pericardium and diaphragm.

Very infrequently and only in very early stage of disease the pleural sheet might be bluntly dissected free from the pericardium and/or from the diaphragmatic muscle tissue preserving them. More frequently there is a substantial diaphragmatic and pericardial tumour invasion. It may be possible to remove the pleural tumour sheet en bloc with the pericardium and diaphragm but it is often easier to remove them separately.

Pericardiectomy

The pericardium is resected using sharp dissection. The incision starts close to the inferior pulmonary vein and is extended down to the diaphragm and across towards the midline. The pericardiophrenic connection is maintained. Digital protection of the heart is advised during pericardiotomy.

Phrenectomy

The diaphragm is resected bluntly by avulsing off the chest wall. The diaphragmatic muscle attachments to the chest wall are manually separated with a fingertip. This is performed from medial to lateral, preserving the peritoneum if possible and a rim of tumour-free muscle (*Figure 8*). On the left it is important to preserve a bridge of crural muscle over the hiatus to reduce the postoperative risk of hiatus hernia. On the right side at the oesophageal hiatus the inferior vena cava must be identified and carefully dissected out the inferior vena cava to ensure macroscopic clear margins since the tumour often wraps around the vessel. It may be necessary to skeletonise the IVC and ligate venous tributaries. The last step in the removal of the tumour is to complete the phrenectomy with the pericardium attached from medial to lateral in the right and lateral to medial on the left.

Prosthetic reconstruction

After resection of the diaphragm, care must be taken to repair firstly the pericardium to support the heart in a sling-like fashion without causing constriction and with a gap

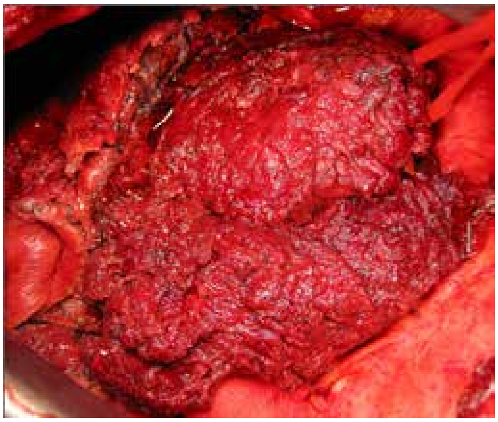


Figure 7 Lung parenchyma completely decorticated.

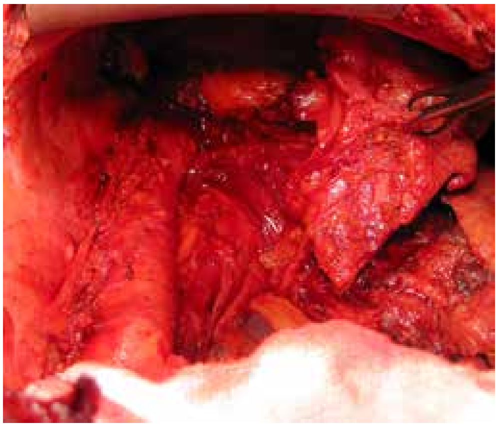


Figure 8 Diaphragm resected bluntly by avulsing off the chest wall.

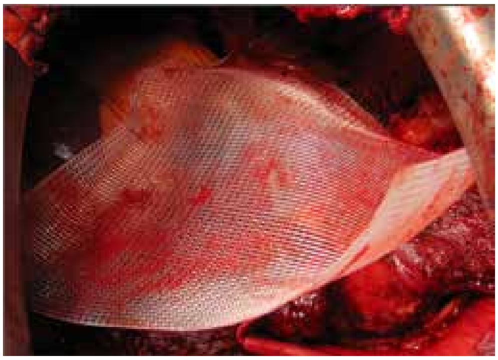


Figure 9 Interrupted sutures to stabilise the Vicryl patch.

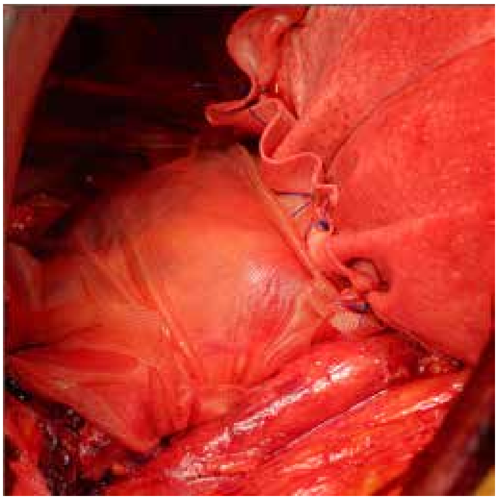


Figure 10 Diaphragm replaced with bioprosthetic patch inserted with interrupted non-absorbable sutures into the peripheral rim of diaphragmatic muscle.

under the patch to prevent the risk of cardiac tamponade. The pericardium is reconstructed using preferably an absorbable material i.e., Vicryl mesh. Five or six evenly spaced interrupted non-absorbable sutures (i.e., Prolene-0) are passed through the remaining rim of pericardium to stabilise the Vicryl patch (*Figure 9*). The inferior of these can be used to anchor the diaphragm patch also.

The diaphragm is replaced with a bioprosthetic patch (i.e., Permacol) preferentially since persistent foreign material can act as a nidus for chronic infection in the presence of pleural sepsis. The patch is inserted with interrupted non-absorbable sutures (i.e., Prolene-0) into the peripheral rim of diaphragmatic muscle (*Figure 10*). In the most early cases it may be impossible to leave a significant peripheral sewing rim anteriorly. In most cases this anterior edge of the patch is secured with pericostal sutures tied on the exterior surface. The patch must be pulled taut to maximise expansion of the residual lung and prevent paradoxical movement of the neohemidiaphragm during inspiration. When postoperative radical hemithorax radiotherapy is planned the prosthesis should be inserted as low as possible, however, this is not routine after EPD and a higher insertion of the patch can aid in controlling the postoperative air leak from the lower lobe.

Following reconstruction and prior to closure it is imperative to perform a systematic lymph node dissection not only of the mediastinal but also the mammary, pericardial and diaphragmatic nodes. Enlarged intercostal nodes should also be removed.

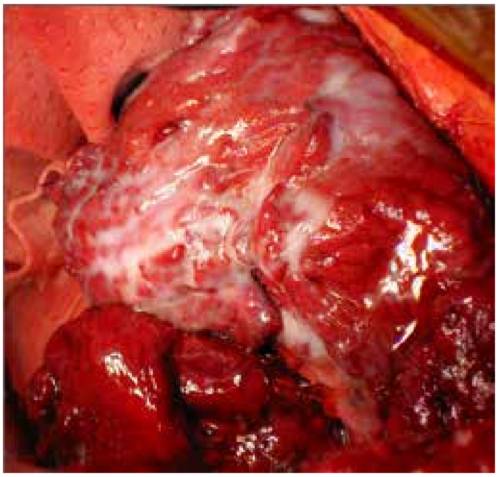


Figure 11 Lung parenchyma sprayed with aerostatic agent.

Figure 12 Oesophageal perforation detected on CT-chest by oral contrast leakage.

Completion

Attention is now turned to obtaining haemostasis performed with electrocautery and surgical metal clips. In consideration of a large postoperative air leak from the denuded lung parenchyma it is imperative to adequately drain the cavity with three large bore drains which we usually place on low suction. Three 32-French chest tubes are inserted: one anterior-apical, one posterior-apical, and one angled basal. The angled tube is generally placed through the most posterior incision. At the end of procedure we perform lavage of the chest cavity with a solution of hyperthermic (40–42°) saline with 10% of Povidone. The iodine lavage prior to closure has been proposed as a useful adjunct that may have anti-tumour properties and may help to sterilise the cavity. The use of a parietal pleural haemostat is also advised. Similarly, the use of a visceral pleural aerostatic agent can reduce the inevitable postoperative air leak (*Figure 11*). There are many alternatives but an aerosolized administration reduces operative time.

Potential postoperative complications/management

Chylothorax–

The areas where the thoracic duct is at risk of iatrogenic damage are just above the aortic arch on the left and low down in the mediastinum on the right. The damage may not be apparent at the operation and may not manifest itself for several days.

The chylous leak can be managed conservatively by restricting oral intake and parenteral nutrition but this rarely succeeds. Early video assisted thoracoscopic clipping of the damaged duct is recommended and location of the leak is facilitated by oral administration of a high fat meal of 20 mL of cream 30 min prior to surgery. The leakage of chylous fluid is dramatically increased and easily visualised.

Oesophageal perforation–

A rare but important complication is a delayed oesophageal perforation. This may be more common in more advanced tumours particularly if the serosal layer of the organ is disrupted in dissection of the pleural sheet. Warning signs include sudden onset chest pain, tachyarrhythmia and subcutaneous emphysema. When detected within 24 hours operative repair is advised using buttressing with an intercostal muscle flap (*Figure 12*).

Diaphragmatic patch dehiscence–

This rare occurrence should be suspected by an abnormal chest radiograph showing elevation of the diaphragmatic patch and in particular a change from the immediate postoperative image. It may be suspected by the finding of an acute tachyarrhythmia in the immediate postoperative period.

Nasogastric suction (every 4 hour) is imperative in the first 24 hr after surgery to prevent acute gastric dilatation which may lead to patch disruption.

Persistent air leak—leading to pleural sepsis

The necessity to remove all the visceral inevitably leads to a prolonged postoperative air leak. There is no possibility to prevent this complication but the use of tissue glues on the raw lung surface can reduce the leak. On the peripheries of the lung the tumour is often invasive and stapled resection is preferred to attempting to preserve every last piece of lung as it will reduce air leak.

We prefer to leave the patient on prophylactic antibiotics for as long as the drains are *in situ* as the risk of pleural sepsis is increased by the presence of foreign material in the cavity.

The use of a biological prosthesis which is incorporated into the body's own tissues may reduce the risk of infection seeding the patch and prolonging the sepsis and eventually requiring patch removal.

Tips

(I) Wear two pairs of gloves. Identify tissue planes by manual dissection, open planes by electrocautery onto double-gloved fingers;

(II) To reduce blood loss from the parenchymal surface during visceral pleurectomy it is advisable to isolate the main pulmonary artery and temporarily clamp the vessel to reduce pulmonary blood flow, if tolerated;

(III) In the case of bulkier tumours visceral pleurectomy is more straightforward but the parietal pleurectomy can be more challenging due to chest wall invasion;

(IV) There may be the temptation to leave the pericardium widely open and avoid reconstruction. Unfortunately the preservation of the adjacent lung does not guard against cardiac dislocation and sudden loss of cardiac output.

doi: 10.21037/shc.2017.06.02

Cite this article as: Di Martino M, Waller DA. Pleurectomy/decortication for malignant pleural mesothelioma. Shanghai Chest 2017;1:13.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Wolf AS, Flores RM. Current Treatment of Mesothelioma: Extrapleural Pneumonectomy Versus Pleurectomy/Decortication. Thorac Surg Clin 2016;26:359-75.
2. Hasegawa S. Extrapleural pneumonectomy or pleurectomy/decortication for malignant pleural mesothelioma. Gen Thorac Cardiovasc Surg 2014;62:516-21.
3. Sharkey AJ, Tenconi S, Nakas A, et al. The effects of an intentional transition from extrapleural pneumonectomy to extended pleurectomy/decortication. Eur J Cardiothorac Surg 2016;49:1632-41.
4. Rice D. Standardizing surgical treatment in malignant pleural mesothelioma. Ann Cardiothorac Surg 2012;1:497-501.
5. Rusch VW. Pleurectomy and Decortication: How I Teach It. Ann Thorac Surg 2017;103:1374-7.
6. Sharkey AJ, Bilancia R, Tenconi S, et al. The management of the diaphragm during radical surgery for malignant pleural mesothelioma. Eur J Cardiothorac Surg 2016;50:311-6.

Extrapleural pneumonectomy

Domenico Galetta[1], Lorenzo Spaggiari[1,2]

[1]Division of Thoracic Surgery, European Institute of Oncology, Milan, Italy; [2]Department of Oncology and Hematology-Oncology-DIPO, University of Milan, Milan, Italy

Correspondence to: Domenico Galetta, MD, PhD. Division of Thoracic Surgery, European Institute of Oncology, Via Ripamonti 435, Milan, Italy. Email: domenico.galetta@ieo.it.

Received: 11 August 2017; Accepted: 29 August 2017; Published: 06 September 2017.
doi: 10.21037/shc.2017.08.13
View this article at: http://dx.doi.org/10.21037/shc.2017.08.13

Introduction

Malignant pleural mesothelioma (MPM) is the major cause of death in patients exposed to asbestos. If not treated, survival of patients with MPM is dismal (1). Surgery or chemotherapy or radiotherapy alone are not effective. Although there is no defined standard treatment for MPM patients, most studies in the literature support the use of curative intent surgery in the setting of combined therapy (1-6).

Prognostic factors associated with longer survival are epithelial histology, female gender, and earlier stage. Women experienced longer survival compared with man, but this finding has been more consistent for younger women and those with epithelial tumors.

Surgery represents the main modality in treating MPM. Two operations have been developed in this context: extrapleural pneumonectomy (EPP), and radical or extended pleurectomy/decortication (P/D). The former, consists in the *en bloc* resection of the lung, parietal and visceral pleurae, diaphragm, and pericardium. P/D include the resection of both the parietal and visceral pleurae, with diaphragmatic and/or pericardial removal in case of their direct neoplastic invasion; in this case, the lung is preserved.

Since Butchart (7) reported the first report of EPP for MPM in seventies, the rate of perioperative mortality due to this operation dropped from 31% to 3.4%. Butchart emphasized that this technique may be indicated for certain types of tumors and, thus, adequate preoperative cardiopulmonary evaluation and careful preoperative management of patients were mandate.

A detailed preoperative evaluation is necessary in order to determine whether complete resection is feasible and whether the patients has sufficient physiological reserve to tolerate this very invasive procedure.

The extend of the spread of MPM is assessed initially by imaging studies. Computed tomography (CT) of the chest and upper abdomen is the primary investigation in assessing the extent of the tumor. It can identify signs of MPM spread, which are indicative of unresectable disease as chest wall invasion, the involvement of the full thickness of the diaphragm, the presence of metastatic spread in the peritoneum o in the contralateral lung or pleura.

PET CT (*Figure 1*) is also routinely used for evaluating nodal and distant metastases. The level of PET avidity of the mesothelioma has been shown to correlate with survival, with great avidity associated with lesser survival. Enlarged and/or PET-positive mediastinal nodes are evaluated with endobronchial ultrasonography (EBUS) and/or, in some centers, by cervical mediastinoscopy.

Chest MRI is sometimes performed to study more precisely invasion of the tumor o the chest wall or diaphragm. In case of transdiaphragmatic extension of tumor and/or ascites should be evaluated with staging laparoscopy because intrabdominal invasion would preclude surgical resection.

Preoperative evaluation of the cardiopulmonary reserve is of the utmost importance in patients for whom EPP is being considered. Respiratory evaluation includes spirometry, diffusion capacity, and quantitative ventilation/perfusion scan. Cardiac tests (stress test and an echocardiogram with Doppler estimation of pulmonary artery pressure) should also be performed to evaluate cardiac function. The presence of pulmonary hypertension is a contraindication to perform EPP.

Operative technique

Preparation and perioperative management

Preparation includes placement of (I) arterial line for

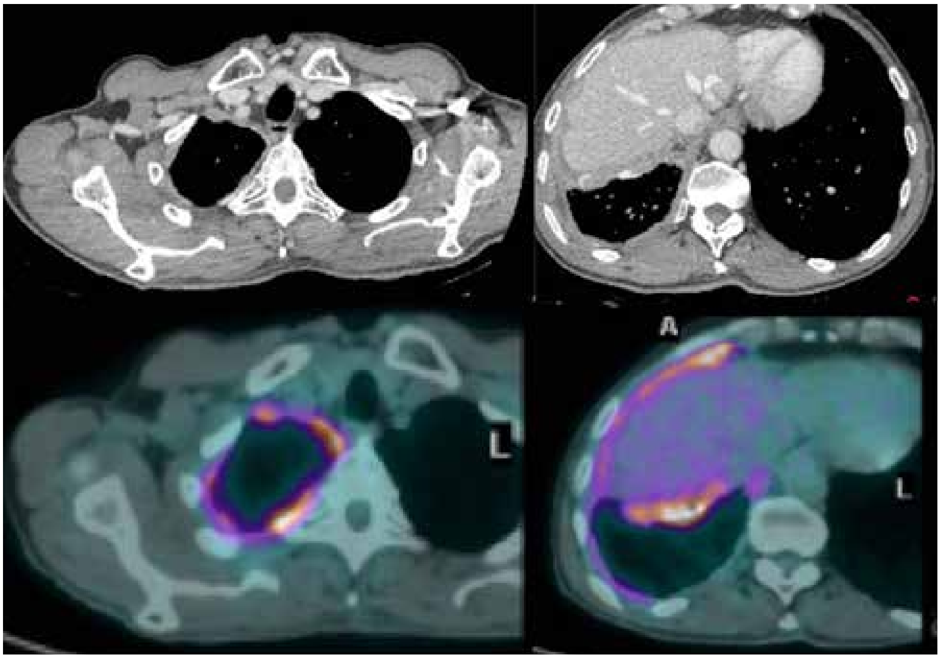


Figure 1 PET and CT scans showing a right MPM with thickness of the parietal pleura in the apex of the thorax and at diaphragmatic level.

monitoring arterial pressure which may rapidly change during the procedure; (II) venous line (central one) for rapid infusion of fluids; (III) epidural catheter for postoperative pain control.

Intubated is performed with a double-lumen to assure one-lung ventilation. A naso-gastric tube is inserted to allow the intraoperatively identification of the esophagus and to decompress the stomach perioperatively avoiding life-treating aspiration.

Exposition

The patient is placed in the lateral position and the operative sterile field should include the hemithorax having as limits the axilla, the neck, the sternum and posteriorly the spine. During operation, the table will change its position according to the different phases of the operation.

During operation, the surgeon is placed to the patient's back and the first assistant on the other side of table. The surgical procedures are performed via a double muscle sparing lateral thoracotomy. Skin incisions are made in the 4th and in the 7th intercostal space, respectively (*Figure 2*). Prior incisions are removed.

Operation

The first step of the intervention after skin incision in the 4th intercostal space is the incision of intercostal muscles exposing the parietal pleura. Identification of the parietal pleural is crucial at this stage. Whilst elevating intercostal muscle with forceps, the extrapleural plane is developed, initially with scissors or a dissector, and next with blunt finger dissection (*Figure 3*).

A big and a smaller finocchietto retractors are placed to effectively keep the wound open, tether the scapula, and to ensure a wide exposure of the pleural cavity. Rib spreading with retractors must be extended gradually as the dissection of the parietal pleura proceeds to avoid excessive strain that could cause a tear in the pleura and the lung. Dissection of the parietal pleura from the endothoracic fascia is conducted anteriorly, posteriorly, superiorly, and inferiorly. The limits of dissection are, posteriorly, the azygous vein on the right and the aorta on the left in order to prevent dramatic venous and/or arterial lesions.

Dissection proceeds over the cupola of the pleura (*Figure 4*) near subclavian vessels. In this area, it is important to try to identify the phrenic nerve and the internal mammary vessels which should be clipped or ligated. Once apical dissection is completed, sponge gauzes are used to pack this space. Pleural dissection proceeds in the posterior mediastinum avoiding esophageal damage. At this step, the esophagus is easily identified by palpating the nasogastric tube previously positioned. Moreover, during this step, the assistant retracts

Figure 2 Patient' position and surgical skin incisions (black lines). Prior thoracoscopic incision, included between the two thoracotomic ones, is removed.

Figure 3 Blunt extrapleural dissection by fingers.

Figure 4 Dissection is continued in the apex by using a double sponge gauze for gentle dissection of the anatomic structures of the apex of the chest.

anteriorly the pleural sac allowing the surgeon to dissect the parietal pleura from the esophagus.

As the dissection is continued down the superior mediastinum, the superior vena cava on the right (*Figure 5*) and the aortic arch on the left are at risk (*Figure 6*). During this step, it is important to pay attention to the anterior

Figure 5 Dissection of the upper portion of the right chest is completed. The superior vena cava and the azygous vein have been dissected. The right phrenic nerve has been spared.

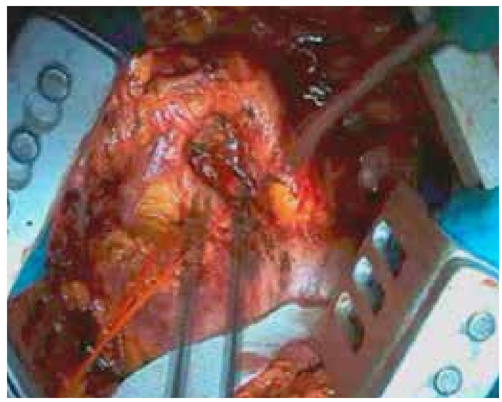


Figure 6 Aortic arch and descending aorta is dissected.

mediastinum and pericardium (*Figure 7*). The parietal pleura and lung are moved posteriorly and the pericardium is opened in the anterior portion to check the presence of intrapericardial infiltration. The absence of involvement of mediastinal structures, allows to continue with the pericardial incision towards the inferior portion of the diaphragm.

At this point, a second thoracotomy is performed at the seventh intercostal space. Once the intercostal muscles are incised and the inferior parietal pleural is identified, the dissection of the parietal pleural proceeds superiorly to encounter the previous dissected pleura. Then the dissection continues posteriorly, anteriorly and inferiorly toward the diaphragm. Here, the diaphragm is bluntly dissected from the chest wall with the fingers. During these maneuvers, caution should be used on both sides: on the right, for the inferior vena cava; on the left, a small portion of the diaphragm is retained to reduce the risk of abdominal organs herniation. Dissection is usually easier at the

Figure 7 The mediastinum is anteriorly gently dissected by sponge gauzes.

Figure 8 The diaphragm is dissected posteriorly, anteriorly and laterally.

muscular part of the diaphragm and more difficult in the central tendon area (*Figure 8*). Generally, this stage of the operation is tedious and time-consuming, and needs a lot of patience. During the dissection, the peritoneum is entered identification the main veins originating from the lever. It is not necessary to close the peritoneum. The pericardial incision is continued to complete the pericardial resection.

Hilar structures are then approached through incision in the 4th intercostal space. Superior and inferior pulmonary veins are isolated and resected intrapericardially by endostaplers (30 mm, white reload). Right pulmonary artery is isolated and resected intrapericardially, while, on the left, pulmonary artery is generally divided extrapericardially due to the short intrapericardial arterial segment by endostaplers (45 mm, white reloads).

The mainstem bronchus is dissected and resected near the carina with a bronchial stapler. The specimen, consisting of the lung within the parietal pleural envelope, hemidiaphragm, and part of the pericardium is removed en bloc from the chest (*Figure 9*).

Lymphadenectomy of the mediastinal stations is routinely performed.

The bronchial stump can be buttressed with a vital pedunculated flap (thymic tissue or omentum). Accurate haemostasis of the entire chest wall is then performed by means of argon beam coagulation. On the left side, due to the high risk of chylothorax, a massive ligation of the tissue near the phreno-pericardial angle, next to the esophagus should be performed.

Diaphragm and pericardium are reconstructed with different types of heterologous patches [Gore-tex, polytetrafluoroethylene (PTFE), Marlex, Vicryl, and bovine pericardium]. After the initial use of a Marlex/Gore-tex mash for diaphragmatic reconstruction, and Gore-tex for pericardial reconstruction, the material actually used by the authors for reconstruction of both diaphragm and pericardium is bovine pericardium patches.

The diaphragm is reconstructed with 1 or 2 20×10 cm patches sutured in the inner portion of the chest wall with separated non-absorbable stitches (1 Polypropylene) (*Figure 10*) which fix the patch to the chest wall (to the tenth rib posteriorly and at the eighth or ninth rib anteriorly and laterally).

Next, the pericardium is reconstructed using a single bovine pericardium patch (*Figure 11*) which is fenestrated to avoid cardiac impairment due to effusion and tamponade. The patch is sutured to cut edge of the pericardium circumferentially using separated non-absorbable stitches (3-0 Polypropylene).

Haemostasis should be checked carefully and all sites of oozing controlled with cautery and argon beam coagulation.

After extrapleural dissection a greater fluid production together with an increased risk of bleeding or chylothorax may occur. Usually the endothoracic cavity may fill rapidly and may produce a more mobile mediastinum. Thus, a chest tube without suction with balanced drainage is necessary. We usually place one 32Ch single tube into the chest connected to a balanced reservoir.

The two thoracotomies are closed n the standard manner. Particular attention is paid to obtaining a watertight intercostal closure to avoid leakage of fluid through the chest wall and pleural cavity infection.

Postoperative management

EPP should be performed in high specialized and high

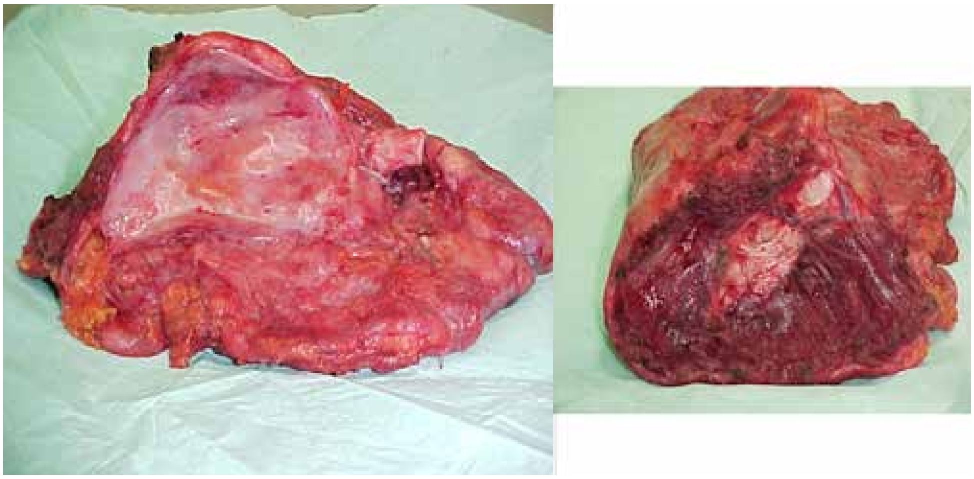


Figure 9 The specimen including the lung en bloc with the parietal pleura, diaphragm and pericardium is removed from the thorax.

Figure 10 The diaphragm is reconstructed by means of pericardial patch.

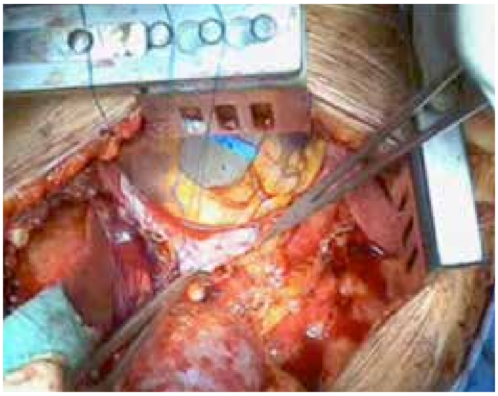


Figure 11 The pericardium is reconstructed by a single pericardial patch.

volume centers in which all the surgical team including anaesthetists, nurses, and critical care team are experienced in managing of these surgical patients.

The patient should be rapidly extubated to reduce the risk of damage on the bronchial stump with positive pressure and strictly monitored postoperatively in the ICU.

Postoperative management includes management of fluid status, physiotherapy, and early mobilization. Antithrombotic prophylaxis with low-molecular weight heparin is routinely administered.

Some complications may occur after EPP and these are usually related to injuries to anatomic structures during intervention: lesion of the recurrent laryngeal nerve may cause vocal cord paralysis and poor cough and/or aspiration. Damages of the sympathetic nerves may occur after extrapleural dissection; this may cause postoperatively mild but refractory vasoplegia. This effect usually responds to oral vasoconstrictors that can be reduced in the postoperative period. In this case, administration of excessive fluids to regulate this benign source of hypotension should be limited to avoid other consequent pulmonary and cardiac complications (atrial fibrillation, pulmonary edema) in these patients with only one lung remaining.

Rare complications after EPP include cardiac or gastric herniation, myocardial infarction, chylothorax, and pulmonary embolus. The most feared complication of this surgery is the bronchopleural fistula that may occurs weeks to months after initial intervention. It should be rapidly evaluated and treated to avoid fatal consequences.

Comments

Cytoreductive surgery is the cornerstone of the multimodality approach to treating patients with MPM. Maximal cytoreduction is critical to extend long-term survival. EPP can achieve this result in most cases of tumor confined to the ipsilateral chest.

In the Italian Multicentric retrospective study (5) on 518 EPPs for MPM, major morbidity was 26% and 90-days mortality rate was 6.9%. The median overall survival was 18 months with a 1-, 2- and 3-year overall survival of 65%, 41%, and 27%, respectively. This study confirmed that female gender with epithelial tumor who received induction therapy had the best prognosis after EPP.

The physiological stresses following EPP are numerous and appropriate patient selection facilitated by through preoperative testing is mandatory. Likewise, the diagnosis of postoperative complications must be pursued vigilantly to facilitate rapid treatment. Many of these complications can be prevented with careful attention to detail in managing the physiologic consequences of EPP.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

doi: 10.21037/shc.2017.08.13
Cite this article as: Galetta D, Spaggiari L. Extrapleural pneumonectomy. Shanghai Chest 2017;1:32.

References

1. Sugarbaker DJ, Wolf AS. Surgery for malignant pleural mesothelioma. Expert Rev Respir Med 2010:4:363-72.
2. Wolf AS, Richards WG Tilleman TR, et al. Characteristics of malignant pleural mesothelioma in women. Ann Thorac Surg 2010;90:949-56
3. Weder W, Kestenholz P, Taverna C, et al. Neoadjuvant chemotherapy followed by extrapleural pneumonectomy in malignant pleural mesothelioma. J Clin Oncol 2004;22:3451-7.
4. Flores RM, Krug LM, Rosenzweig KE, et al. Induction chemotherapy, extrapleural pneumonectomy, and postoperative high-dose radiotherapy for locally advanced malignant pleural mesothelioma: a phase II trial. J Thorac Oncol 2006:1;289-95.
5. Spaggiari L, Marulli G, Bovolato P, et al. Extrapleural pneumonectomy for malignant mesothelioma: an Italian multicentric retrospective study. Ann Thorac Surg 2014;97:1859-65.
6. Casiraghi M, Maisonneuve P, Brambilla D, et al. Induction chemotherapy, extrapleural pneumonectomy, and adjuvant radiotherapy for malignant pleural mesothelioma. Eur J Cardiothorac Surg 2017. [Epub ahead of print].
7. Butchart EG, Ashcroft T, Barnsley WC, et al. Pleuropneumonectomy in the management of diffuse malignant mesothelioma of the pleura. Experience with 29 patients. Thorax 1976;31:15-24.

A guide to open surgical tracheostomy

Kenneth Muscat, Andrea Bille, Ricard Simo

Head and Neck and Thoracic Surgery Units, Guy's and St Thomas' NHS Foundation Trust, London, UK

Correspondence to: Kenneth Muscat. Head and Neck and Thoracic Surgery Units, Guy's and St Thomas' NHS Foundation Trust, London, UK. Email: kenncat@gmail.com.

Received: 22 March 2017; Accepted: 07 April 2017; Published: 30 May 2017.
doi: 10.21037/shc.2017.05.05
View this article at: http://dx.doi.org/10.21037/shc.2017.05.05

Introduction

Tracheostomy is recognised to be one of the oldest surgical procedures and references to the creation of a surgical airway in the neck can be dated back to 3600BC with pictures being depicted on Egyptian artisanry. Chevalier Jackson established the principals of the tracheostomy operation in the beginning of the twentieth century and these have grossly remained unchanged till present date (1). The term tracheostomy refers to the creation of a stoma at the skin surface leading to the trachea whereas a tracheotomy refers to the proper surgical opening in the trachea. A surgical tracheostomy can be performed under local or general anaesthesia, the scenario can be either elective or emergency setting and it can be either temporary or permanent in nature. There are multiple indications for such procedure. Upper airway obstruction can be caused by a multitude of processes including neurological, neoplastic, infective or inflammatory causes. A tracheostomy can be used to bypass the level of obstruction. In cases of prolonged mechanical ventilation, a tracheostomy replaces the endotracheal intubation to wean off anaesthetised patients, decrease the rate of subglottic stenosis, decrease the dead space and work of breathing and providing better control on secretions of the lower respiratory tract (2). A tracheostomy may also be performed as part of another surgical procedure, mostly for airway protection. An 'end' tracheostomy may be formed in associations with certain procedures such as a laryngectomy. Other variants of the classical surgical tracheostomy are the minitracheostomy insertion through the cricothyroid membrane and the percutaneous tracheostomy technique where the trachea is punctured from the anterior neck and the tract is serially dilated until the insertion of a standard tracheostomy tube is enabled (1,2). The latter may or may not be performed under direct vision using flexible endoscopy. A combination of such techniques may also be useful in certain selected cases.

In the elective setting, it is essential to obtain adequate consent prior to performing a tracheostomy. It is important for the patient to understand the rationale behind the decision and to understand that postoperatively there will be a variable period of communication difficulty due to lack of vocalisation. The patient should also be informed about the various complications that may arise and that a tracheostomy could end up being a permanent solution. It is imperative for the surgeon to check the relevant preoperative investigations with special reference to coagulation studies. One should consider positioning issues in the planning phase. Making sure the patient does not have an unstable cervical spine is a must as this would preclude neck extension. Children should not be hyperextended due to the higher risk of damage to the thoracic inlet vessels. A good practice in the intensive care setting is to check the endotracheal tube positioning on the latest chest X-ray. In case the patient presents with difficult anatomy such as tracheal deviation due to neck masses or a suspicion of abnormal major vessel passage or ectasia in the neck arises, the surgeon should ask for additional radiological investigations and decide regarding where is the optimum location to perform the procedure. Preoperatively, the surgeon should have familiarised himself with the selection of tracheostomy tubes available and decided which one to use according to the indication. A tube of a size above and a size below the one chosen should be readily available. Occasionally special tubes with extra length or reinforcement may be needed and a tracheostomy procedure should not be started until these are available.

Figure 1 The neck is placed in extended position. The skin is prepared with antiseptic solution and appropriate surgical drapes are placed maintaining sterility. The thyroid notch, the lower border of the cricoid cartilage and the suprasternal notch are marked. The tracheostomy incision is marked as a transverse line placed halfway between the lower border of cricoid cartilage and suprasternal notch. Infiltration with local anaesthetic mixed with adrenaline solution can be applied after these landmarks are noted.

Operative technique

Preparation and exposition

The procedure should, whenever possible, be carried out in an operating theatre with adequate lighting and stocked with a large selection of tracheostomy tubes. The patient should be placed in supine position. The neck is to be fully extended by placing a shoulder roll underneath the upper back area and the head is stabilised on a head ring. The shoulders should be at symmetrical level so the midline neck structures are not skewed to one side. Local antiseptic solution is applied and sterile conditions should be maintained throughout the procedure. Intravenous antibiotics are given according to hospital protocols. Key landmarks are marked on the skin and the incision site is placed halfway between the lower border of the cricoid and the suprasternal notch. This is then infiltrated with 5 to 10 mL of 0.25% bupivacaine solution mixed with 1:200,000 adrenaline. The chosen tracheostomy tube should be available on the operating trolley and checked by one of the surgical team for any cuff leaks (*Figure 1*).

Operation

This description applies to adults having a tracheostomy under general anaesthesia. A transverse incision through skin is made half way between the inferior border of the cricoid cartilage and the sternal notch. The size is usually 3 cm but may be extended as necessary if adverse anatomical conditions are encountered. Once skin has been incised, dissection continues through subcutaneous fat. Thinned platysma fibers and the superficial investing layer of deep cervical fascia are entered and strap muscles are identified. A self-retaining retractor will be helpful at this point. Blunt dissection in the midline through the linea alba is carried out and the strap muscles are retracted laterally using Langenbeck retractors. The thyroid isthmus comes into view and this can have a variable position and size. It is skeletonised and can be divided either using clamps and transfixion sutures or using monopolar or bipolar diathermy. The anterior tracheal wall is identified and cleaned. It is useful to identify the cricoid cartilage so to be able to assess the entry point for the tracheotomy. Larger retractors are used to clear the tissues laterally so to ensure adequate exposure. The tracheotomy is usually carried out in the 3rd or 4th tracheal rings and the area is marked with bipolar diathermy. Tracheostomy tube check is reconfirmed and sterile connecting equipment should be available. The anaesthetist is alerted and a square tracheal window is created, being as conservative as possible. Careful incision of the membranous tissue between the rings is carried out with the aim not to rupture the endotracheal tube cuff. Generous suction of any secretions is ensured. A blunt cricoid hook is inserted at the top of the tracheotomy and gentle superior retraction is applied. The anaesthetist should be instructed to withdraw the tube under the direction of the surgeon. When the tip is immediately above the tracheotomy, the withdrawal is stopped and the tracheostomy tube is inserted from one of the sides and gently rotated in place. The tracheostomy cuff is then inflated and the position is checked by confirming bilateral chest expansion and carbon dioxide trace uptake on the anaesthetic machine. Only then the cricoid hook is removed from the tracheotomy. The incision is closed loosely and the tracheostomy tube is secured in position with sutures and ties or Velcro tapes. Tracheostomy dressing is finally applied (*Figures 2-12*).

Completion

One of the first things to check for, in the immediate postoperative period, is the presence of bleeding for the tracheostomy site. The tracheostomy site is also checked for audible air leak, in which case further air is inflated in the tracheostomy cuff. The neck is palpated for surgical emphysema to check if the skin sutures have been placed

Figure 2 Incision through skin and dissection through subcutaneous tissues performed. Strap muscles identified and divided vertically in the midline. Care is taken not to damage the anterior jugular veins that usually lie slightly more lateral on either side of the midline.

Figure 4 Thyroid isthmus divided in the midline using bipolar diathermy after being dissected off the trachea using as surgical clip. Care is taken to do meticulous haemostasis as the isthmus is a very vascular structure that can ooze profusely. This step is usually necessary to improve visualisation of the trachea.

Figure 3 Identification of the thyroid isthmus is carried out. One should identify any large vessels, especially thyroid veins that are usually placed at the inferior border of the isthmus. Haemostasis and dissection of isthmus are achieved with bipolar diathermy.

Figure 5 Exposure of the trachea by blunt dissection. Deeper retractors are placed for adequate visualisation on each side.

too tight around the tracheostomy tube. On the other-hand, if too loose, there may be fluid leaks and subsequent infections. A chest X-ray should be ordered to exclude any lung complications such as pneumothorax. The patient is usually nursed in a reverse trendelenburg position and it is ensured that the tracheostomy tube is not pulled laterally by the ventilator tubing system. The various components of the tracheostomy tube kit that are not being used by the patient, such as insertion trocars and spare inner tubes, should be sealed in a bag and given during a proper handover to the nursing staff taking care of the patient. These nurses should be experienced in the care of tracheostomy patients and knowledgeable about the potential complications (3). It is ensured that appropriate humidification and nebulisers are given and regular suctioning is administered. Instructions to deflate the cuff should be given only once the risk of aspiration passes.

Comments

Although there are many variations in performing a classical open surgical tracheostomy, these are all based on a standard technique composed of few fundamental steps. It is a safe procedure in experienced hands or where there is adequate supervision. It can also be associated with significant morbidity and mortality if not performed in a

Figure 6. Tracheotomy window created at the level of the 3rd and 4th tracheal rings. The incision area is marked first with bipolar after confirming the position of the cricoid cartilage and counting of the tracheal rings. The width of the tracheotomy window should never exceed a third of the diameter of the trachea and generally one should be as conservative as possible. If a window is created, a maximum of 2 tracheal rings are partially excised. This step is done with sharp dissection using a blade 15 knife. Care is taken not to damage the underlying endotracheal tube. The anaesthetist is warned before starting this stage to monitor for any air leak and to start preparing for the eventual tube change.

Figure 7 Tracheotomy window performed and meticulous haemostasis ensured using bipolar diathermy. The endotracheal tube is seen through the window. A member of the anaesthetic team should be controlling the endotracheal tube from the top end.

logical systematic way, especially when patients present with abnormal features.

Tips and tricks

A large neck always presents a challenging case for

Figure 8 Checking of the tracheostomy tube. The correct size is confirmed and the cuff is inflated and checked for any leaks. The plastic trocar is inserted inside the tube. At this stage, it is also ensured that all necessary connecting equipment is present and a good level of communication is present between the surgeon and the anaesthetist.

Figure 9 Insertion of the tracheostomy tube. The tracheotomy window is secured and controlled either with tracheal dilators or with a blunt cricoid hook. The tip of the tube and trocar is lubricated with a water based gel and the tube is inserted gently from a lateral position and twisted in.

tracheostomy insertion. One should maximise the exposure by doing a generous incision. An extra assistant is usually very useful to help in retraction. It is obligatory to have adequate lighting. One should not rush and all the necessary time is taken to identify anatomy systematically. Subcutaneous and peri-thyroid fat can be removed if necessary. Adequate tracheostomy tubes should be available, preferably those with an adjustable flange. In the postoperative period, it would be worthwhile to do the first tube change over a guide-wire as in a deep neck the formation of the tracheostomy tract is delayed

Figure 10 The final correct position of the tracheostomy tube is attained. The cuff is inflated with air and an inner tube is inserted if needed. A sterile connector is used to connect the tracheostomy tube with the anaesthetic machine.

Figure 11 Skin incision is closed loosely if necessary. The tracheostomy tube is secured in position with sutures and the connector is ensured to be in a neutral position and not pulling on the tracheostomy tube.

and there is the higher risk of false passage formation.

Incisions can be wrongly placed, either too high or too low. This can make it difficult to identify the key anatomical structures and make proper placement of the tracheotomy window challenging. The thyroid isthmus should always be dealt with and ensured that there is no bleeding afterwards. When the isthmus is large, one should perform an isthmusectomy and send this excised part for histological analysis. Otherwise one can consider suturing the divided isthmus to the strap muscles so it does not fall in the way and does not occlude the tracheotomy window.

The tracheotomy can be performed in a number of ways, including horizontal incisions, vertical incisions, various shapes of window excisions and the usage of a Bjork flap. If it is done too high there is a significant risk of subglottic stenosis formation; if done too low it will make tube change very challenging. The same happens if the window is made too small, whereas if made too large there can be a significant leak and a higher risk of tube dislodgement. Roughened edges of the tracheotomy have a higher tendency for persistent bleeding. The Bjork flap technique is a double-edged sword as it can make tube change more easy but is technically more difficult and may cause airway obstruction if incorrectly performed and difficult closure of the tracheostomy if the patient is decannulated (1). Whatever technique is used, one has to perform this step in a systematic manner to ensure the best outcome for the patient.

The tracheostomy tube choice should to be correct on the first attempt. In the stage of forming a new fresh tracheostomy, the tube has to be cuffed to protect the patient's airway and provide a seal for ventilation. We prefer to use double lumen tubes as they are easier to take care of on the wards and pose less problems with blockage. If the patient is going to restart using his voice in the postoperative period, it would be worthwhile to insert a fenestrated tube and use a non-fenestrated inner tube until necessary. The right insertion technique is of paramount importance as one can easily create a false passage and end up with airway obstruction either during the procedure or worse later on in the postoperative period. Whatever tube is used, this must be secured in multiple ways so to prevent dislodgement or false tract formation (3).

Caveats

Intraoperative complications may result when the surgeon deviates from working in the midline. This can result in damage to the contents of the carotid sheath, perforation of the oesophagus and damage to the recurrent laryngeal nerves. The safest way to avoid these complications is to identify key anatomical structures in a stepwise manner, have adequate exposure and haemostasis. The position of the cricoid and other key structures should be checked frequently by digital manipulation. If the cricoid cartilage is inadvertently damaged, the tracheotomy should be sited lower and the damage repaired. The most common source of bleeding is the thyroid isthmus and the inferior thyroid veins. There should be a low threshold for re-exploration of the tracheostomy wound if bleeding persists (4). Air embolism resulting from open large inferior thyroid veins is extremely rare and should be prevented by adequate

Figure 12 Encountering thyroid isthmus problems. On the left one can see an enlarged thyroid isthmus that could create problems with visualisation of the trachea and appropriate placement of the tracheotomy window. In this case, an isthmusectomy is being performed, so removing the whole thyroid isthmus out of the operative field. On the right one can observe floppy prominent thyroid isthmus tissue being sutured with absorbable sutures laterally so it does not fall on top of the trachea or tracheotomy window.

ligation of such vessels. Superior mediastinal vessels may be pulled above the suprasternal notch whereas pleurae may be in a higher position in patients with emphysema and other chronic obstructive lung pathology. Careful dissection prevents such injuries.

An early postoperative complication may be accidental extubation (3). If there is a suspicion one should confirm the tube position by passing a flexible endoscope down the tube. If it is displaced one should replace the tube or change it to a longer one, preferably in a safe environment with adequate instrumentation. Tube blockage by crusting or dried blood may occur and should be prevented by regular suctioning. Local infection may be prevented by meticulous surgical technique and proper placement of the tube together with administration of antibiotics according to the local hospital policy. Tracheoesophageal fistulae may develop due to persistent pressure from a tracheostomy tube on the posterior wall of the trachea. Recurrent aspirations despite the tube cuff being inflated would be a sign for this. If the tube position is pushing excessively anteriorly, one may run the risk of causing a fistula between the trachea and the innominate artery especially if it is running an anomalous high passage. It may be rarely heralded by sentinel bleeds but usually presents with massive uncontrollable haemorrhage (4). Tracheal stenosis, tracheomalacia and a persistent tracheocutaneous fistula are late complications that may need surgical intervention to be managed.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Pracy JP, Rogers M. Tracheostomy. In: Watkinson J, Gilbert RW. eds. Stell & Maran's textbook of head and neck surgery and oncology. CRC Press, 2012:273-280.
2. Cheung NH, Napolitano LM. Tracheostomy: epidemiology, indications, timing, technique, and outcomes. Respir Care 2014;59:895-915; discussion 916-9.
3. McGrath BA, Bates L, Atkinson D, et al. Multidisciplinary guidelines for the management of tracheostomy and laryngectomy airway emergencies. Anaesthesia 2012;67:1025-41.
4. Bradley PJ. Bleeding around a tracheostomy wound: what to consider and what to do? J Laryngol Otol 2009;123:952-6.

doi: 10.21037/shc.2017.05.05
Cite this article as: Muscat K, Bille A, Simo R. A guide to open surgical tracheostomy. Shanghai Chest 2017;1:4.

Tracheal resection and reconstruction

Michele Salati[1], **Ricardo Mingarini Terra**[2]

[1]Unit of Thoracic Surgery, AOU Ospedali Riuniti di Ancona, Ancona, Italy; [2]Division of Thoracic Surgery, Hospital das Clinicas, University of Sao Paulo Medical School, Sao Paulo, Brazil

Correspondence to: Michele Salati. Unit of Thoracic Surgery, AOU Ospedali Riuniti di Ancona, Ancona, Italy. Email: michelesalati@icloud.com.

Received: 13 June 2017; Accepted: 04 July 2017; Published: 25 July 2017.
doi: 10.21037/shc.2017.07.02
View this article at: http://dx.doi.org/10.21037/shc.2017.07.02

Introduction

Tracheal resection and following reconstruction procedure could be indicated for treating several benign tracheal diseases as well as primary and secondary neoplasm of the trachea. Tracheal stenosis derived from prolonged intubation or previous procedure on trachea (for instance tracheostomy) is largely the most frequent diagnosis leading patients to surgical treatment. The stricture shouldn't involve a tracheal segment longer than 5 cm or 50% of the entire tracheal length in order to perform a safe tracheal resection and reconstruction.

Indication for surgical treatment and preferred surgical strategy should be established carefully, taking into account the endoscopic assessment of the larynx and airways as well as their radiologic (CT scan) study. The integration of these preoperative studies is able to offer detailed information about the tracheal lesion, which could influence the management of the surgical procedure or, as an alternative, the choice of a more conservative treatment.

It should be underlined that tracheal resection and reconstruction procedures should be carried out in institutions able to offer adequate radiologic support, instruments and expertise for the endoscopic evaluation and treatment of tracheal lesions and the management of potential postoperative complications, intensive postoperative care setting and voice and swallowing evaluations services.

Operative technique

Preparation

The patient is positioned supine on the operating table.

A surgical cushion is placed horizontally at the level of the scapulae, in order to facilitate the extension of the neck. The head is supported by a circular cushion to prevent hyperextension.

In the right position, chin, neck and sternum should be aligned and horizontally positioned (eventually modifying the surgical bed axis) (*Figure 1*).

Before starting the surgical procedure is recommended to perform an intraoperative endoscopic evaluation of larynx and airways in order to verify if previous findings indicating the resection are still confirmed. In particular, the following parameters should be carefully assessed: length and diameter of the stenosis, location of the stenosis, mucosal status, stability of the tracheal wall.

Exposition

The sterile surgical field should be represented by an ideal rhombus having the apical vertex in the midpoint of the jaw, the lateral vertex on the midpoint of the claviculae for both sides, and the inferior vertex at the level of the sternal xiphoid process (in the case a sternotomy was needed).

A transverse cervical incision is performed halfway between the inferior border of thyroid cartilage and the sternal notch. The incision should be laterally extended over the sternal portion of the sternocleidomastoid muscle. If a previous scar was present (due to a previous tracheostomy for instance), this could define the level of the incision that should incorporate it.

Skin and platysma are dissected until the plane of cervical fascia and pre-thyroid strap muscles. The resulting two muscle-cutaneous flaps are raised in order to expose the deeper surgical field, from the laryngeal prominence to the upper border of the sternal manubrium (*Figure 2*).

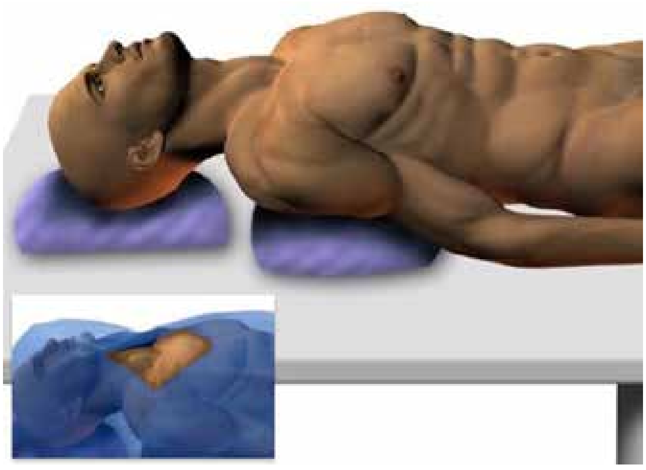


Figure 1 Patient position and sterile field.

Operation (1,2)

Cervical fascia is opened along the midline and the sternohyoid and sternothyroid muscles are retracted laterally from both sides.

The anterior larynx and tracheal wall are now exposed as well as the isthmus of the thyroid gland, which is divided between sutures (*Figure 2*).

At this time the tracheal stricture should be identified and its upper and lower borders clearly marked, eventually using the endoscopic view and the transillumination. After that, the pretracheal visceral fascia is opened from the anterior cricoid ring to below the stricture. The opening of this plane should be carefully prolonged until reaching the carina, as it is usually done for the mediastinoscopy procedure. This maneuver permits the anterior mobilization of the tracheal wall (anterior release). At the beginning of the anterior release, it is useful to put at least two (one for each side) lateral stay sutures one or two tracheal ring below the lower border of the stricture in order to traction up the trachea during this procedure. The pretracheal fascia should be open laterally not beyond the tracheoesophageal angles in order to avoid any injury to the recurrent nerves.

As the stricture's inferior border is recognized, at this level the diseased trachea is circumferentially mobilized dividing it from the esophagus using a sharp dissection very close to the tracheal wall in order to preserve the nerves (*Figure 3*). This circular dissection shouldn't be extended distally toward the healthy trachea, for preserving as much as possible the blood supply of this crucial anastomotic area.

Just below the stricture (eventually through it) the trachea is opened after retracting the orotracheal tube above the stenosis (*Figure 3*).

Three other stay suture were applied on both lateral sides and in the middle portion of the distal resected trachea to avoid deformities of the tracheal wall and migration of the distal trachea down to the lower mediastinum. The distal part of the trachea is then intubated using a sterile armored orotracheal tube that is connected to the anesthesia breathing circuit outside the operative field. Once opened and ventilated, the distal trachea could be carefully inspected in order to verify if the divided margin is healthy or if the fibrotic tissue is still involving the margin. In this case, another slice of distal trachea could be resected until obtaining a healthy distal border for the anastomosis (*Figure 4*) (3).

If necessary the posterior membranous tracheal wall could be divided by blunt dissection from the esophagus till reaching the carina posteriorly. This allows a further mobilization of the distal trachea (posterior release), but obviously this maneuver must spare the tracheoesophageal angle for preserving the recurrent laryngeal nerve and the tracheal blood supply as well (this recommendation is never overemphasized) (4).

At this point, the proximal stenotic tract of the trachea can be pulled up using Allis clamps, in order to divide it from the esophagus and from the surrounding tissues that could be involved in the fibrotic reaction around the diseased trachea. Once the upper border of the stricture is identified and isolated for the whole circumference, the trachea is divided at this level and the specimen removed. Even in this case, the healthiness of the upper tracheal margin should be carefully assessed and possibly a further slice of fibrotic trachea could be removed (*Figure 5*).

Before performing the tracheal reconstruction, any accidental lesion of the esophagus is carefully evaluated, filling it with a methylene blue solution and looking for potential filtering points.

As previously done for the distal trachea, three stay suture should be applied to the proximal trachea. Pulling the upper and lower stay sutures in opposite convergent directions and rotating and pushing the head of the patient towards the sternum, the tracheal superior and inferior borders could be progressively approached each other. In this way the potential tension of the anastomosis is assessed. In case the borders approximate with excessive tension,

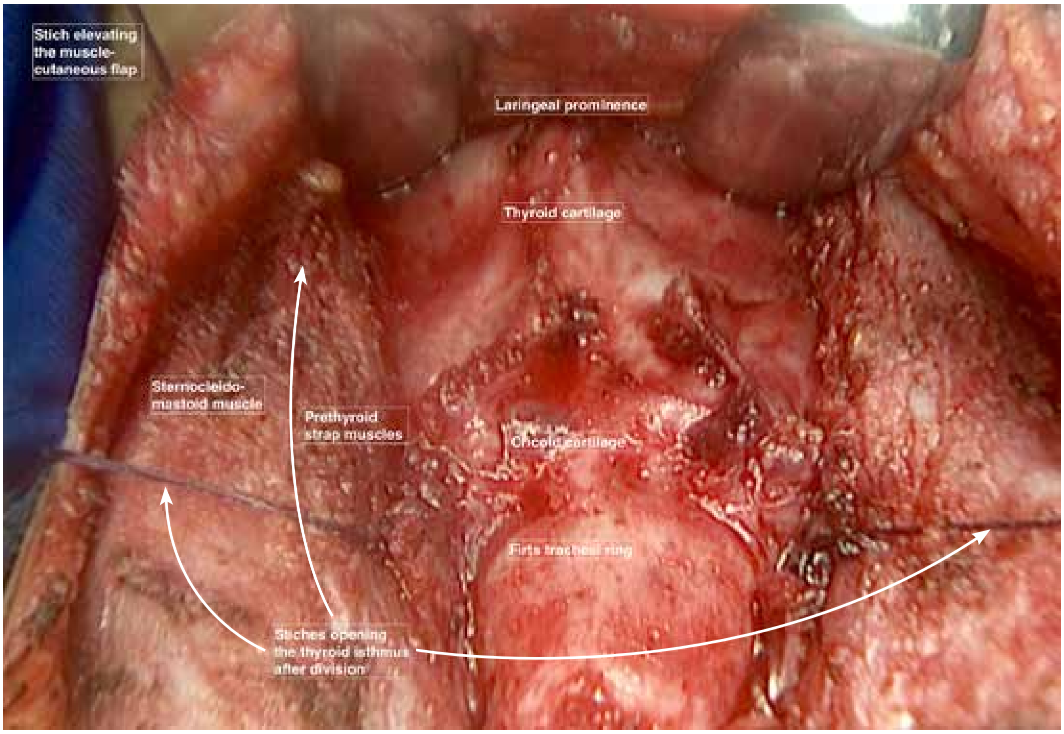


Figure 2 Tracheal exposition.

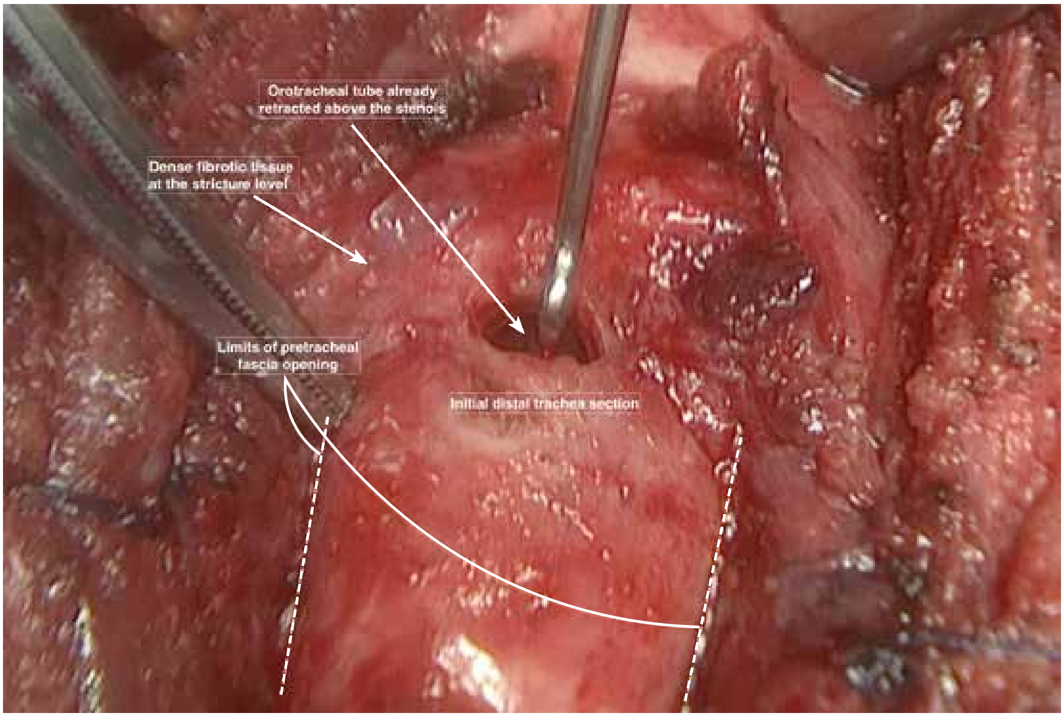


Figure 3 Distal tracheal opening.

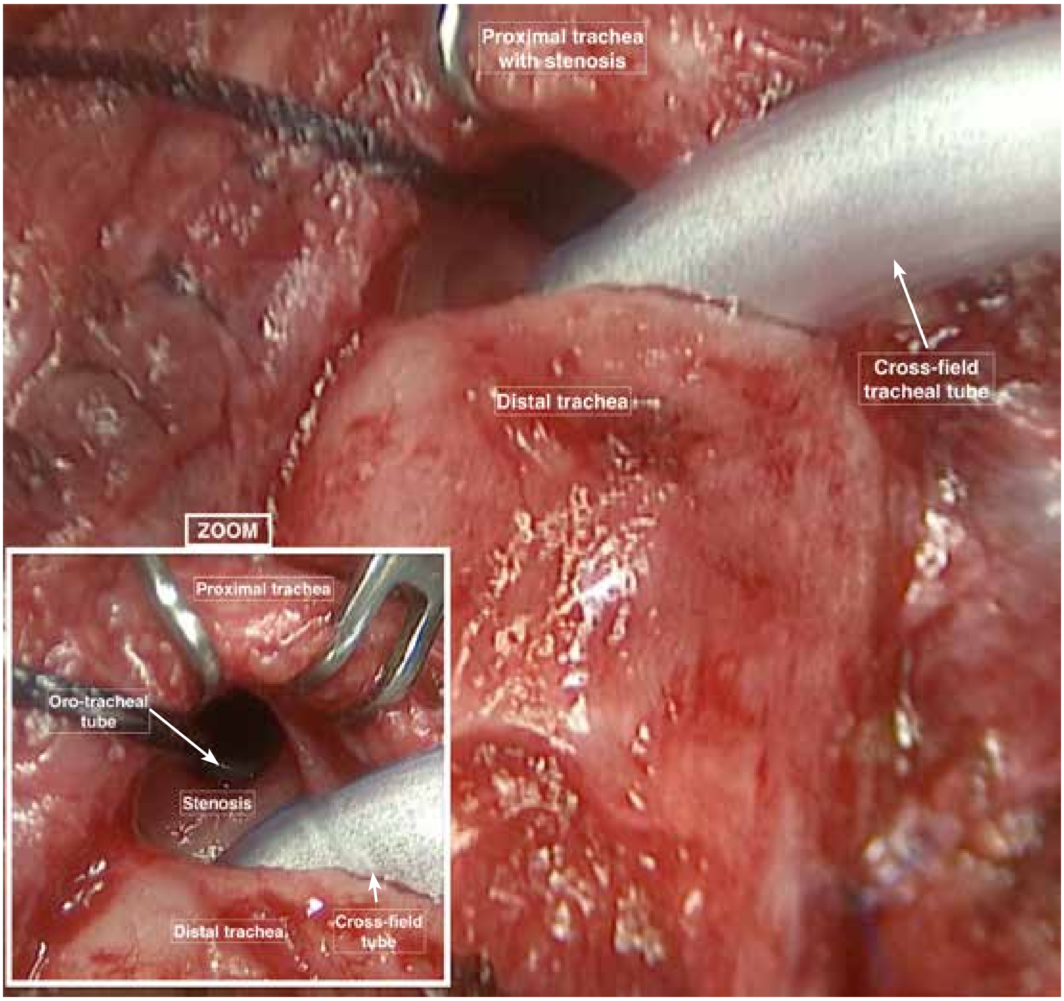


Figure 4 Cross field intubation.

further release procedures could be performed (as reported within comment section), otherwise the cushion under the scapulae is removed and the reconstruction phase could start.

We prefer to perform the end to end anastomosis with interrupted sutures for both anterior and posterior tracheal walls. The stitches are passed entering the lower segment of the trachea (3 to 5 millimeters from the free margin) from outside to inside the lumen and the opposite path from inside to outside is followed for the upper segment (*Figure 6*). In this way, the knots will be placed outside the tracheal wall for the whole circumference, minimizing the development of granulation tissue within the mucosal surface.

The starting point is represented by the midline of the membranous tracheal wall. Stitches are placed one after the other with a distance of 3–4 millimeters, moving from the middle to the lateral sides, pulling up or laterally the armored ventilating tube in order to facilitate the procedure. Once the suture reaches the stay stitches level, this tube is removed from the surgical field and the orotracheal one is pulled down crossing over the anastomotic line (*Figure 7*).

It is necessary to pay the utmost attention during this phase to avoid that the tube could pass through any previously settled suture. This could lead to accidentally tie the tube to the anastomosis, with the need of completely reopening the suture at the moment of extubation.

Following the same order of their placement, the posterior stitches are tied with a constant traction on the stay sutures. These stay sutures are tied with the corresponding ones in each tracheal segment, before starting the closure of the

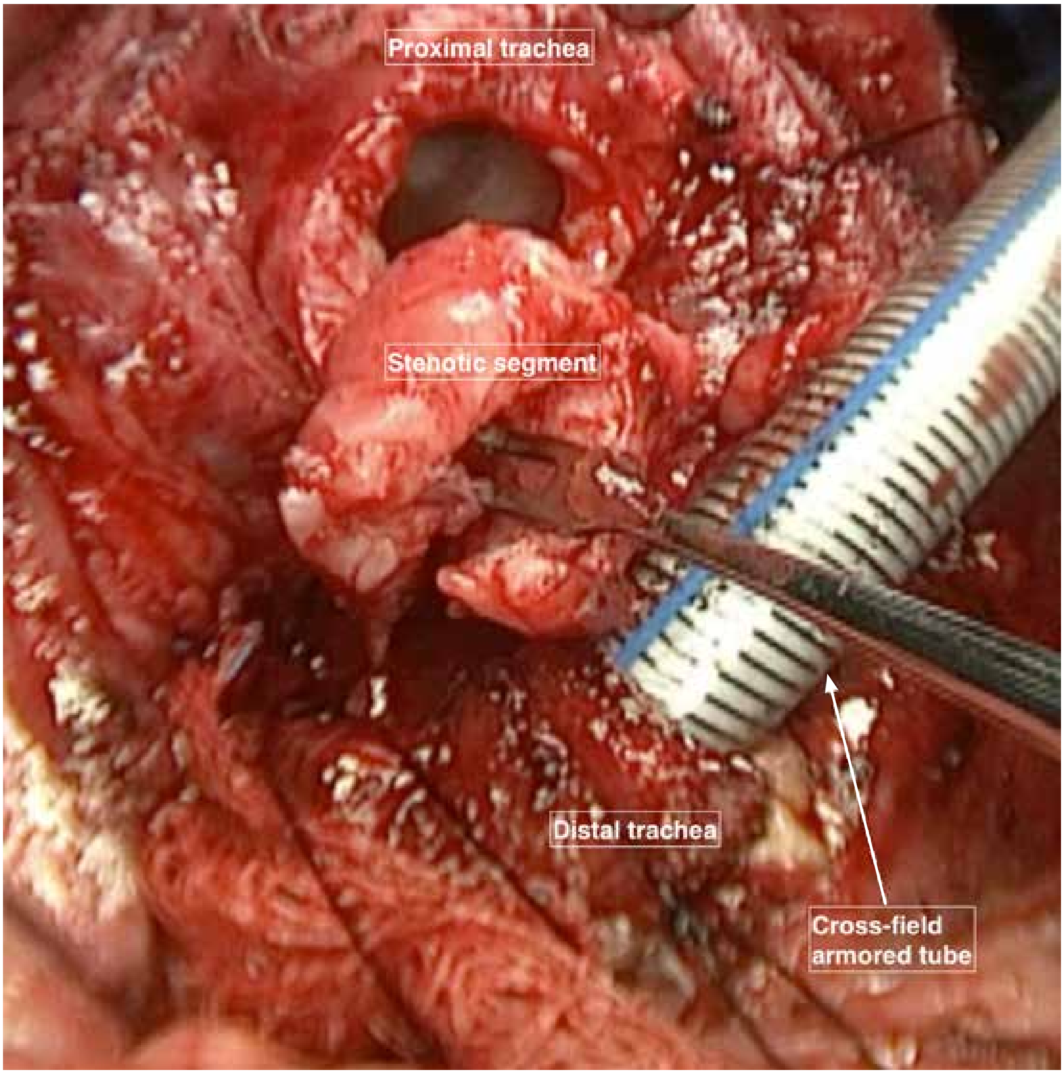


Figure 5 Resection of the stenotic segment.

anterolateral cartilaginous portion of the trachea (*Figure 8*).

The complete sealing of the anastomosis is then tested. The endotracheal balloon is deflated and the surgical field is filled with water to cover the suture line. During the ventilation any bubbling site from the anastomosis is detected and the leaking points are carefully closed with an extra suture.

The final anastomosis is buttressed using the strap muscles, that are approximate each other along the midline from both sides with interrupted sutures. If any lesion of the esophagus was previously sutured, usually the left side sternothyroid or the sternohyoid muscles are used to separate the esophagus from the posterior tracheal wall at this level.

Completion

Before proceeding with closure of collar neck incision, it should be evaluated if patient could benefit of positioning a tracheostomy cannula (as later discussed within the caveats paragraph). In this case a short vertical incision (usually involving two rings) could be performed in the tracheal midline preferentially below the anastomosis. A un-cuffed silicon cannula should be placed through the tracheostomy.

Finally, the platysma, the subcutaneous tissues, and the skin are sutured closing the surgical wound. Sometimes, a safety large caliber stitch is applied from the chin to the chest wall at the level of sternal manubrium, in order to prevent the neck extension, which could generate excessive

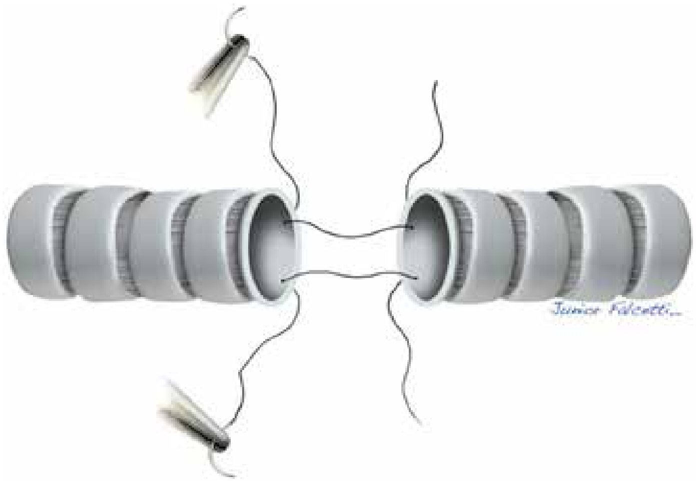


Figure 6 Initial tracheal reconstruction stitches.

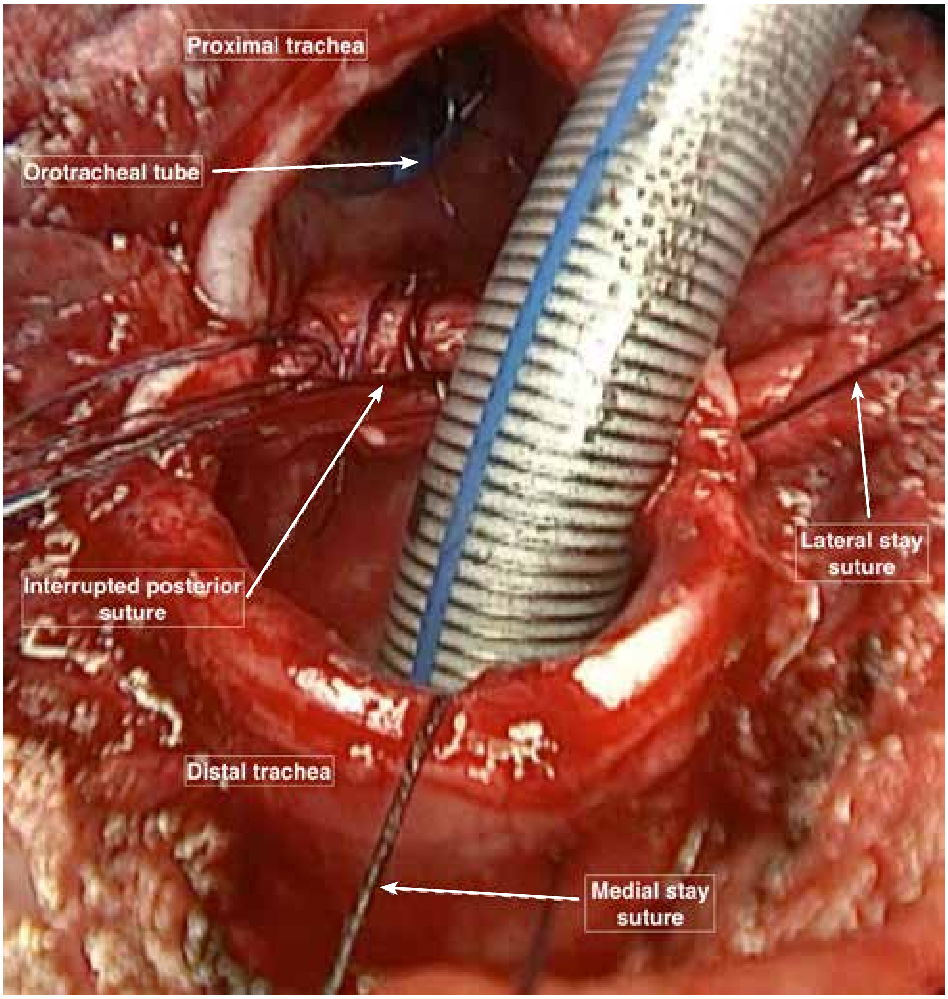


Figure 7 Reconstruction legend.

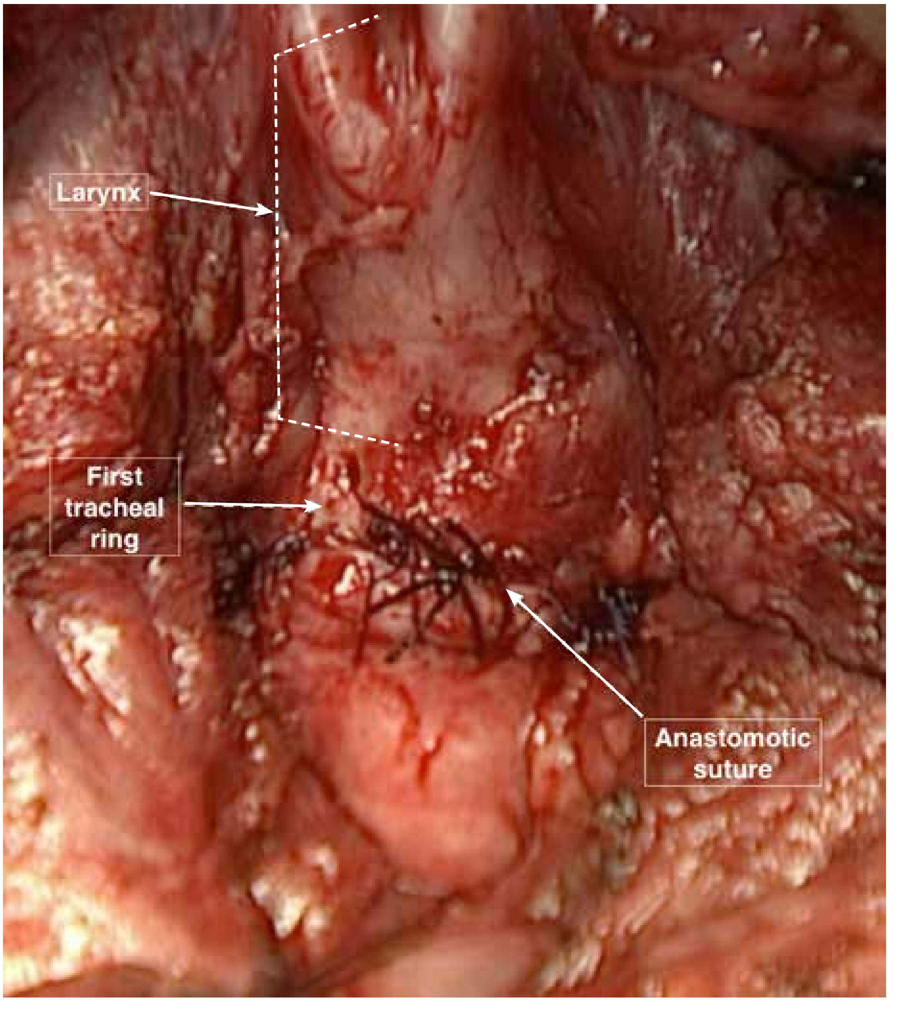


Figure 8 Final view legend.

tension on the anastomosis.

Comments

The majority of tracheal resection and reconstruction procedures can be performed using the described standard technique. Nevertheless, during the operation, several problems could arise which need to be managed effectively, keeping in mind that often a second surgical treatment is not possible or burdened by higher risk of morbidity and mortality. In particular, an anastomosis under tension, the contact of the anastomosis with a repaired esophageal lesion or with the innominate artery, and the potential need of a tracheostomy represent crucial situations which should be carefully managed before ending the operation.

Tips

In case an excessive anastomotic tension is verified at the moment of reconstruction, three different release procedures could be performed in order to gain an additional tracheal mobilization of two centimeters with each of them.

The suprathyroid laryngeal release (5) is carried out using the same cervical access already performed. The area between the hyoid bone and the thyroid cartilage is exposed retracting the sternohyoid muscles. The division of thyrohyoid muscle allows exposing the thyrohyoid membrane and the correspondent ligament, which are then resected. This maneuver associated with the resection of the superior thyroid cornua leads to the drop of the larynx.

The suprahyoid laryngeal release (6) is preferably performed through a second surgical incision placed exactly upon the hyoid bone. Once the superior border of this bone is identified, the muscles here inserted (mylohyoid, geniohyoid and genioglossus) are divided from the midline to both lateral sides until reaching the digastric muscle ligaments. The hyoid bone is then resected at the same level just medially to the digastric slings. This procedure exposes the pre-epiglottic space and allows releasing the larynx jointly to the body of the hyoid bone.

The hilar release is rarely performed due to the need of a supplemental thoracotomic access. Usually, the right side is preferred and the pericardium exposed. A longitudinal incision of the pericardium is performed between the phrenic nerve and the anterior border of the main right pulmonary artery and the pulmonary veins. The veins should be encircled by the incision and the pericardium should be divided up to the fibrous pericardial septum (between the pericardium and the inferior vena cava). This maneuver allows mobilizing all the pulmonary hilar structures (right main bronchus, right pulmonary artery and veins) as well as the trachea and moving them cervically.

Caveats

Esophageal perforation

Iatrogenic perforation of the esophagus could be accidentally produced during this kind of surgical procedures, especially while the posterior wall of the tracheal stricture is divided from the esophagus. In order to isolate the stenosed segments of trachea as well as to perform the posterior release as safely as possible, we recommend inserting a nasogastric tube through the esophageal lumen as a landmark. This allows identifying more simply the esophagus by palpation at any time during the surgical procedure. Moreover, before proceeding with the reconstruction phase, we routinely look for any lesion of the esophageal wall filling it with a methylene blue solution. If a perforation is detected, it is usually sealed by interrupted sutures in two layers. The site of repair is isolated by the reconstructed trachea, especially if close to the anastomotic area, using a strap muscle rotated between the posterior tracheal wall and the esophagus.

Risk of tracheoinnominate fistula

In some case, procedures of exposure and mobilization of the trachea and level of anastomosis lead to a close contact between the tracheal suture and the innominate artery. During the early postoperative period, this situation could influence the development of a tracheoinnominate fistula. As a consequence is strongly recommended to separate the artery and the tracheal anastomosis at the end of the reconstruction phase. To this purpose, a strap muscle could be rotated downward in front of the anterior tracheal wall, which will be divided from the artery. It is important to anchor the free margin of the rotated muscle to the tracheal wall distally to the anastomosis in order to completely cover and separate it from other structures.

Need for tracheostomy

At the end of the surgical procedure it could be necessary to perform a temporary tracheostomy, even though the preferred early postoperative management after a tracheal resection and reconstruction is represented by the immediate extubation within the operative room, without placement of any tracheal prosthesis. Nevertheless if any doubt exists about patency of airways or viability of anastomotic tissue or excessive tension at the end of the surgical procedure, positioning an uncuffed tracheostomy cannula seems the safer maneuver. It allows maintaining an effective airway while tissues are recovering from edema and inflammation caused by the surgical procedure and moreover it usually decrease the anastomotic tension facilitating the healing processes. Temporary tracheostomy cannula should be removed after a direct endoscopic assessment of treated airways.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Grillo HC. Tracheal surgery. In: Ravitch M, Steichen F. Editors. Atlas of general thoracic surgery. Philadelphia: WB Saunders, 1987:293-331.
2. Grillo HC, Donahue DM, Mathisen DJ, et al. Postintubation tracheal stenosis. Treatment and results. J Thorac Cardiovasc Surg 1995;109:486-92; discussion 492-3.
3. Mathisen DJ. Subglottic Tracheal Resection. Oper Tech Thorac Cardiovasc Surg 1998;3:142-53.

4. Pearson FG, Cooper JD, Nelems JM, et al. Primary tracheal anastomosis after resection of the cricoid cartilage with preservation of recurrent laryngeal nerves. J Thorac Cardiovasc Surg 1975;70:806-16.
5. Dedo HH, Fishman NH. Laryngeal release and sleeve resection for tracheal stenosis. Ann Otol Rhinol Laryngol 1969;78:285-96.
6. Montgomery WW. Suprahyoid release for tracheal anastomosis. Arch Otolaryngol 1974;99:255-60.

doi: 10.21037/shc.2017.07.02
Cite this article as: Salati M, Terra RM. Tracheal resection and reconstruction. Shanghai Chest 2017;1:16.

Carinal resection

Ricardo Mingarini Terra[1], Michele Salati[2]

[1]Division of Thoracic Surgery, Hospital das Clinicas, University of Sao Paulo Medical School, Sao Paulo, Brazil; [2]Unit of Thoracic Surgery, AOU Ospedali Riuniti di Ancona, Ancona, Italy

Correspondence to: Ricardo Mingarini Terra. Division of Thoracic Surgery, Hospital das Clinicas, University of Sao Paulo Medical School, Sao Paulo, Brazil. Email: rmterra@uol.com.br.

Received: 13 June 2017; Accepted: 04 July 2017; Published: 28 July 2017.
doi: 10.21037/shc.2017.07.03
View this article at: http://dx.doi.org/10.21037/shc.2017.07.03

Introduction

Carinal resection is a challenging procedure that is rarely performed and which requires both strict attention to technical details and good patient selection. Most patients who undergo carinal resection have lung or airway cancer; squamous cell carcinoma, carcinoids, and adenoid cystic carcinoma are the most frequent. However, less often, it can also be indicated in benign cases as tuberculosis associated strictures or post-pneumonectomy fistula.

Patient selection is critical; therefore, in patients with lung cancer thorough staging is mandatory, since patients with N2 disease usually have a dismal prognosis. Since carinal resection is a major thoracic procedure, pre-operative functional evaluation is also very important to select the candidates adequately. All cases should undergo detailed anatomic assessment including imaging and bronchoscopy. Such exams will help to define the access route, the extension of the resection, and the need for associated procedures (1,2).

Operative technique

The carina may be accessed by right thoracotomy or median sternotomy. Carinal resection through left thoracotomy, even though feasible, is difficult and implies extensive mobilization of the aortic arch (2,3).

Tumors that involve the carina but do not require lung resection might be approached either by right thoracotomy or by sternotomy. Tumors that extend more distally in the left main stem bronchus are more easily approached through median sternotomy since this route allows both reimplantation of the right bronchus in the trachea and resection of the left lung. When resection of the right lung or of the right upper lobe is anticipated, the better access is through a right thoracotomy (1).

Preparation

With the patient in the OR, it is advisable to perform a bronchoscopy in order to confirm the extension of the resection and the planned reconstruction.

Anesthesia for patients undergoing carinal resection can be very challenging due to ventilation issues. There are three options for intra-operative ventilation support: jet-ventilation, intermittent cross-field ventilation, or in selected cases veno-venous extracorporeal membrane oxygenation (ECMO). Close cooperation with the anesthesia team is extremely important for a successful procedure (1,2).

As for patient positioning, patients undergoing median sternotomy should be in dorsal decubitus with a small cushion placed horizontally in the scapular region to elevate the sternum. Patients undergoing right thoracotomy should be in left lateral decubitus with an axilar cushion and a pillow between the legs. We prefer to use a support to hold the right arm.

Exposition

The access to the carina varies according to the access route chosen, sternotomy or right thoracotomy.

Sternotomy

After preparation, a skin incision is made in the anterior chest midline extending from the sternal notch to the

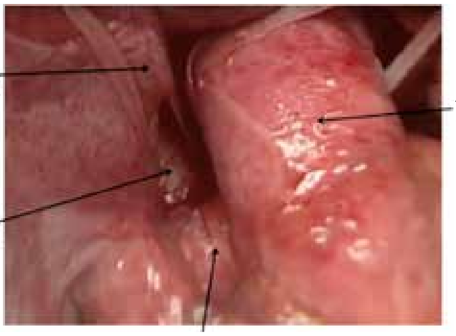


Figure 1 Intraoperative view of the transsternal approach to the carina and left main stem bronchus. This patient underwent reamputation of the left main stem bronchus after left pneumonectomy.

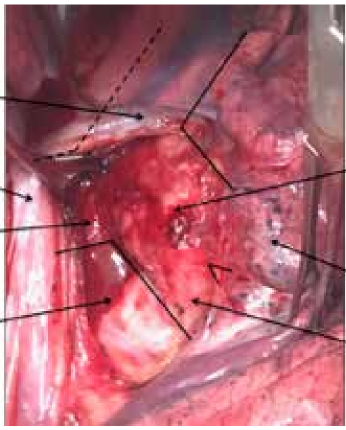


Figure 2 Intraoperative view of a transthoracic (right-sided) approach to the carina. This patient had an adenoid cystic carcinoma of the right main bronchus invading the carina. The azygos arch is not divided yet; dividing it allows for full exposure of the distal trachea ad carina.

xiphoid process. Then, the subcutaneous tissue is incised until the anterior sternal periosteum. The interclavicular ligament is cut and the periosteum divided and cauterized. Following this, the sternum is separated in the midline with a pneumatic sternal saw and a retractor applied to expose the mediastinal structures.

After removal of thymic and fat tissue covering the pericardium, the great vessels are exposed and the pericardium opened. Left brachiocephalic vein is encircled and retracted superiorly, superior vena cava is encircled and retracted laterally, ascending aorta is encircled and retracted laterally, and finally, left pulmonary artery encircled and retracted inferiorly. These maneuvers allow for exposure of the distal trachea and carina. The space is pretty tight with this approach and aorta retraction can be particularly challenging in older patients; these aspects should be kept in mind when selecting the access route. Another point is that, a good mobilization of the left pulmonary artery exposes the left main bronchus very well (*Figure 1*).

Right thoracotomy

After preparation of the patient, a muscle-sparing lateral thoracotomy is performed over the fifth intercostal space. After dividing the skin and subcutaneous tissue and retracting the latissimus dorsi and anterior serratus muscles, the fifth intercostal space should be identified and opened but with careful dissection of the intercostal muscle and its vascular pedicle since it will be used later as muscular flap to cover the airway anastomosis.

After entering the chest, it is very important to inspect and evaluate the extension of the disease particularly looking for vena cava invasion and compromise of the right lung hilar structures. The next step is to open the mediastinal pleura below the azygos arch and remove the subcarinal lymph nodes. Following this, the azygos arch is divided exposing the posterior aspect of the distal trachea and carina (*Figure 2*).

Operation

Release maneuvers

A very important aspect of the carinal surgery is to assure that airway reconstruction is tension-free to reduce the possibility of complications as dehiscence or stenosis. Therefore, there are some maneuvers that should be done in order to release the involved structures and facilitate the approximation of the two-ends of the anastomosis.

The most frequently used release maneuver is the development of a pretracheal plane, similarly to what is done in tracheal surgery. One must be cautious, though, in avoiding dissecting the lateral wall of the trachea to prevent devascularization. Pretracheal dissection alone provides distal mobilization of the trachea of up to 2 cm without compromising lateral blood supply and can be performed when the access route is either through thoracotomy or sternotomy (2,3).

Another release maneuver that can be used when the access route is thoracotomy is the hilar release. Significant anastomotic tension reduction can be achieved by, after

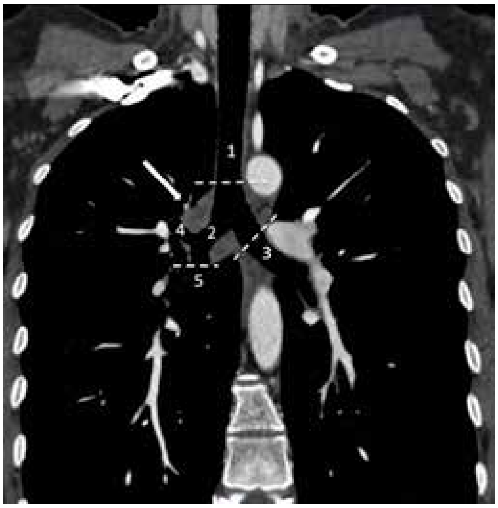


Figure 3 Chest computerized tomography of a patient with a right main bronchus cystic adenoid carcinoma (arrow) extending to the carina (confirmed by bronchoscopy). 1, trachea; 2, right main stem bronchus; 3, left main stem bronchus; 4, right upper lobe bronchus; 5, bronchus intermedius. The planned resection in this patient is depicted by the dashed lines and involves the carina, right main bronchus, and right upper lobe. As the tumor did not extend to the bronchus intermedius, it was possible to spare the right middle and lower lobes.

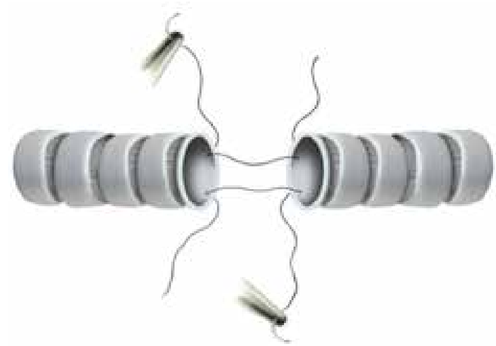


Figure 4 Airway reconstruction (end-to-end anastomosis). Repair sutures in the transitions between membranous and cartilaginous wall. Knots should be tied in the external surface of the airway.

division of the inferior pulmonary ligament, performing a U-shaped incision in the pericardium beneath the inferior pulmonary vein and intrapericardial division of the raphe extending from the inferior pulmonary vein to the inferior vena cava (2,3).

Carinal resection associated or not to lung resection

After carinal exposure, the trachea, the right and left main bronchus should be encircled and tapes should be placed around these structures. Gentle dissection is critical to avoid devascularization and to prevent injury to the recurrent laryngeal nerve that runs parallel to the trachea. Paratracheal lymphadenectomy should be limited.

The extension of airway resection should be planned before the procedure and revised intraoperatively by the means of frozen-section analysis of the margins. Lesions restricted to the distal trachea and carina do not require lung resection and involve only the resection of the carina. Lesions extending to distal left main stem bronchus may require left pneumonectomy. Lesions extending to the right main bronchus may require upper lobectomy (when restricted to the right upper lobe and right main stem bronchus) or right pneumonectomy (when the lesion extends to the bronchus intermedius or involves more lobes) (*Figure 3*).

Reconstruction

After removal of the specimen, it is necessary to reconstruct the airway and the reconstruction varies a lot depending on the resection performed. Nevertheless, some basic principles should be followed in all anastomosis.

First, repair sutures (PDS 3.0) should be applied in the transition between the cartilaginous and membranous wall bilaterally. These sutures should be made so that the knot is tied in the external surface of the airway (*Figure 4*). Second, avoid trauma of the airway mucosa through gentle handling of the tissue. Third, perform a PDS 4.0 continuous suture approximating the cartilaginous walls of the two ends and starting from the portion deepest in the mediastinum (if the access was through a sternotomy, start with the membranous wall). The suture should involve all airway layers and be placed 3 to 4 mm from the cut edge. Size mismatch is extremely frequent and should be corrected with adequate spacing between stiches. Fourth, repeat this last step in the membranous wall (or cartilaginous wall, if membranous wall was already sutured). Fifth, approximate the two ends and tie the deeper knots. Sixth, finish the suturing of both walls and tie the knots in the more superficial extremity of the anastomosis. Finally, test for air leaks (1-3).

The peculiarities of the most frequent reconstructions are detailed below.

- ❖ "Neocarina": patients who undergo limited resection of the carina may have their airway reconstructed by the means of a "neocarina"

(*Figure 5*). In this technique, the right and left main bronchus are sutured together and then attached to the distal trachea. It is important to suture the medial cartilaginous wall of the two bronchi with interrupted sutured and be aware that the left main bronchus mobility is usually limited by the aortic arch; therefore, longer resections of this bronchus may preclude this type of reconstruction. The anastomosis to the distal trachea follows the principles previously enumerated (1).

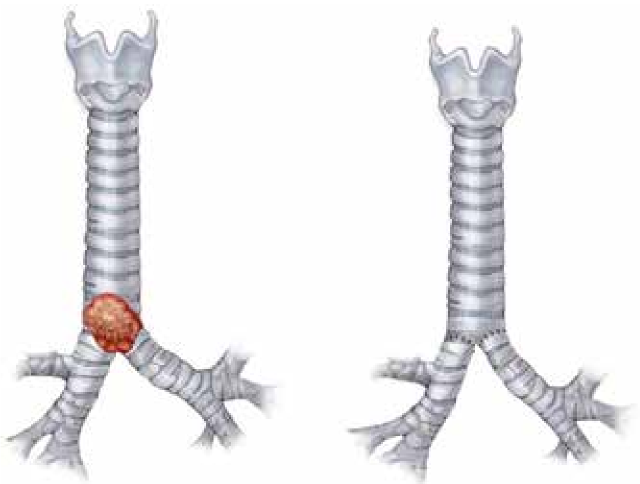


Figure 5 "Neocarina", reconstruction technique used in patients who had limited resection of the carina. Right and left main stem bronchus are sutured together and then attached to the distal trachea.

- ❖ Right sleeve pneumonectomy: the most frequent situation involving carinal resection is the right sleeve pneumonectomy. In these cases, patients have large tumors involving more than one lobe, extending to the bronchus intermedius, and/or invading the pulmonary artery. The resection of the right lung altogether with the carina, makes it necessary an end-to-end anastomosis of the left main stem bronchus to the distal trachea (*Figure 6*) (1,2).
- ❖ Anastomosis of the carina to the left bronchus and reimplantation of the bronchus intermedius: patients in which the carina was resected altogether with right upper lobe sparing the middle and lower lobes undergo a more complicated reconstruction. In such cases there are some options, but the most popular is end-to-end anastomosis of the left main bronchus to the trachea and an end-to-side anastomosis of the intermedius bronchus to an opening in the left main bronchus (*Figure 7*).

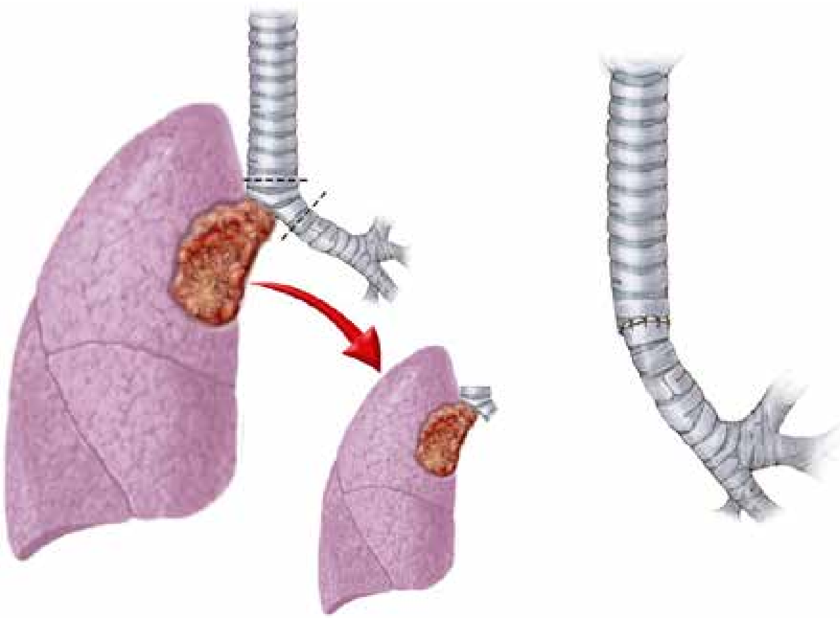


Figure 6 Right sleeve pneumonectomy. The right lung is resected altogether with the carina, the left main stem bronchus is sutured to the distal trachea.

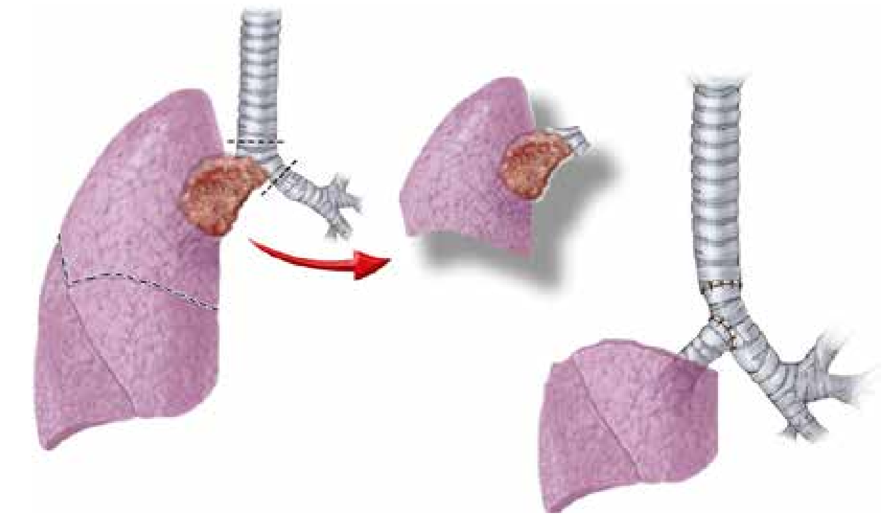


Figure 7 Carinal and upper lobe resection. Reconstruction with end-to-end anastomosis of the left main bronchus to the carina and end-to-side anastomosis of the intermedius bronchus to an opening in the left main bronchus.

The end-to-end anastomosis follows the same principles previously described, but the end-to-side anastomosis has additional issues. First, the ovoid opening in the left main bronchus should be at least one cm away from the anastomosis of the trachea to reduce problems related to devascularization of the tissue. Second, the opening must performed at the medial cartilaginous wall avoiding the membranous wall to provide rigidity and avoid collapse of the anastomosis (1,2).

Completion

After completing the reconstruction, the anastomosis should be tested for air leaks and then the intercostal muscle flap prepared at the beginning of the procedure placed around the anastomosis to protect it.

A 28 Fr chest tube is placed in the mediastinum (sternotomy) or pleural space (thoracotomy) and the chest closed.

Comment

Tips, tricks and caveats

One of the most challenging issues of carinal surgery is intraoperative ventilation. Discuss the strategy thoroughly with the anesthesia team before the procedure either the option be jet ventilation, cross-field intermittent ventilation, or ECMO.

The most feared complication of carinal surgery is anastomotic dehiscence, and, in fact, mortality associated to this complication is extremely high. Besides the release maneuvers and the gentle handling of the tissues, other actions could decrease the risk of anastomotic complications. First, avoid extensive dissection of the trachea and bronchus, try not dissect more than 2 cm away from the cut edge. Second, tailor the suturing to accommodate for the ends size mismatch, avoid cutting wedges of the bronchi or trachea or using other similar strategies because they usually compromise vascularization of the anastomosis line. Finally, the length of airway resection should not exceed 4 cm, otherwise the tension will too high and increase the risk of dehiscence (3,4).

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Gonfiotti A, Jaus MO, Barale D, et al. Carinal resection.

Thorac Surg Clin 2014;24:477-84.
2. Lanuti M, Mathisen DJ. Carinal resection. Thorac Surg Clin 2004;14:199-209.
3. Tapias LF, Ott HC, Mathisen DJ. Complications Following Carinal Resections and Sleeve Resections. Thorac Surg Clin 2015;25:435-47.
4. de Perrot M, Fadel E, Mercier O, et al. Long-term results after carinal resection for carcinoma: does the benefit warrant the risk? J Thorac Cardiovasc Surg 2006;131:81-9.

doi: 10.21037/shc.2017.07.03
Cite this article as: Terra RM, Salati M. Carinal resection. Shanghai Chest 2017;1:17.

Tracheal sleeve pneumonectomy: indications and surgical operative techniques

Mario Nosotti, Ilaria Righi, Francesco Damarco, Lorenzo Rosso

Thoracic Surgery and Lung Transplant Unit, Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, University of Milan, Milan, Italy
Correspondence to: Ilaria Righi, MD. Thoracic Surgery and Lung transplant Unit, Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, University of Milan, via Francesco Sforza 35, 20122 Milan, Italy. Email: ilaria.righi@policlinico.mi.it.

Received: 10 August 2017; Accepted: 21 August 2017; Published: 29 August 2017.
doi: 10.21037/shc.2017.08.11
View this article at: http://dx.doi.org/10.21037/shc.2017.08.11

Introduction

Tracheal sleeve pneumonectomy is a challenging surgical procedure for resection of cancers involving lung, lower trachea, carina and tracheobronchial angle. The most common indications are non-small cell lung cancers, bronchogenic carcinoma, carcinoid tumor, adenoid cystic carcinoma or inflammatory strictures. Other common indication is a positive resection margin after a standard pneumonectomy.

This type of surgery is currently still infrequent, because of the complexity and the high risk of complications. The recent improvement of surgical techniques, different ventilation modalities and postoperative management has reduced dramatically the mortality and morbidity, especially in high volume centers (1).

The careful selection of the patient is the central point for a successful operation (*Table 1*). Absolute contraindications include insufficient pulmonary reserve, impaired cardiac function, N2/N3 nodal disease, and excessive airway involvement (2).

Relative contraindications include prior neoadjuvant radiation (>45 Gy) and steroid use, because of higher risk of anastomotic dehiscence.

Tips and tricks

- ❖ Pre-operative evaluation by bronchoscopy and CT scan: a tension free anastomosis is possible only if the tumor does not extend beyond 1.5 cm of the main bronchus or 2.5–3.5 cm of the distal trachea. The total distance of the airway resection must be less than 4 cm because of the risk of anastomotic dehiscence.
- ❖ Steroids should be withdrawn at least 3–4 weeks before surgery.
- ❖ Mediastinoscopy should be performed at the same time of planned surgery to prevent mediastinal scarring that could reduce tracheal mobility (3).
- ❖ Is not recommended to repeat mediastinoscopy also in order to avoid excessive devascularization.
- ❖ EBUS is a reliable node-staging technique for its high sensibility and specificity, and can avoid the problem of scare or devascularization when mediastinal staging is planned long before surgery

Anesthesiological approach

Preparation

In this scenario a cooperation between surgeons and anesthesiologists is fundamental (4).

There are several different types of ventilation that can be chosen:

- ❖ Long, armored, flexible single-lumen endotracheal tube: typically placed in the trachea at the beginning of surgery. It can be taken forward the left or right mainstem bronchus during the procedure. Once the airway has been transected, the patient is ventilated with a cross-fields sterile endotracheal tube in the mainstem bronchus, passed by the anesthetist and connected with a sterile tubing system.

  During the surgical anastomosis the tube can be intermittently slided out. After the completion of the posterior wall of the anastomosis, the cross-field tube can be removed and the original endotracheal tube can be inserted in the mainstem bronchus.

Table 1 Preoperative evaluation

Type of evaluation	Tests required
Physical examination	BMI, general condition
Hematochemical and urine analysis	Standard preoperative ematochemical analysis
Pulmonary function	Basal and stress spirometry (PFR)
	Diffusing capacity of the lung for carbon-monoxide (DLCO)
	Arterial blood gas analysis
Cardiac function	Cardiologic evaluation
	Electrocardiography
	Transthoracic echocardiography
	Cardiopulmonary exercise testing
Imaging	Chest X-ray
	Chest, upper abdomen computed tomography (CT) with i.v. contrast
	Brain MRI/brain CT with i.v. contrast
	Positron emission tomography (PET)
	Perfusion scan
Bronchoscopy with biopsies to evaluate the airway involvement	–
Assessment of mediastinal lymph nodes	Mediastinoscopy can exclude N2/N3 disease and mobilize pretracheal plane for an additional mobility
	Endobronchial ultrasound with transbronchial fine needle aspiration cytology is an alternative to mediastinoscopy especially in the case of previous intervention on the anterior mediastinum

i.v., intravenous.

- Double-lumen tube to allow single lung ventilation: this type of tube is rigid and difficult to pass through distal carina.
- High frequency jet ventilation: a technique of mechanical ventilation that uses very high rates (>100 breaths/minute) with small tidal volumes (100–150/minute) delivered by a small catheter into the mainstem bronchus through the retracted single or double-lumen endotracheal tube. This technique guarantees ventilation without the side effects of positive pressure, but can lead to carbon dioxide retention. Because of the small diameter of the catheter, surgical reconstruction is much easier (4).
- Intermittent apneic ventilation: when the oxygen saturation decreases, the endotracheal tube is inserted across the open airway and the patient is hyperventilated with 100% oxygen. This results in a rise of oxygen saturation so that surgeons can go on preparing surgical anastomosis after having thrown back the tube.
- Long and thin single-lumen tube of 45 cm with a self-expanding cuff.
- Cardiopulmonary bypass/ECMO: in our experience it's better to plan tracheal sleeve pneumonectomy without these supports. The use of extracorporeal oxygenation is restricted to situations in which gas exchange is not sufficient during single lung ventilation or in case of major bleeding during surgery.

Surgical approach

Median sternotomy, anterolateral thoracotomy, posterolateral thoracotomy, bilateral thoracotomy, hemi-clamshell or clamshell can be used to approach lower trachea, carina and tracheobronchial angle.

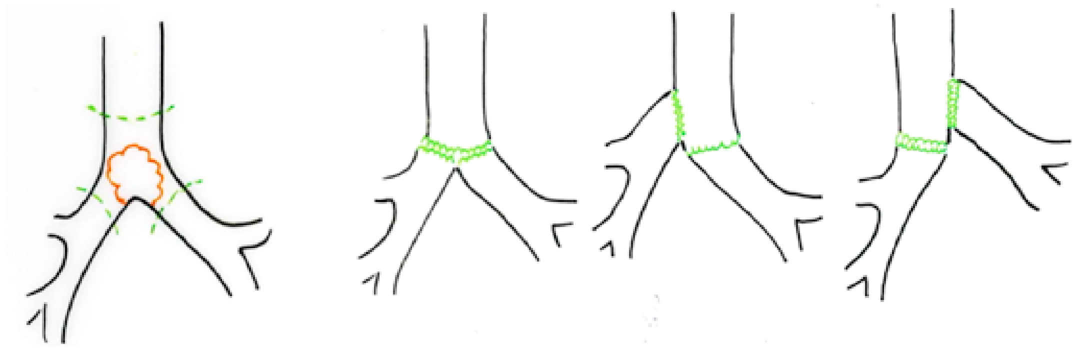


Figure 1 Different types of carinal reconstructions: these vary with the site and the extent of the tumor.

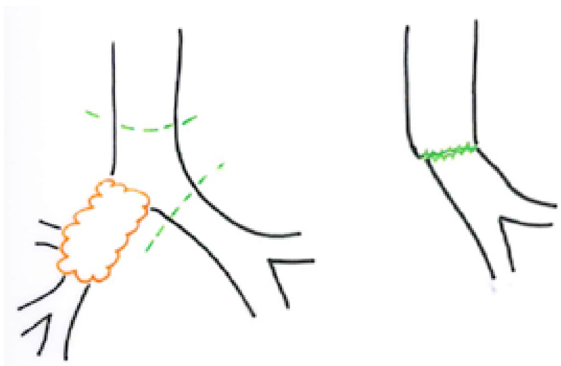


Figure 2 Example of right carinal sleeve pneumonectomy. The trachea and the left main bronchus are anatomized.

The type of incision varies according to the site of the tumor, and therefore patient's positioning depends on this choice.

In this chapter we won't talk about carinal reconstruction without pulmonary resection, so we have just illustrated the main reconstructions types below (*Figure 1*) (5).

Right carinal sleeve pneumonectomy

Right sleeve pneumonectomy is the most frequent pulmonary resection with carinal reconstruction. Several surgical approaches are possible and the choice depends on the surgeon's preference as well as on the local pathological condition (*Figures 2,3*).

Transthoracic approach

We suggest a standard right posterolateral thoracotomy in fourth intercostal space. First of all we divide the inferior pulmonary ligament to free the whole lung (*Figure 4*). The azygos vein can be divided to improve exposure of the carinal space (*Figures 5,6*). We prepare the pretracheal plane, open the pericardium, suspend the trachea as well as the mainstem bronchus at both sides (*Figures 7,8*). We suggest to use intraoperative bronchoscopy to identify the proximal and distal extend of the tumor and the point where transect the airway. For ventilation we prefer to use the first described method, so a cross-field sterile endotracheal tube is positioned (*Figure 9*). Endotracheal tube is withdrawn and the trachea is transected. Mid-lateral stay sutures 2-0 are placed on its wall (*Figure 10*). After that the left mainstem bronchus is cutted and inspected (*Figure 11*). The right pulmonary artery and veins are encircled and ligated.

Subsequently we proceed with *en bloc* removal of the specimen and start with reconstruction. Bronchial margins must be examined, so frozen sections are imperative: in case of positive margins, a balance must be struck between the need of R0 resection and concern about reconstructing the airway.

Bronchial traction absorbable sutures with 2-0 or 3-0 are placed on tracheal wall to stabilize the structure and give the surgeon the feeling of tension of the suture (*Figure 12*) (2).

There are several ways to perform the anastomosis: we prefer to use 4-0 absorbable interrupted sutures with knots tied outside (*Figure 13*), beginning with back row and ending with front row, starting to tie the knots gradually in a symmetric sequence from the opposite sites of the suture. Any size disparity between distal trachea and left mainstem bronchus is corrected by stretching the bronchial lumen to the size of the tracheal one (6).

Before closing the sutures, the patient's neck is flexed (*Figure 14*) to move closer the distal trachea to the relatively fixed left main bronchus. In fact, that applies to any anastomosis, is crucial the absence of traction for tissue healing. The anastomosis is inspected with flexible

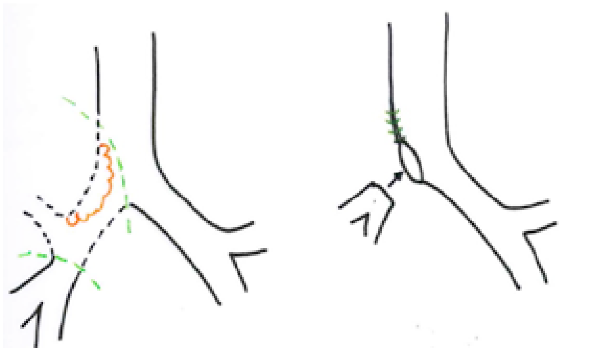


Figure 3 In this (rare) case a margin of trachea has had to be removed due to the site of tumor. The discrepancy of diameter between trachea and bronchus intermedius was managed suturing the proximal orifice before performing anastomosis.

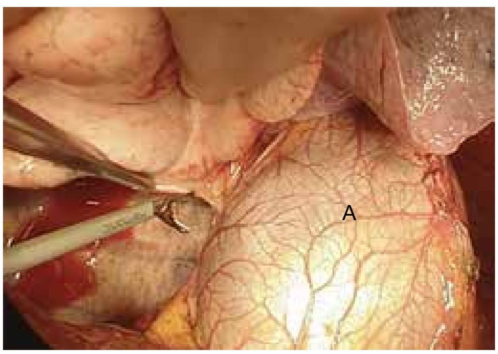


Figure 4 Dissection of inferior right ligament. (A) Pericardium.

bronchoscope, and a pedicle flap of pleura or pericardial fat is passed around to separate the suture line from vascular structures (2).

Transternal approach

The patient is positioned supine with the neck extended and both arms abducted. The median sternotomy is performed in the standard way, but the incision can be extended cranially for a better control of the left brachiocephalic vein (7). After initial dissection, the left brachiocephalic vein and artery are isolated and surrounded. The anterior pericardium is opened. Ascending aorta is isolated, surrounded and retracted to the left, while the superior vena cava is retracted to the right, to expose the trachea. A careful dissection of the airway is performed primarily on the anterior planes to avoid injury to blood supply. After that we reach the right pulmonary artery on the side, dissect

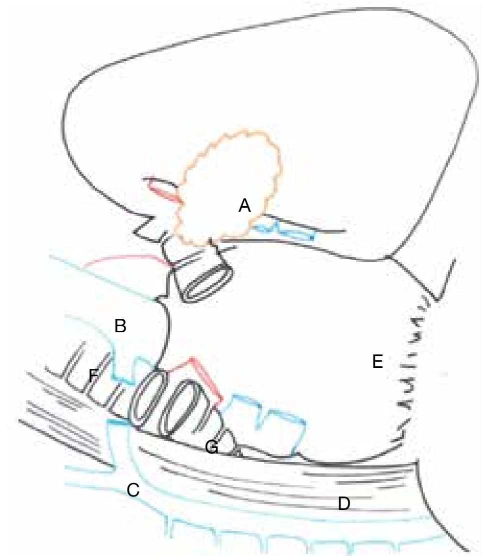


Figure 5 Anatomical view from a right thoracotomy. In the upper part the specimen (A) removed *en bloc* (right lung with tumor). The azygos vein (C) is transected to obtain tracheal mobilization. The tracheal and bronchial edges are not tailored, because the size discrepancy will be adjusted while completing the suture. Resection of wedges to reduce the circumference is usually not necessary. Some intussusception inevitably occurs. Superior vena cava (B), esophagus (D), pericardium (E), trachea (F), left mainstem bronchus (G).

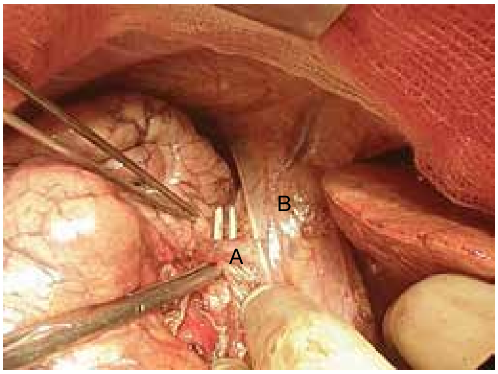


Figure 6 Isolation and ligation of azygos vein to obtain release of peritracheal tissue. (A) Azygos vein; (B) superior vena cava.

it and isolate it from the mainstem bronchus (8).

Transection of arterial and venous structures is performed. The posterior pericardium is incised to a wide exposure of the airway. The distal trachea and the proximal bronchi are dissected circumferentially and suspended. To

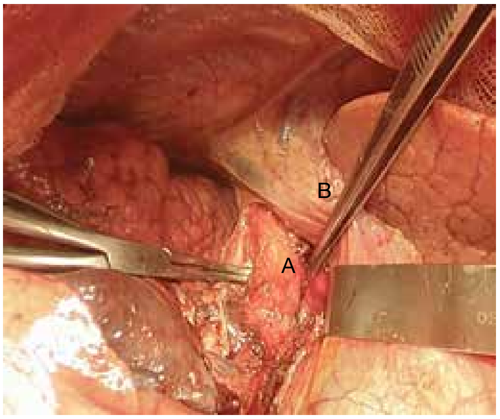


Figure 7 Isolation of trachea that is encircled with tape. (A) Trachea; (B) superior vena cava.

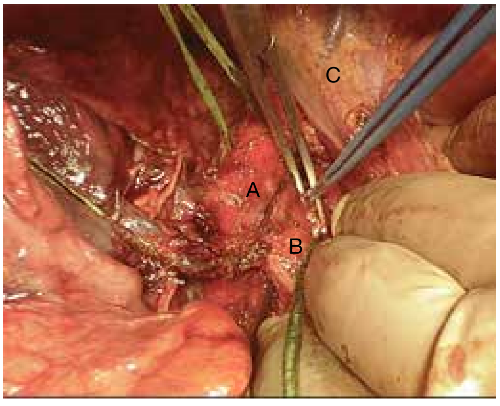


Figure 8 Preparation of the pre tracheal plane and exposition of the carena and the both main bronchi. Dissection of peritracheal tissue to obtain optimal mobilization of trachea. (A) Trachea; (B) left main broncus; (C) superior vena cava.

increase the mobility of the trachea we suggest to carry out an extensive nodal dissection in this moment.

We recommend to perform intraoperative bronchoscopy to identify the extension of the tumor and decide where to transect the airway. The left mainstem bronchus is transected and inspected. Mid-lateral stay sutures 2-0 are placed to stabilize the structure and a cross-field sterile endotracheal tube is positioned for left lung ventilation. Endotracheal tube is withdrawn and the trachea is transected and a right pneumonectomy is performed.

Mid-lateral stay sutures 2-0 are placed on its wall to stabilize the structure. The sutures (interrupted absorbable 4-0), are placed usually from the midline of the membranous wall posteriorly carrying on to the mid-lateral stay suture (*Figures 15,16*) (2).

Flexion of the neck leads to approximation of the two sections of transected airway. Because a tension-free anastomosis is the key point, if tissue traction seems excessive it is necessary a further dissection of the trachea or the left mainstem bronchus. Eventually a left hilar release could be done, otherwise this procedure is normally performed via a left anterior thoracotomy (with an incision of the pericardium below the inferior pulmonary veins or circumferentially) (8).

The stitches are then tied in the same way that we described before. When the anastomosis is completed the original endotracheal tube is pushed in over the sutures for a standard ventilation.

Clamshell approach

The access to thoracic organs with the clamshell incision

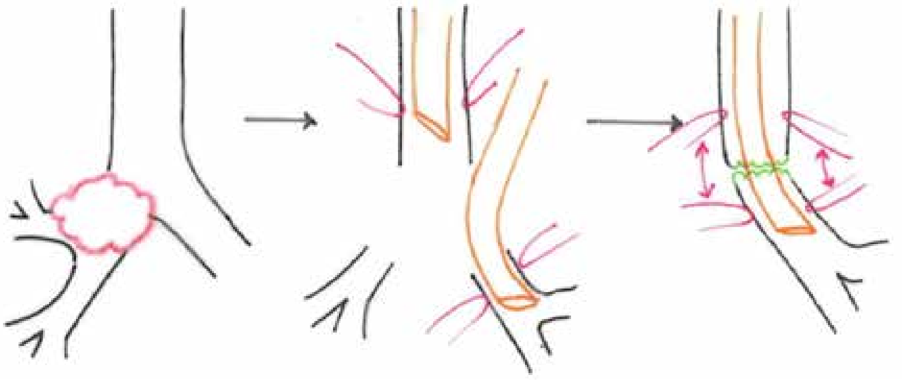


Figure 9 Endotracheal tube (orange) has been pulled back and a cross-field ventilation through left mainstem bronchus has been performed. In pink lateral traction sutures.

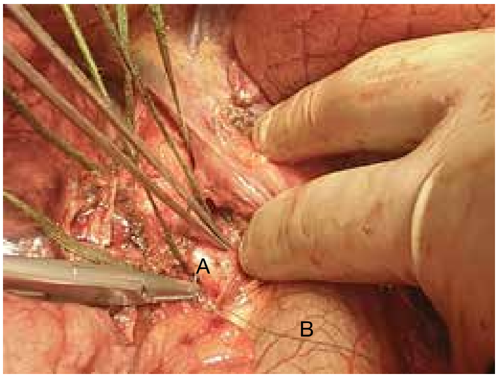


Figure 10 Apposition of mid-lateral traction sutures in the lateral wall, one ring distant from the cut edges on the cartilaginous tissue. (A) Left main bronchus; (B) pericardium.

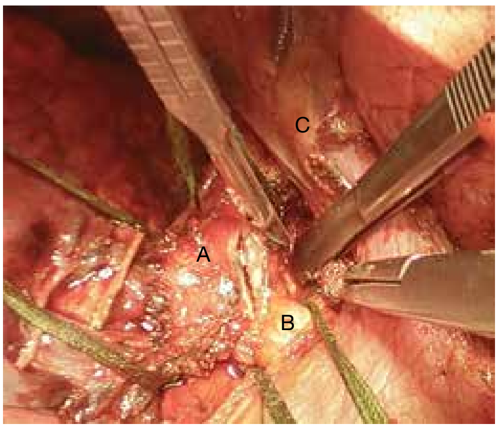


Figure 11 Bronchoscopy has been performed and the decision where to place the proximal cutting edge (incision with scalpel) made. (A) Trachea; (B) left main bronchus; (C) superior vena cava.

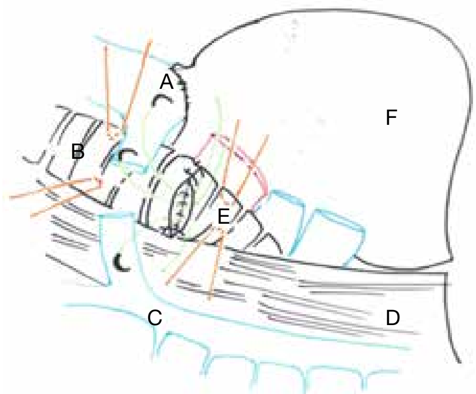


Figure 12 From right thoracotomy: traction sutures (in orange) are first placed to test the tension of the anastomosis. After that, anastomotic suture is placed with interrupted 4-0 absorbable stitches (in green).

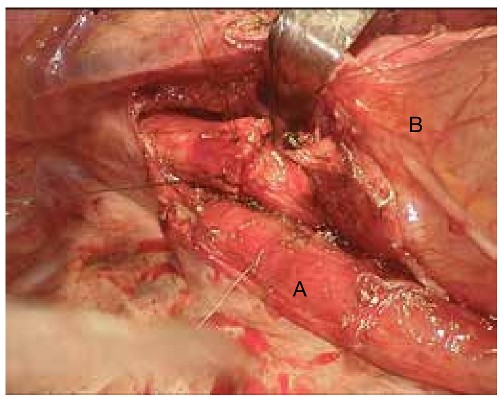


Figure 13 The suture is completed, and the knots tied outside. After the pneumatic proof with saline solution, a second layer flap (with pericardium or intercostal muscle) is always used. (A) Esophagus; (B) pericardium.

is similar to that obtained with the median sternotomy, but the clamshell incision allows larger bilateral exposure to the two pleural cavities and the pulmonary hilum, with sufficient exposure of the posterior surface of the airway. This approach is advantageous to achieve the maximum left hilar release when the airway reconstruction faces an extensive gap.

Sequential posterolateral thoracotomies or right thoracotomy associated with left video assisted thoracic surgery (VATS) are alternatives to clamshell incision.

Here a brief summary of a clinical case that you can see in the figures (*Figures 4,6-8,10,11,13,15-21*). This is a case of a 41-year-old female patient, affected by adenoid cystic tumor of the right main bronchus, which involves the carina and the first centimeter of the left main bronchus. Due to the necessity of resect a wide part of trachea, the best approach for this right sleeve pneumonectomy is a clamshell incision. This allows a major left hilar release with the maximum mobilization of the left main bronchus.

VATS approach

Recently, VATS approach to right sleeve pneumonectomy has been described. These little case series are restricted to single author's experience, due to the technical challenging. Very short carinal resection seem to be the main indication

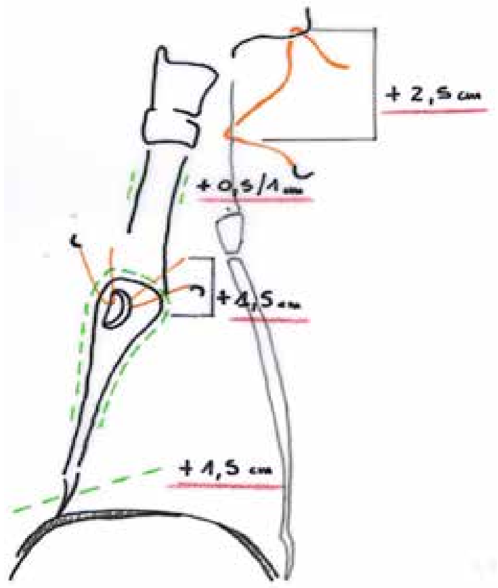


Figure 14 Tension is enemy of successful bronchoplastic procedure. Here there are the points where pericardial or peribronchial tissues dissection, division of inferior pulmonary ligament, dissection of peritracheal soft tissue (green dotted lines) can release the structures and can avoid traction on the anastomosis. In the figure is specified how many centimetres of release can be obtained in each site of dissection. In orange the stich on chin and the traction sutures on the edge of trachea section.

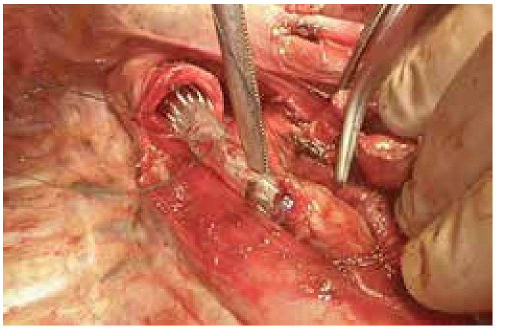


Figure 15 After right pneumonectomy and resection of the distal trachea and carina, the beginning of end-to-end anastomosis between trachea and left main bronchus (absorbable monofilament 4/0 interrupted suture). The gap between the trachea and the left main bronchus should be ≤4 cm.

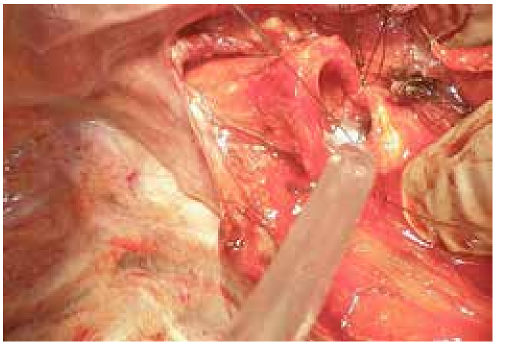


Figure 16 Traction sutures are tied before the anastomotic sutures, and cervical flexion is raccomended during this maneuver. As each stich of the posterior and anterior wall is tied, excess suture is removed.

for this approach (9,10).

Left sleeve pneumonectomy

This kind of tracheal resection (*Figure 22*) is much less frequent than right sleeve pneumonectomy due to the length of the left main bronchus and to the fact that tumors of this side very often invade the structures of the subaortic space.

Furthermore, this kind of bronchoplasty is more challenging because of the aortic arch, which covers the lower trachea and the right mainstem bronchus (6).

Surgery can be performed via different approaches. In every case it's important to avoid devascularization of trachea and main bronchus, and to minimize airway tension by extended releasing maneuvers.

Thoracotomy approach

When the tumor invades the left mainstem bronchus with a limited involvement of the carina, a left thoracotomy is the best choice. It offers an excellent exposure of the pleural space and a sufficient access to the posterior mediastinum (6).

A left posterolateral thoracotomy is performed in fourth intercostal space. The aorta is suspended and retracted laterally and cranially to expose the aortopulmonary window (*Figure 23*). Pulmonary artery and aorta are separated. The anterolateral plane of the trachea and the right mainstem bronchus are dissected.

An extended lymph node dissection is performed. The hilar arterial and venous vessels are divided.

The trachea, the left and right mainstem bronchus are encircled.

The ventilation of the right lung with a cross-fields sterile endotracheal tube follows the cutting of the airway.

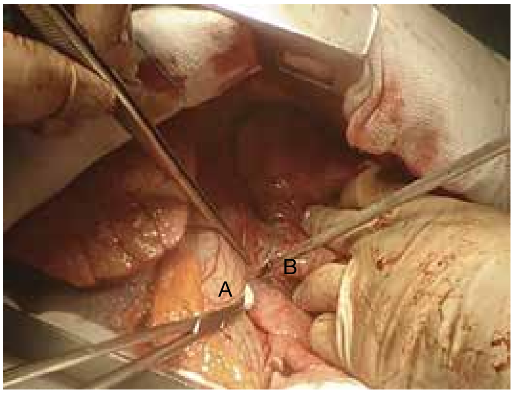


Figure 17 Vision of the left hilum by a clamshell incision. Dissection of the mediastinal pleura on the left inferior vein and inferior ligament. (A) Left ventricle; (B) left inferior vein.

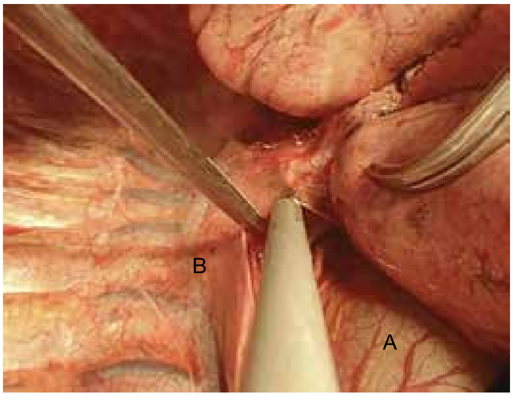


Figure 18 Incision of right mediastinal pleura to obtain hilar release. (A) Pericardium; (B) azygos vein.

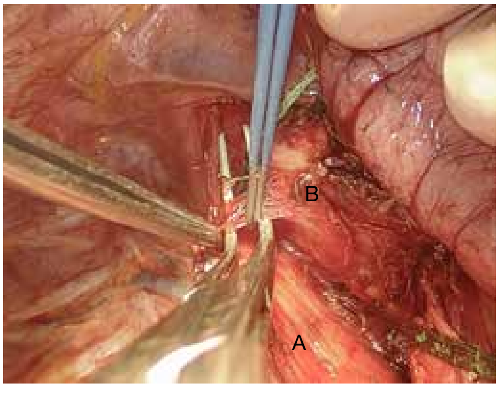


Figure 19 Retraction of the trachea and dissection of the retrotracheal plane to obtain maximum mobilization. (A) Esophagus; (B) posterior wall of trachea.

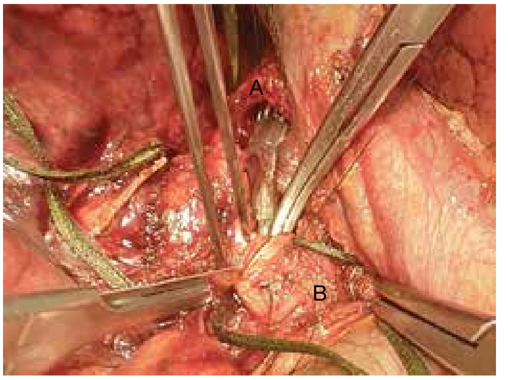


Figure 20 Through the tracheal incision there is the orotracheal tube, that is correctly placed into the left main bronchus. The section of left main bronchus has been completed. (A) Trachea at the edge of transection; (B) left main bronchus.

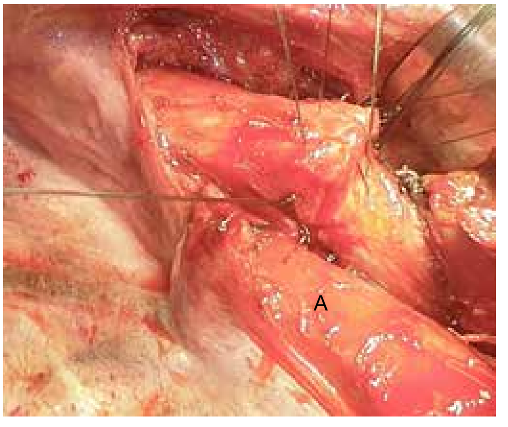


Figure 21 After positioning the anastomotic sutures, the paired lateral stitches are tied on each sides at the same time. This reduces the tension as the next sutures are tied, and allow to decide how many stitches are necessary. (A) Esophagus.

Left pneumonectomy is performed.

Lateral traction absorbable suture with 2-0 are placed in the distal trachea and right mainstem bronchus. The anastomosis is achieved with a circumferential 4-0 interrupted suture with the knots tied in the outside, which starts at the farthest point from the surgeon. All stiches are sequentially placed before knots are tied.

Any size discrepancy between trachea and right bronchus should be adjusted with each stitch instead of tailoring the section margin (2). The patient's chin is flexed to approximate the suture. First of all, it's better to tie the

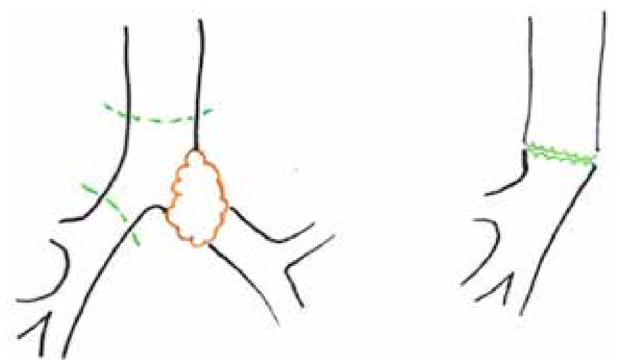


Figure 22 Airway reconstruction after left sleeve pneumonectomy.

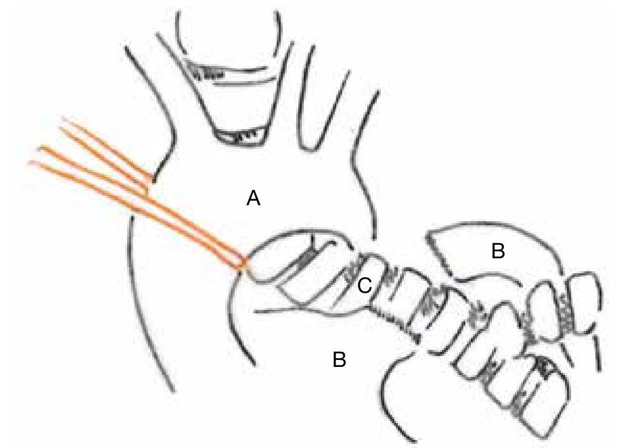


Figure 23 Retraction of aortic arch (A) for a right exposure and section of pulmonary artery (B) and left mainstem bronchus (C).

traction stitches, and after the stitches on the cartilage side. The membranous sutures are the last one to be tightened.

Sternotomic approach

The median sternotomy allows a bilateral access to mediastinum with a good anterior exposure of the trachea (despite the presence of aortic arch that doesn't allow the access to this part of the mediastinum). On the other hands the control of the left pulmonary veins is more difficult, and the access to the posterior part of mediastinum is limited and the presence of aortic arch does not allow to expose the entire surface of the airway.

After median sternotomy, the anterior pericardium is opened. The superior vena cava is encircled and retracted to the right, the aorta is retracted to the left leading to the exposure of the posterior pericardium.

For a better exposure of the left mainstem bronchus is necessary to retract the aorta to the right: this maneuver allows isolation and section of the right pulmonary artery follows by the two pulmonary veins (*Figure 23*) (5).

The endotracheal tube is retracted and the airway is divided with two sections: on distal trachea and on proximal right bronchus. Left pneumonectomy is therefore performed. The right lung ventilation depends on a cross-fields sterile endotracheal tube. We suggest to increase the mobility of the pretracheal plane by hilar release and by dissection of the tissue that cover the right bronchus and trachea. As usual, lateral traction sutures are placed on either side.

Unlike thoracotomic approach, in this situation the interrupted anastomotic stitches are placed in the membranous trachea first and tied inside. Afterwards interrupted 4-0 suture are placed in the cartilaginous trachea and tied outside.

Clamshell approach

The clamshell approach has the same advantages previously exposed for the right sleeve pneumonectomy; in addition, the combination of anterior view of the mediastinum and the lateral view of the left pleural cavity makes this approach particularly attractive for the left sleeve pneumonectomy.

Combined approach

A smart combined approach to left pneumonectomy with carinal resection includes the right thoracotomy for carinal resection and anastomosis between the trachea and the right main bronchus followed by a left VATS pneumonectomy (9,10).

Common auxiliary maneuvers and postoperative care

Anastomotic prophylactic coverage is advisable especially to isolate the suture line from the vascular structures immediately anterior to the anastomosis: pericardial fat, pleural flap, azygos vein flap or intercostal muscle flap are commonly used. We test air leakage by soaking anastomosis in sterile warm saline solution. Systematic lymph node dissection is a routine practice.

When a considerable tract of the trachea was resected, a heavy stich between the chin and the skin overlying the sternal manubrium is recommended to limit patient's neck extension and to protect the airway anastomosis in the early postoperative day (~7 days) (2).

Postoperative care begins with a flexible bronchoscopy after the surgery to control the anastomosis and to clean up the secretions. Most of the patients are extubated in the operating room. The management is focused on systematic pulmonary toilet maneuvers with early mobilization, serial bronchoscopies and physiotherapic exercises.

To obtain the best pain control we suggest to use epidural anesthesia.

Perioperative wide spectrum antibiotic therapy is usually recommended and its duration is determined by the clinical status and the quality of the secretions. Caution intravenous fluids administration is required to avoid fluid overload.

Some authors suggest to use beta-blockers or calcium channel blockers to prevent atrial arrhythmias.

A flexible surveillance bronchoscopy is appropriate to evaluate the anastomosis before discharge from the hospital (~7 days postoperatively).

Tips and tricks

❖ Transternal approach allows a bilateral control of the airway and it is a good choice for tumor of the distal trachea only with minimal involvement of the mainstem bronchi (<2 cm).
❖ Lateral dissection to the proposed lines of transection should be limited to avoid devascularization of the airway (<2 cm). Same attention must be taken during lymph node dissection.
❖ To avoid injury of the left recurrent laryngeal nerve during the dissection we suggest to stay very close to the trachea.
❖ To reduce the tension of the suture a good maneuver is to dissect the anterior pretracheal plane (commonly during the mediastinoscopy) and release the hilum (*Figures 4,8,18,19*).
❖ Intraoperative bronchoscopy is very helpful to determinate the extension of the tumor. Use transillumination or a transbronchial needle to mark the exact point.
❖ Transection of the trachea and mainstem bronchus must be performed perpendicular to the axis.
❖ Perform a complete circumferential section of the airway without leaving rim of cartilage between the structures
❖ The distance of the resection line to the tumor should be >1 cm.
❖ Do not tailor trachea or bronchus to correct size discrepancy.
❖ Traction sutures should not be placed in the membranous wall, since they may tear as they are tied.
❖ Many authors prefer the technique in which running sutures are used for membranous part and interrupted sutures are used for the cartilaginous part.
❖ Intraoperative frozen-section examination of the proximal and distal resection line is mandatory.
❖ Wrap the anastomosis with intercostal muscle flap, pericardium or pericardial fat.
❖ Immediate post-anastomosis bronchoscopy is useful to check the suture.
❖ In few selected cases a temporary tracheotomy can be performed in the first days to facilitate direct aspiration of secretions.

Comments

Complications

The main cause of death is related to the development of respiratory failure:

❖ Adult respiratory distress syndrome (ARDS) and post pneumonectomy pulmonary edema: this syndrome occurs in the first 72 hours in 10% of patients with an associated mortality risk of 90%. The cause remains unclear but maybe it results from a combination of systemic inflammatory response, barotrauma, fluid overload and lymphatic interruption. Current recommendations include minimizing pulmonary artery pressures, minimizing mean and peak airway pressure, diuretics, non-invasive ventilation and fluid restriction.
❖ Anastomotic dehiscence: it occurs from 11% to 17% and it is mostly related to tension, faulty anastomotic technique or intraoperative devascularization with subsequent ischemia. The overall death rate is close to 44%. If there is any evidence of immediate anastomotic leak it is necessary a surgical repair. If dehiscence occurs, it's necessary to protect airway with endotracheal ventilation, set up a multi-spectrum antibiotic therapy and drain the pneumonectomy space with a chest tube or performing an open thoracostomy. Necrosis and ischemia can be treated with hyperbaric oxygen therapy. Delayed stenosis and granulation tissue are considered late complications and can benefit from pneumatic dilatation eventually followed by endobronchial stenting (11).
❖ Vocal cord dysfunction: injury to the recurrent laryngeal nerves with vocal cord palsy is possible,

but it is usually temporary and it resolves in several months. It can be useful a chin tuck maneuver to improve airway protection from aspiration. Keep attention during the tracheal dissection maneuvers to avoid nerve injury (12).

- ❖ The best treatment for complications remains their prevention.

The tumor involvement of the superior vena cava increases the technical difficulty and the risk of complications.

Results

The results of tracheal sleeve pneumonectomy have improved over time and the procedure is relatively safe in experienced centers. The current perioperative mortality rates in selected patients ranges from 7% to 10%, and the morbidity and mortality are very close to standard pneumonectomy.

Mediastinal lymph node involvement is the main prognostic factor: the long-term results for N2/N3 nodal disease remain poor with a 5-year survival of 12–15% (1). If the mediastinal lymph nodes are negative the survival rate reaches 53%. These data highlights the importance of preoperative mediastinal staging (3).

So if the preoperative staging of tumors invading the airway space demonstrates nodal involvement (stage IIIb), there must be questions and doubts about the advantage of this surgery in those patients (see contraindications) (13).

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. de Perrot M, Shields TW, LoCicero J, et al. Tracheal Sleeve Pneumonectomy. In: Shields TW, LoCicero J, Reed CE, et al. editors. General Thoracic Surgery. 7th Edition. Ambler: Lippincott Williams & Wilkins, 2009.
2. Grillo HC. Surgery of the trachea and bronchi. London: BC Decker Inc., 2004
3. Silvestri GA, Gonzalez AV, Jantz MA, et al. Methods for staging non-small cell lung cancer: Diagnosis and management of lung cancer, 3rd ed: American College of Chest Physicians evidence-based clinical practice guidelines. Chest 2013;143:e211S-e250S.
4. Young-Beyer P, Wilson RS. Anesthetic management for tracheal resection and reconstruction. J Cardiothorac Anesth 1988;2:821-35.
5. Ginsberg RJ. Carinal Resection and Sleeve Pneumonectomy Using a Transsternal Oper Tech Thorac Cardiovasc Surg 1998;3:203-16.
6. Dartevelle P, Macchiarini P. Techniques of pneumonectomy. Sleeve pneumonectomy. Chest Surg Clin N Am 1999;9:407-17, xi.
7. Grillo HC. Carinal reconstruction. Ann Thorac Surg 1982;34:356-73.
8. Weder W, Inci I. Carinal resection and sleeve pneumonectomy. J Thorac Dis 2016;8:S882-S888.
9. Gonzalez-Rivas D, Yang Y, Stupnik T, et al. Uniportal video-assisted thoracoscopic bronchovascular, tracheal and carinal sleeve resections†. Eur J Cardiothorac Surg 2016;49 Suppl 1:i6-16.
10. Ai B, Liao Y, Zhang Z, et al. Single-stage bilateral thoracic surgery via a combined VATS and open approach for left central bronchogenic carcinoma with carinal invasion: report of two cases. J Cardiothorac Surg 2015;10:76.
11. Mathisen DJ, Morse C. Master Techniques in Surgery: Thoracic Surgery: Lung Resections, Bronchoplasty. Lippincott Williams and Wilkins, 2014.
12. Banki F, Wood DE. Techniques of Performing Left Carinal Pneumonectomy. Oper Tech Thorac Cardiovasc Surg 2007;12:194-209.
13. Dartevelle PG, Macchiarini P, Chapelier AR. 1986: Tracheal sleeve pneumonectomy for bronchogenic carcinoma: report of 55 cases. Updated in 1995. Ann Thorac Surg 1995;60:1854-5.

doi: 10.21037/shc.2017.08.11
Cite this article as: Nosotti M, Righi I, Damarco F, Rosso L. Tracheal sleeve pneumonectomy: indications and surgical operative techniques. Shanghai Chest 2017;1:29.

Rib fracture repair

Thomas W. White, Sarah Majercik

Trauma and Surgical Critical Care, Intermountain Medical Center, Salt Lake City, Utah, USA

Correspondence to: Thomas W. White. Trauma and Surgical Critical Care, Intermountain Medical Center, Salt Lake City, Utah, USA. Email: Tom.White@imail.org.

Received: 21 April 2017; Accepted: 19 May 2017; Published: 14 June 2017.

doi: 10.21037/shc.2017.05.07

View this article at: http://dx.doi.org/10.21037/shc.2017.05.07

Introduction

Blunt chest wall trauma and the resultant fracture of ribs is exceedingly common and is the source of significant morbidity and potential mortality. Surgical repair for markedly displaced rib fractures, particularly in the setting of flail chest has been attempted sporadically for over 50 years. In the last decade, rib-specific plating systems have been introduced. These have helped to usher in the era of modern rib repair and have made surgical stabilization of rib fractures (SSRF) technically easier, safer, and arguably more effective. In the United States, the procedure is increasingly utilized by trauma, orthopedic, and thoracic surgeons.

Two recently published consensus statements have attempted to codify the indications, contra-indications, timing, and technical aspects of SSRF (1,2). In brief, patients with three or more severely displaced rib fractures or flail chest (two or more contiguous ribs fractured in two or more places) should be considered for repair whether they require mechanical ventilation or not. Other candidates may include patients who fail optimal non-operative management regardless of fracture pattern, and patients with rib fractures who require thoracotomy for another reason. Severe traumatic brain injury and unstable spine fracture are absolute contraindications to immediate SSRF. The role of pulmonary contusion in the decision to repair the unstable chest wall remains controversial, but in general is not a contraindication.

Operative techniques

Preparation

Once the trauma patient has been satisfactorily resuscitated, hemodynamic stability has been achieved, and a thorough evaluation of all injuries completed, a decision to proceed with operative fixation of rib fractures can be made. Three-dimensional reformatted images of the chest CT scan (*Figure 1*), while not mandatory, are extremely helpful in delineating the true extent of fractures, chest wall deformity/instability, and in incision planning. Pre-operative patient optimization must include aggressive multi-modal pain control, pulmonary hygiene, and an assessment of pulmonary function, i.e., spirometry. Pre-operative bronchoscopy can clear bronchial secretions and blood, and assist in placement of a double-lumen endotracheal tube, if necessary. Many surgeons utilize VATS routinely (3). These authors do so selectively to assist in evacuation of hemothorax, localize fractures, and to rule-out diaphragm laceration.

Operation

Lateral decubitus positioning provides access to the majority of rib fractures. Supine position with a bump will provide ideal exposure for anterior and antero-lateral fractures. Many patients will have multiple fracture lines and may benefit from dual incisions. Prone positioning with 90-degree abduction of the ipsilateral arm will rotate the scapula laterally and optimize exposure to posterior and subscapular fractures (*Figure 2*).

Proper placement of the surgical incision(s) should minimize incision length and soft–tissue trauma. We have increasingly adopted non-traditional incisions, such as oblique or vertical, and avoid muscle transection whenever feasible. "Splitting" (without dividing) the latissimus dorsi is routine and provides excellent exposure to most lateral and posterior fractures. The *triangle of auscultation* affords the surgeon reliable access to the subscapular space (*Figure 3*).

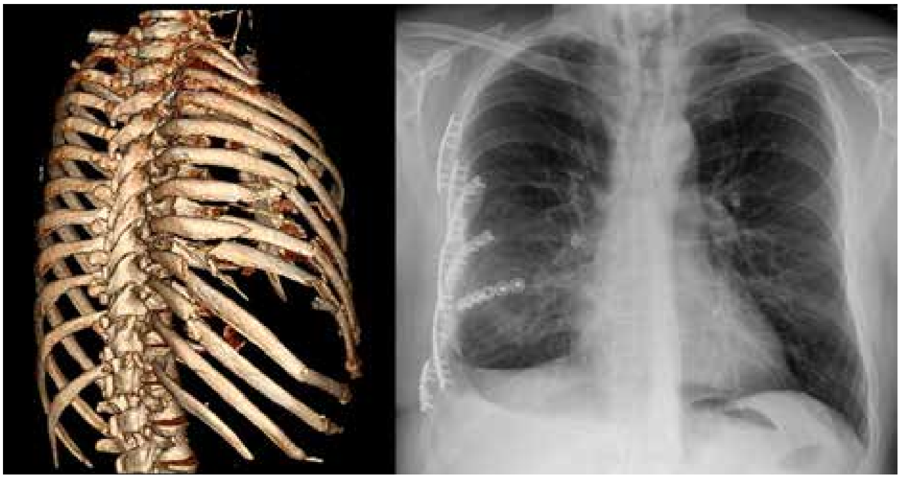


Figure 1 3D rendering of chest CT scan.

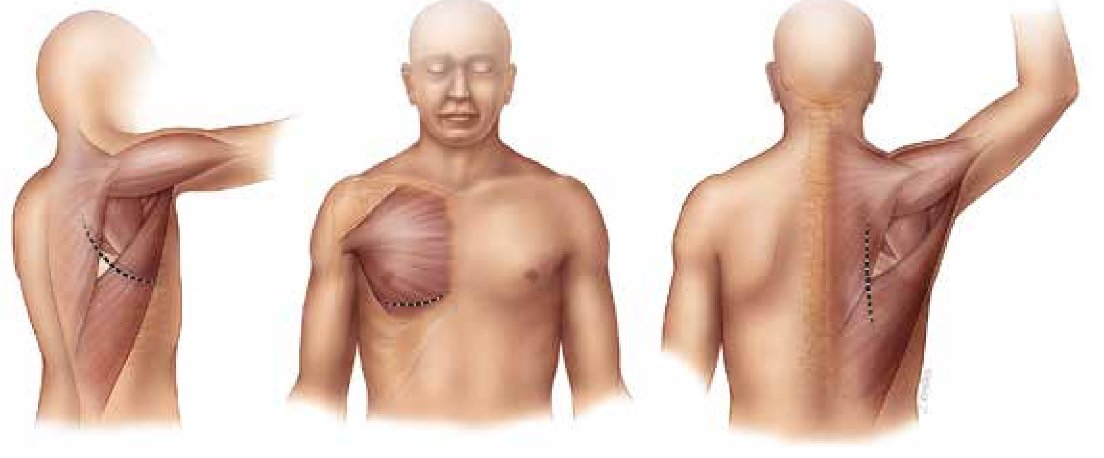


Figure 2 Common muscle sparing incisions (subscapular, inframammary and posterior vertical).

Following skin incision, sub-cutaneous flap development will allow access to multiple fractures through the same incision. Fractures are generally easily palpable through the musculature and should be exposed individually. Self-retaining retractors such as the Bookwalter or Thompson type retractor can aid in this exposure. Fracture reduction is usually quite simply accomplished with lifting of the depressed rib segment with a right-angle clamp or finger and the fracture ends can be "perched" in proper reduction. Reduction of multiple adjacent fractures in sequence prior to fixation will help maintain chest wall contour and aid in hardware placement.

Clearing the rib of its anterior soft tissue envelope is necessary for 3 centimeters on either side of the fracture to facilitate precise matching of rib prosthesis to the rib surface. Aggressive exposure of the fractured rib ends is unnecessary and undesirable.

Several rib-specific plating systems are now commercially available. They share multiple design features; notably, semi-rigid fixation with anterior plate positioning and locking screws. The flexible nature of ribs makes locking screws critical to minimize failure. Additionally, these systems are low profile, made from titanium, and easily shapeable (*Figure 4*).

Rib thickness is variable. Thus, prior to plating, in most systems, rib thickness is measured with a caliper to determine optimal screw length. Bi-cortical screw purchase of the rib is considered the standard at this time, but one

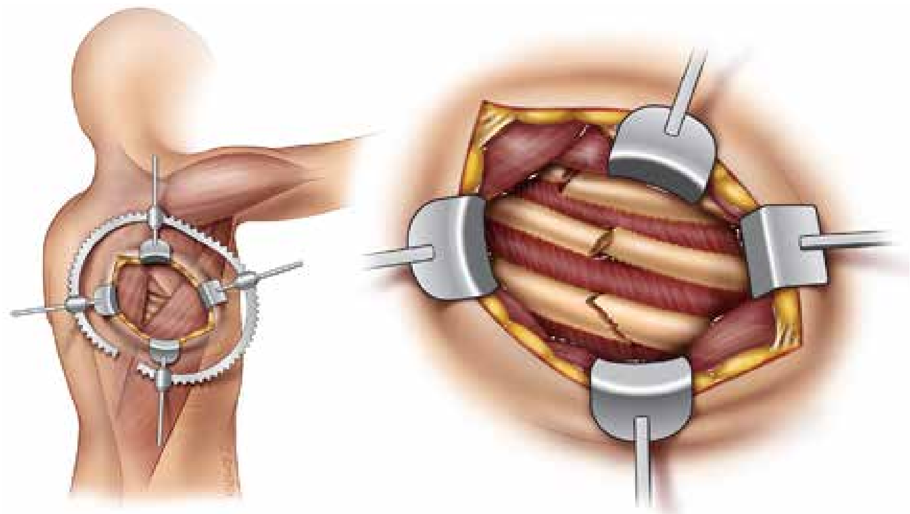


Figure 3 Subscapular exposure through the triangle of auscultation.

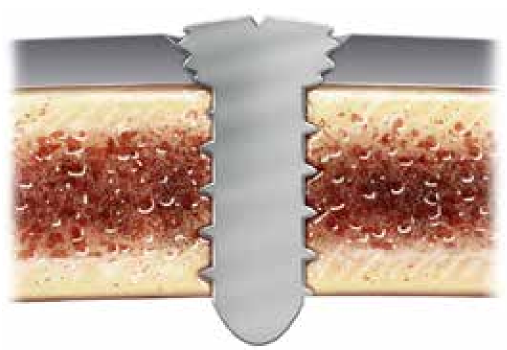


Figure 4 Bi-cortical fixation with locking screw construct.

commercially-available system utilizes shorter uni-cortical screws with non-parallel orientation. The surgeon will assess the obliqueness of the fracture line to determine how many screw holes to leave open in the middle of the plate. One should strive for a minimum of 3 cm of plate fixation on each side of the fracture (*Figure 5*). The plate should be shaped to the precise contour of the anterior rib surface with no gaps and with minimal tension. Plate holding forceps or right angle clamps will hold the plate in position and the rib in reduction for screw placement. Current systems utilize either pre-drilling or self-tapping screws.

Ribs have complex shapes and precise matching of plates to ribs will often require bending and twisting in two or more planes. All of the available systems have "low profile" or right angled drill and screwdriver instruments to accommodate fixation at the extremes of exposure, i.e. underneath the scapula or close to the spine.

It is unnecessary to repair every broken rib. In general, ribs 1,2,11, and 12 should be avoided. Chest wall stability increases with each rib stabilized and it is reasonable to fix all rib fractures that are readily approachable through the index incision. One should make a concerted attempt to repair both fracture lines in the setting of flail (*Figure 6*).

Completion

Closure is made easier with muscle sparing approaches. Absorbable sutures in a running or interrupted fashion, are used to close muscular "windows". The decision to place a closed suction drain in the sub-cutaneous space is based on host factors and surgeon preference. Chest tube placement is optional but strongly suggested by these authors. We utilize soft, fluted tubes of 24Fr diameter. This is an excellent opportunity to lavage the pleural space with 1 or 2 liters of warm saline. These authors use this blind lavage technique and have had excellent results with minimal incidence of retained hemothorax (4). Placement of a regional analgesia catheter or intercostal rib blocks complete the procedure (*Figure 7*).

Comments

Rib fracture repair, like any other procedure, has a definite learning curve. Those new to SSRF should select patients

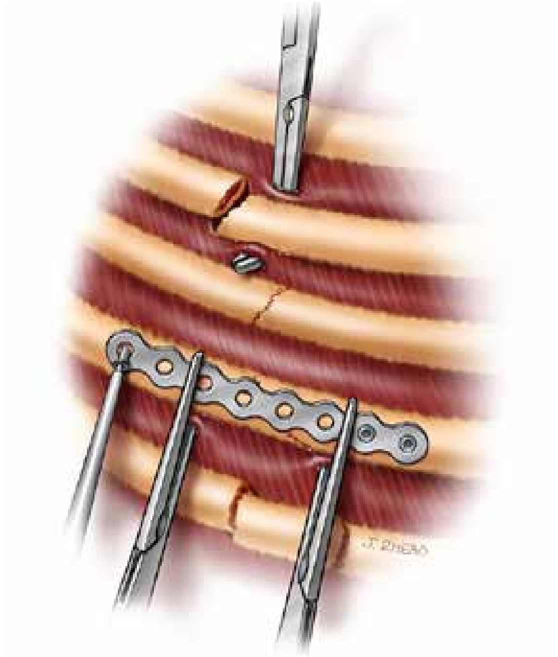


Figure 5 Fracture reduction and plate application.

Figure 6 Various fracture and plate configurations.

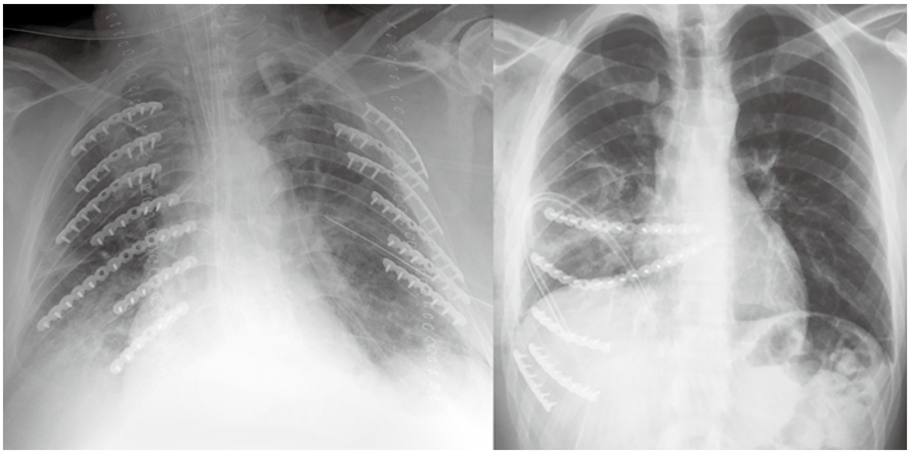


Figure 7 Bilateral fracture repair and costo-sternal bridging.

with lateral fracture patterns, avoiding the more difficult fractures at the extremes of exposure. Length of incision will naturally diminish as one gains experience and confidence in adequate exposure and reduction of fractures. Most rib repairs in the US are performed by trauma or thoracic surgeons, although this varies from center to center. Surgeons new to the principles of osteosynthesis may wish to enlist the help of an orthopedist colleague as they navigate their early experience.

Acknowledgements

We would like to thank Jill Rhead as our talented and generous Medical Illustrator for the chapter.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Pieracci FM, Majercik S, Ali-Osman F, et al. Consensus statement: Surgical stabilization of rib fractures rib fracture colloquium clinical practice guidelines. Injury 2017;48:307-21.
2. Kasotakis G, Hasenboehler EA, Streib EW, et al. Operative fixation of rib fractures after blunt trauma: A practice management guideline from the Eastern Association for the Surgery of Trauma. J Trauma Acute Care Surg 2017;82:618-26.
3. Pieracci FM, Lin Y, Rodil M, et al. A prospective, controlled clinical evaluation of surgical stabilization of severe rib fractures. J Trauma Acute Care Surg 2016;80:187-94.
4. Majercik S, Vijayakumar S, Olsen G, et al. Surgical stabilization of severe rib fractures decreases incidence of retained hemothorax and empyema. Am J Surg 2015;210:1112-6; discussion 1116-7.

doi: 10.21037/shc.2017.05.07
Cite this article as: White TW, Majercik S. Rib fracture repair. Shanghai Chest 2017;1:11.

Chest wall surgical stabilization after thoracic trauma: indications and techniques

Roberto Crisci, Duilio Divisi

Thoracic Surgery Unit, University of L'Aquila, "G. Mazzini" Hospital, Piazza Italia 1, Teramo, Italy
Correspondence to: Duilio Divisi, MD, PhD. Piazza Italia n.1, 64100 Teramo, Italy. Email: duilio.divisi@aslteramo.it.

Received: 02 March 2017; Accepted: 23 March 2017; Published: 30 May 2017.
doi: 10.21037/shc.2017.05.04
View this article at: http://dx.doi.org/10.21037/shc.2017.05.04

Introduction

The increase in work and road traffic accident has made chest wall traumas very relevant (1,2). This pathological situation is, often, characterized by flail chest, chest wall deformity with displaced rib edges, rib or sternal fractures with nonunion, determining a retraction of the thorax and disability (3,4). Conservative treatment consists in a better control of pain and in a careful bronchial cleaning, up to prolonged mechanical ventilation. This method, in case of flail chest with paradoxical movements of the rib segments or of sternal fracture with overlap of the stumps and/or lesion of the costal cartilages, ensures an internal pneumatic stabilization (5). The main limitation of this technique is related to the risk of ventilator acquired pneumonia, inability to complete reduce the deformity and, lastly, the impossibility of weaning from the ventilator (6). Surgical stabilization adopted once concomitant soft tissue, bone, spine or cranial injuries are resolved, ensures an effective sternocostal stiffness and a physiological mobility of the chest, favouring a valid postoperative respiratory rehabilitation. The chest wall trauma can also determine an additional pathological condition often linked to the common use of seat belts, requiring invasive treatment: the dislocation between the manubrium and the body of the sternum. Restoration of the anatomic structural continuity and alignment of the sternum allows a rapid functional recovery, through the improvement of the respiratory mechanics and lung volumes. The purpose of the study was to evaluate the different surgical methods of sternocostal osteosynthesis, highlighting tips and tricks of techniques.

Flail chest

Couraud *et al.* (7) defined it as "a wall segment disjointed from the rib cage". The definition of "flail chest" makes a clear reference to the paradoxical movement of the chest wall due to freely movable parietal strip (8,9). Considering the literature, we can define the "flail chest" as a loss of parietal stability following the segmental fracture of 2 or more neighbouring ribs, along with a gradual reduction of lung volumes and deterioration of lung function. Topographically it can be classified as: (I) anterior, with fracture foci regarding only the bone component or the bilateral costochondral joints, usually associated to a lesion of the sternum (*Figure 1*); (II) lateral or anterolateral, with fracture foci localised both in the bone and cartilage matrix of the ribs (*Figure 2*); (III) posterior or posterolateral, that rarely require surgical consolidation as parietal stiffness is guaranteed by the scapula and the muscles articulated on the chest (*Figure 3*); complex, characterized by multiple foci of fracture along the ribs. The type of flail chest dictates the choice of approach that should be adopted before the spontaneous consolidation of the stumps (within the first 4–5 days following the trauma). Three are the options: (I) thoracotomy, with a large section of the latissimus dorsi and serratus anterior. This access provides a wide exposure of the surgical field, dominating pleural cavity and allowing treatment of any concomitant injuries (lung or esophageal lacerations, diaphragmatic, tracheobronchial or vascular ruptures); (II) axillary "muscle-sparing" mini-thoracotomy, indicated in the case of unilateral rib fractures with reduced size and localization; (III) longitudinal suprasternal incision with dissection of the pectoralis major muscle beams on the

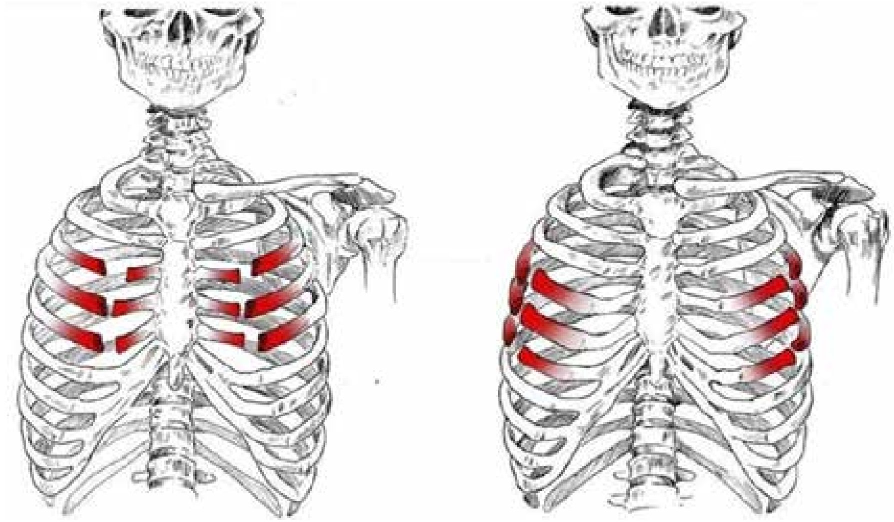


Figure 1 Anterior flail chest, with bilateral costochondral joints or rib lesions.

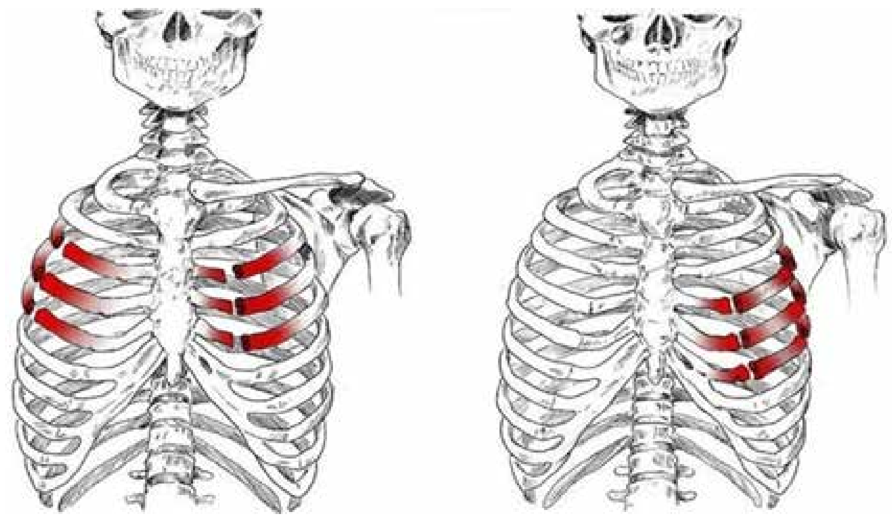


Figure 2 Anterolateral or lateral flail chest.

midline, allows the stabilization of the bilateral rib fractures located in the anterior and lateral costal arches.

Techniques of chest wall surgical stabilization

Flail chest correction carried out with suspension methods of the chest or osteosynthesis implantable devices.

External Traction

It is an obsolete method (10-12), consisting in the perpendicular traction of the floating ribs to the tie-rods in order to fix deformity and ensure normal lung ventilation. Traction, whose degree and duration are linked to both parietal mobility and respiratory insufficiency, can be applied either on soft tissue either or bone component. The first option is performed by the percutaneous introduction of steel wire or metal pin of varying calibre, such as to be positioned tangentially to the external surface of the rib cage and coming out above of the insertion point. Unfortunately, the pulling force on muscles, subcutaneous and skin do not guarantee an acceptable thoracic stability,

Figure 3 Posterior flail chest necessitating surgical fixation.

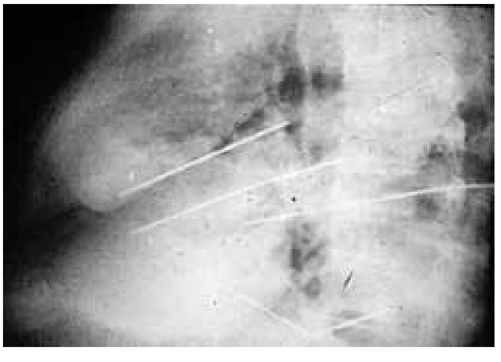


Figure 4 Osteosynthesis with Kirschner's pins.

leading to a progressive tissue section with bleeding and infection risk. The bone component traction requires the dissection of the chosen ribs, usually placed in a central position respect to the flail chest size, making a tunnel between the internal rib surface and the periosteum. The metal device hooks around the ribs in "horseshoe" formation, allowing a constant traction over time. In case of anterior flail chest different techniques were proposed such as a clothes hanger hook (13) or a clamp (14) between the two tables of the sternum, steel wire around the sternum after dissection of retrosternal space or a metal plate fixed to the sternum by two screws with distal hooks in the side edge (12). However, even though the bone traction offers a better performance than the same technique applied to the soft tissues, it also leads to significant complications: (I) the iatrogenic pneumothorax, due to the accidental injury to the parietal pleura which often requires a thoracostomy tube insertion; (II) the sliding of the wire or pin towards the fracture stump, causes progressive bone erosion; (III) bleeding, following the intercostal or internal mammary vessel lesions; (IV) wear of the device.

Kirschner method of osteosynthesis

Currently rarely used, is muscle sparing mini-thoracotomy, both in video-assisted thoracoscopy or percutaneously (15,16). The original technique consists in the introduction of metal pins of appropriate calibre in the central cavity of ribs by drilling the anterior cortex about two centimetres from the lesion. Then, through pronation/supination movements, the device is pushed up to exceed foci fractures, escaping the intact cortex and stabilizing the injury. In order to obtain a greater resistance, it is recommended that the points of entry and exit of the pin must be placed equidistant from each other with respect to the damaged area (*Figure 4*). Steel wire option offers two possible approaches (17,18): (I) shaping around the fractured ribs to form a metal sleeve; (II) vertical introduction inside the chest, including a rib already stabilised with plate and clavicle or sternum. Kirschner's technique has several disadvantages: (I) stabilisation of the commuted foci is difficult; (II) sealing is weak, causing wear and fragility of the device; (III) device displacement, determining bleeding for vascular lesion.

Osteosynthesis according to the method of Borelly

The sliding-staples-struts are characterised by a triple component (19,20): (I) the strut, where it is possible to recognize a single hook whose function is to articulate the rib and a "U" shaped mechanism positioned upwardly that represents the sliding plane of the metal plate; (II) the plate, is between 70 and 200 mm in length and not particularly rigid such as to be shaped according to the morphology of the ribs; (III) the straight and angular joints from 15° to 45°, which allow the device to adapt to the rib orientation. The device, shaped before fixation, must be placed perpendicularly to the longitudinal axis of the rib, in order to obtain a good hold (*Figure 5*). The advantage of this method is linked to the adaptability of the implant, which allows the stabilisation of multiple foci fractures to the replacement of the entire broken rib (*Figure 6*). Furthermore, Borrelly *et al.* (21) noticed the reduction in overall mortality of 8% and in length of mechanical ventilation from 5.8 to 2.98 days. The implant characteristics extend its use, with and without meshes or methyl methacrylate prosthesis, in the chest wall reconstruction for large defect following primary or secondary tumour resection (22, 23).

Osteosynthesis with Judet struts

It is a technique described in the seventies (24) but still widely used today because of its excellent functional and morphological results in the unilateral flail chest. Steel struts are characterised by a linear component, variable in length and width (from 12 to 24), with two or three pairs of hooks. The branches of the hooks appear asymmetrical, being respectively at an acute and obtuse angle depending on the fixation at the lower or higher costal margin (*Figure 7*). The application requires a wide subperiosteal exposure of the outbreaks as well as the preventive reduction of fractures (*Figure 8*), paying attention to the preservation of the intercostal vascular pedicle in order to avoid necrosis or pseudarthrosis of the stumps. Positioning is carried out by tightening the struts with the specific pliers by means of an abductive movement from the outside towards the inside and a semicircular movement from the bottom to the top (*Figure 9*). Advantages of this method (25,26) consist in its relative simplicity of execution and the preservation of rib articular mobility despite an excellent stabilization (*Figure 10*), determining minimal recourse of assisted ventilation and shorter hospitalization. Disadvantages are as follow: 1) the need of a wide posterolateral thoracotomy in order to totally dominate the lesion area; 2) the stabilisation of the single foci fracture for a period of time, increasing the operative time; 3) the possible long-term persistence of pain, if the intercostal nerve is inadvertently pressed between the branches of struts; 4) the spontaneous rupture of the device (*Figure 11*), requiring immediate removal to avoid vascular lesion. The latter inconvenience seems to be overcome by using the new titanium struts (*Figure 12*). The use of the Sanchez-Lloret struts (*Figure 13*) is preferable in the case of multiple comminuted rib fractures (27). This device differs from the Judet struts for their typical straight and not angled claws of the hooks, facilitating their modelling based on the physiological orientation of the ribs.

Figure 5 Courtesy of Prof. Borrelly. Intraoperative view of "atelles-agrafes".

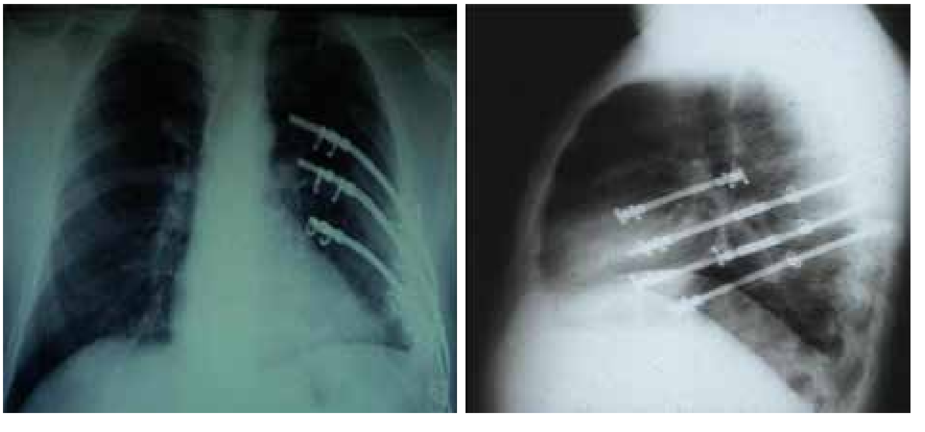


Figure 6 Courtesy of Prof. Borrelly. Postoperative chest X-ray evaluation.

Osteosynthesis with titanium plate and screws

In the last decade, titanium has replaced steel for the low friction coefficient and the high corrosion-thermal-mechanical resistance despite the low density. The use of plate is mainly recommended in anterior, anterolateral and lateral flail chest especially in case of bone loss (*Figure 14*). Types of plaques and the application techniques are variegated (28-30). In our clinical practice we use threaded screws (3 mm in diameter, 8–18 mm in length) and titanium plates (2.4 mm in thickness, 248.5 mm in length for 30 threaded holes divided into two parts of 15 holes with a central link). Using a special tool, the plates can be modelled based on the morphological characteristics of the lesion (*Figure 15*); the screws, whose length is measured with accuracy by means of the depth gauge, are fixed by making a hole in the anterior cortex using a drill with an appropriate locking mechanism so as not to exceed the posterior cortex. Anterior flail chest can be successfully treated by means of a single 30 holes plate, articulated centrally with respect to the longitudinal diameter of the defect. In order to ensure a symmetrical respiratory dynamics it is crucial that the two parts of 15 holes are bilaterally equidistant from the foci fractures; this involves firstly the central link fixation of plate to the sternum and subsequently the application of its distal ends over the stumps, on an undamaged segment

Figure 7 Judet struts.

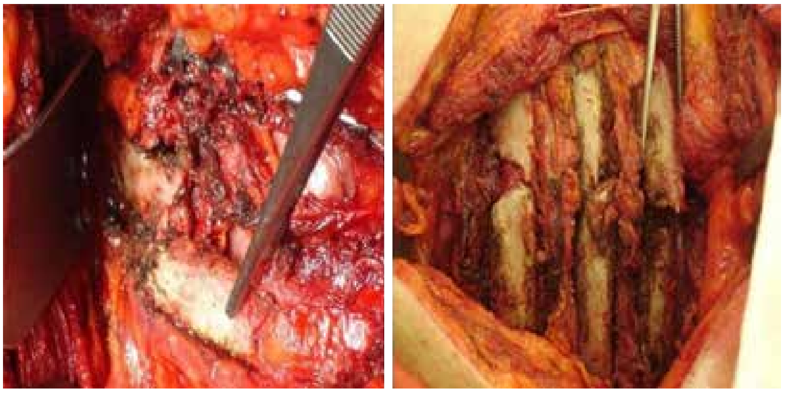


Figure 8 Subperiosteal alignment of outbreak fractures.

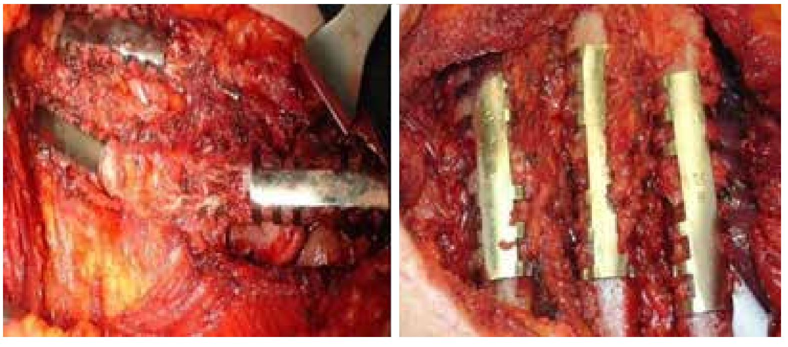


Figure 9 Stabilization with Judet struts.

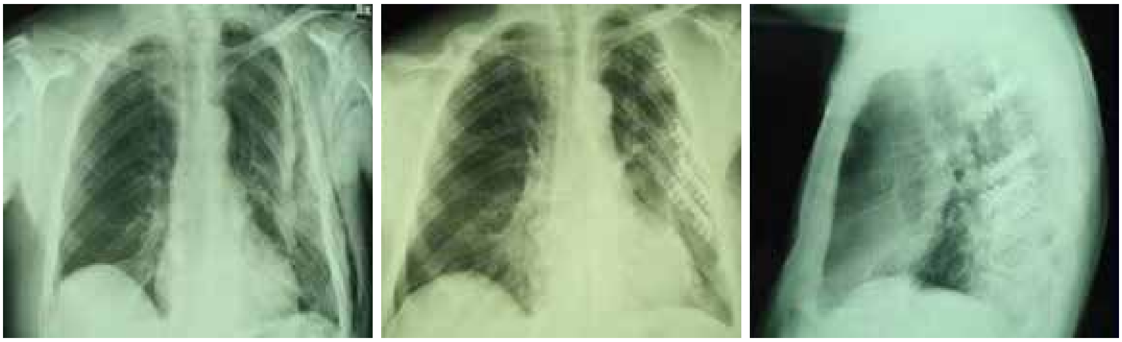


Figure 10 Chest X-ray shows a large flail chest between the 2nd and 8th left ribs and the surgical Judet strut target.

Figure 11 Spontaneous breaking of Judet strut.

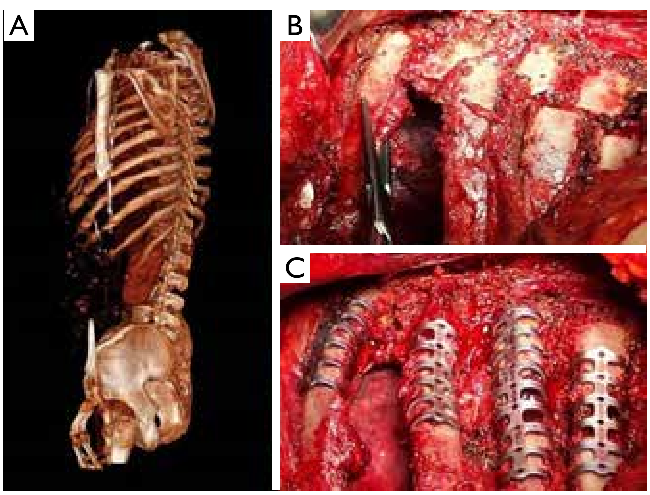


Figure 12 (A) 3-dimensional computed tomography reconstruction shows posterior flail chest; (B) intraoperative view displays the posterior fractures of 6th, 7th, 8th, 9th left ribs; (C) osteosynthesis with the new titanium struts.

Figure 13 Overview of Judet and Sanchez-Lloret struts, with specific tools for intervention.

of rib. In case of anterolateral or lateral flail chest the osteosynthesis with plate allows restoration of the normal thoracic continuity and chest wall stiffness (*Figure 16*). Despite the undoubted advantages of the method (running fast, safe and easily with an excellent stability of the rib cage) and the minimal complications (reduction of rib mobility or infection requiring the removal of device) there is still a lack of consensus in using titanium plate. Landercasper *et al.* (31), in 32 flail chest patients not surgically treated, showed that the 25% complained of chest restriction, 50% of persistent chest pain and 57% of spirometry abnormality at 5 year follow-up. Marasco *et al.* (32), studying 23 patients surgically and 23 patients conservatively treated, revealed better findings with the invasive approach in: (I) total intensive care unit stay (324 *vs.* 448 hours, P=0.03); (II) hospitalization (20 *vs.* 25 days, P=0.24); c) cost saving ($14,443 per operated patient).

Other techniques of osteosynthesis

Debates on the surgical approach to flail chest led to the development of methods, which still require extensive

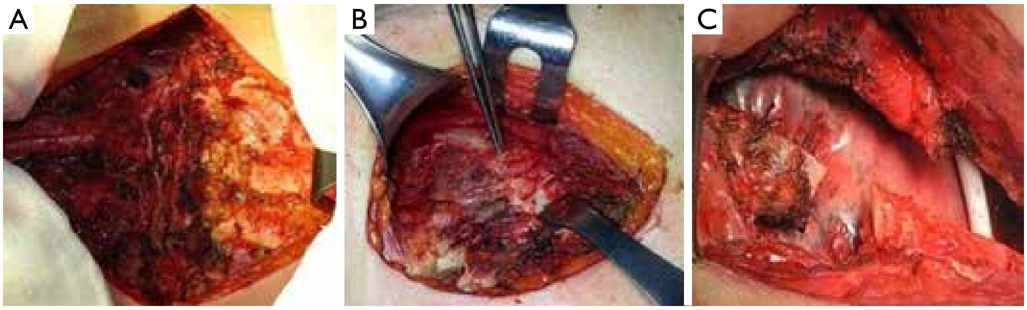


Figure 14 Different topographical aspects of flail chest: (A) anterior, with bilateral fracture of costochondral joints between the 4th and 7th rib; (B) anterolateral, with lesion of the 3rd and 4th left costochondral joints; (C) lateral, with destruction of a rib segment.

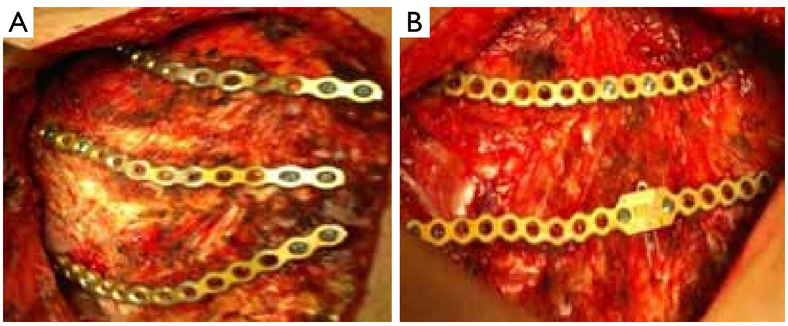


Figure 15 Right anterolateral (A) and anterior (B) flail chest positively stabilized with titanium plate.

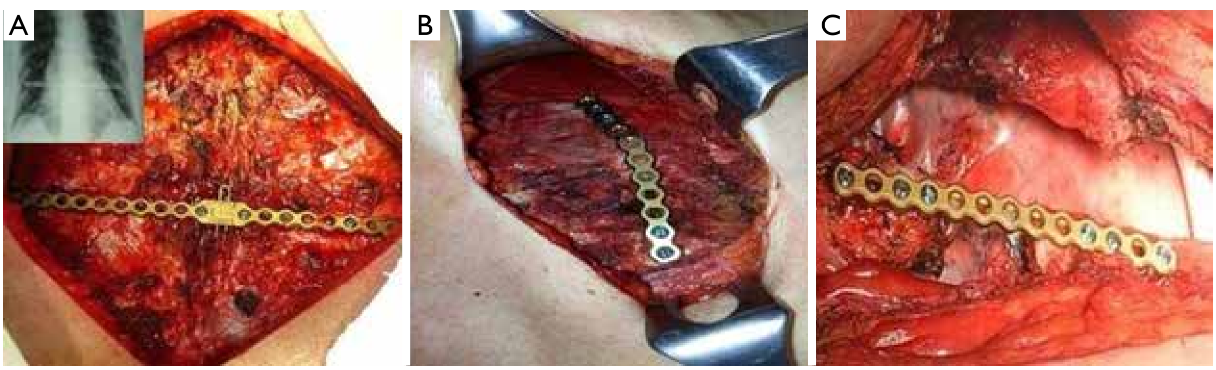


Figure 16 Osteosynthesis with titanium plate, re-establishing the stability and the physiological chest wall dynamics in the three pathological situations.

clinical confirmation. Bibas *et al.* (33) have proposed the use of Marlex mesh, fixed through polypropylene zero to totally cover the site of the lesion and coated with 40 mL of methyl methacrylate, whose polymerisation determines the invasion of the adjacent bone and muscles. Advantages consist in the easy supply of the devices, the reduction of operative time and the minimal tendency to infection. Mayberry *et al.* (34) have treated 10 flail chest patients by resorbable polylactide plate, shaped accordingly to the rib morphology by heating it to 60 degrees for 15 seconds. Disadvantages were: (I) the impossibility of weaning from mechanical ventilation (5 patients); (II) pain with thoracic instability (4 patients); (III) large chest wall defect (1 patient). The main advantages of this method compared to the plate technique consist in a more rapid and durable healing as well as the unnecessary removing of the device.

Flail chest

Flail chest determines a mixed respiratory insufficiency due to oxygen transfer alteration and hypoventilation with carbon dioxide retention. We tried to correct this pathological alteration by the association between conservative treatment and surgical approach. Advantages and disadvantages of different methods of osteosynthesis are already described in the respective paragraphs. Two aspects deserve to be further investigated: a) the thoracic analgesia; b) the steroid treatment for pulmonary contusion. Thoracic epidural analgesia (TEA) is the gold standard to providing adequate pain relief (35) although it is used rather than intercostal or paravertebral nerve blocks or patient-centered analgesia. This underutilization is due to technical failures (up to 30%) and experience or skills of the anesthesiologist (36). Paravertebral analgesia may be equivalent to epidural analgesia and may be appropriate when epidural is contraindicated. Currently, dexmedetomidine has been proposed because of high selective α-2 adrenoceptor agonists showing analgesic, sedative, sympatholytic and amnestic properties without respiratory depression (37,38). Pulmonary contusion due to blunt chest trauma leads to an early activation of the oxidant-antioxidant cascade, a delayed pulmonary capillary leakage, an elevation both in thromboxane and prostacyclin values; this reaction precedes the progressive bilateral neutrophil infiltration. The complications and risks versus benefit of steroid use have been widely investigated (39). Boybeyi *et al.* (40), studying the dimethyl sulfoxide and dexamethasone intraperitoneally administered in experimental pulmonary contused models, noticed that the first prevents further pulmonary injury decreasing both neutrophil infiltration and endothelial injury while the second might have a role in the development of inflammation. Ocalan *et al.* (41), analyzing the budesonide inhalatory effects on pulmonary contusion in 55 rats, showed an improvement of $SatO_2$ and PaO_2 compatible with a minimization of inflammatory pulmonary reactions.

Isolated sternal fracture and manubriosternal dislocation

The first case of surgical correction of the sternal fracture was described by McKim in 1943 (42). However, the randomized studies regarding the indications and techniques for traumatic sternal lesion stabilization are few and incomplete despite the considerable increase in injuries. Knobloch *et al.* (43) revealed 0.64% of sternal fractures in 42,055 traumatized patients as well as the correlation between injury severity score (r^2=0.92) and maximal abbreviated injury scale (r^2=0.81) and the deceleration velocity. Harston *et al.* (44), reviewing over 20 years of literature, displayed 52 patients with plates and 24 with wires surgically treated for sternal fracture, highlighting the need for a shared management especially in absence of concomitant injuries. In fact, the associated soft tissue, chest wall, spine and cranium lesions showed mortality between 25% and 45% (45). Also, we have noticed (46) in 65 patients with an isolated sternal fracture and a manubriosternal dislocation underwent surgical approach the quality-of-life improvement, the safe intraoperative and postoperative management using titanium plate compared with steel plate and steel wire. Surgical stabilization of isolated sternal fracture without underlying injuries is still particularly debated. Mayberry *et al.* (47) have found three key points: (I) the presence of a sternal deformity; (II) the sternal continuity loss for a period more than six weeks; (III) the persistence of chest pain, between two and eight weeks after trauma for the majority of surveyed surgeons. Based on our experience we suggested to add the oblique stumps and unstable nonunion of the sternum, with the overlap and mobility of the outbreak fractures. The indirect mechanism of trauma determines the hyperextension of the cervical and dorsal spine, or the hyperflexion of the head on the chest (*Figure 17*), or the sudden contraction of the abdominal and sternocleidomastoid muscles. Morphological characteristics of the sternal dislocation depend on the type of traumatic event, showing the posterior (Type 1: direct trauma) or anterior luxation (Type 2: indirect trauma) of the sternal body in respect to the manubrium. In this condition, the invasive approach is indicated in the case of respiratory failure due to a morphological alteration of the rib cage, kyphosis of the cervicothoracic spine with neck stiffness and pain associated with a serious esthetic damage. Surgical osteosynthesis of traumatic sternal lesions, the purpose of which is the restoration of the normal dynamic ventilation, is frequently pursued through metal wires or rigid plate and screws.

Osteosynthesis with metal wires

It is not an easy technique but still widely in use (47,48),

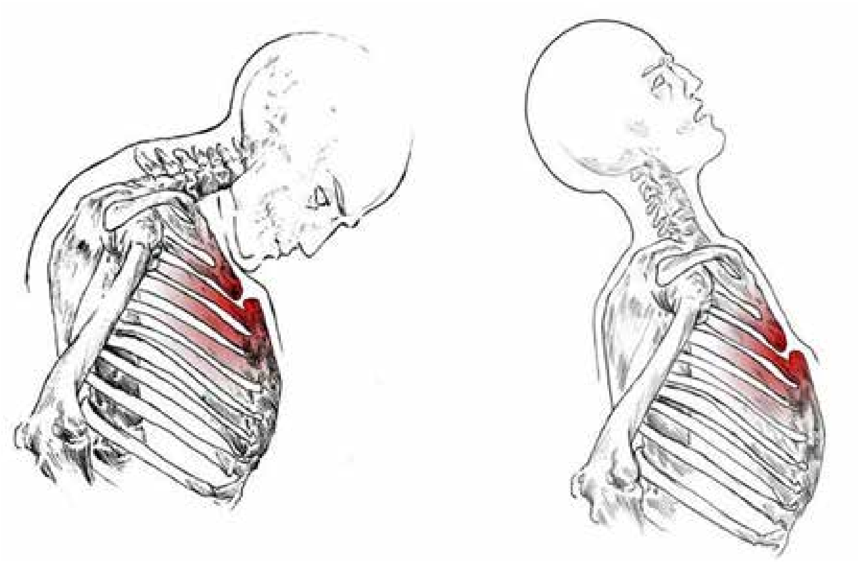


Figure 17 Indirect mechanisms of traumatic sternal lesion.

Figure 18 Metal wire which wrongly does not cross the posterior cortical margin of the sternum; the intact fracture site is downstream.

although clinical results are questionable. Method consists in the midline section of the pectoralis major muscle sternal beams, subperiosteal exposure of the fracture or luxation foci, dissection of the retrosternal and intercostal spaces bilaterally in order to stabilize the stumps by means of U-shaped or X-shaped stitches in the full thickness of the bone. The congruous dissection of the surgical site and surrounding structures prevents an abnormal or wrong positioning of the wire (*Figure 18*); the patient may incur in a high risk of vascular lesions facing a poor sternal stability.

Osteosynthesis with plate and screws

Different methods supported by a wide material availability have been proposed in sternal surgical stabilization (49-51). In our clinical practice we used both metal and titanium plates, characterised by an extremely easy fixation technique.

Isolated Sternal Fracture

The steel plates, no longer commercially available, are T-shaped. After section of the pectoralis major muscle sternal beams and subperiosteal exposure of the fracture site, the plate is fixed to the sternum by 3–5 threaded screws inserted into the anterior cortical margin and anchored to the posterior cortical in order to lift and stabilize the stumps (*Figure 19*). While this method allows an excellent surgical correction, three are the drawbacks: (I) difficult shaping of the plate, particularly rigid; (II) choice of the screw on the basis of the surgeon's experience and not through the clear assessment of the required length; (III) displacement of the plate and screws in the suprasternal plane or between the beams of the major pectoralis muscle. These difficulties seem to be overcome with the new titanium plate, which can be easily shaped according to the morphological aspects of the lesion. The threaded holes of the plate allow the simultaneous anchoring of the threaded screws both to

Figure 19 Correct fixation of T-shaped steel plate.

Figure 20 Isolated sternal fracture stabilized by titanium plate and demineralized bone matrix.

the sternum and the plate itself, inhibiting the likelihood of the displacement of the implant. Also, the use of a depth gauge able to calculate the distance between the two sternal cortical margins, ensures to the ability of objectively establishing the exact length of the screws to be employed. Gallo *et al.* (52) have set out three technical principles to be followed in the case of chronic traumatic sternal fracture: (I) the removal of the abnormal bone callus; (II) the internal fixation using rigid plates; (III) the autologous bone graft. In our experience, we have never carried out the bone transplant. If the loss of substance determined a solution of continuity of the sternum, we fix the implant with demineralized bone matrix (*Figure 20*).

Manubriosternal dislocation

After a longitudinal incision of the skin and subcutaneous tissue, the pectoralis major beams are dissected from the second to the fifth rib bilaterally for 3–4 cm (46). The subperiosteal dissection of the sternum, the excision of the manubriosternal synchondrosis already damaged by the traumatic event and the cuneiform chondrectomy of the third and fourth rib cartilage bilaterally, in order to align the manubrium and the body of the sternum, were carried out. From two to four threaded screws, whose length was precisely established by means of a depth gauge, per side based on the extension of the dislocation foci allow titanium plate fixation with the method already described. The use of the central part of the plate, including fitting U-shaped and needle hooking, ensures the physiological adaptation of the sternum to the respiratory excursions of the chest wall. Whether associating a sternal fracture, the application of the linear ends of the plate allows a better stiffness (*Figure 21*). Use of demineralized bone matrix can facilitate the bone callus formation due to the osteoinductive activity and the surrounding blood cells compatibility. Two 18 French Spiral drains were placed above the rib cage in order to avoid a blood or serous fluid collection. Advantages of this technique are as follows: (I) excellent stabilization, with preservation of the chest motility; (II) inhibition of serious thoracic spine and cage deformities; (III) reduction of iatrogenic complications; (IV) rapid recovery of respiratory function; (V) shorter duration of hospital stay with reduction in costs; (VI) undeniable aesthetic and antalgic outcomes.

Traumatic sternal lesions

The methods for isolated sternal fracture stabilization are still debated. Different techniques were proposed successfully: (I) wires associated with two threaded pins inserted between the two tables of the sternum, crossing the line of fracture (53); (II) X-shaped plate (54); (III) volar distal radius plate (55). We showed excellent outcomes with linear titanium plate. This device allows: (I) the rigid support of the sternum, inhibiting the abnormal movement of the fracture foci and/or bleeding; (II) the prevention of implant displacement, by means of the screws anchored simultaneously to the plate and sternum; (III) the rapid recovery of respiratory function associated with the pain reduction, determining excellent quality-adjusted life years. Manubriosternal dislocation is not widely treated in literature. We opine that respiratory insufficiency based on

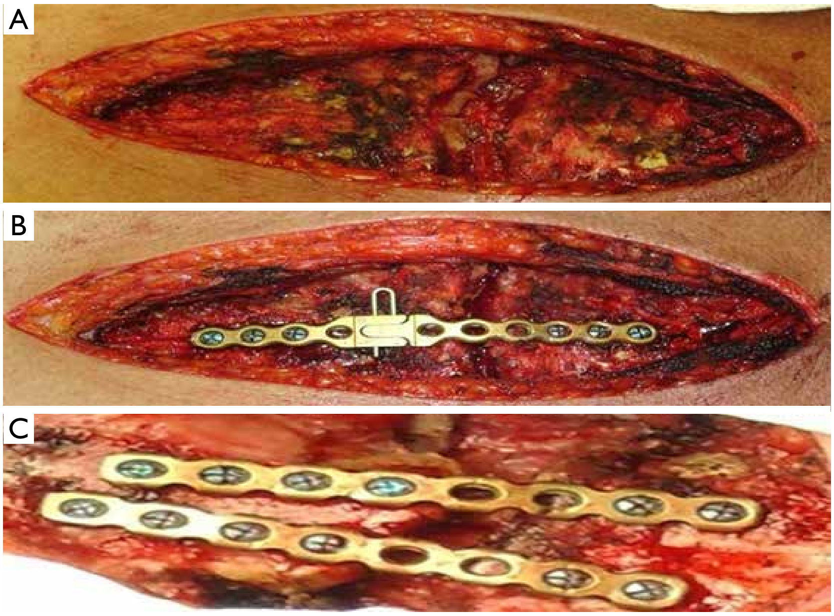


Figure 21 Manubriosternal dislocation: (A) damaged synchondrosis between manubrium and body of the sternum; (B) and (C) stabilization with the different segments of titanium plate.

ankylosis and chest deformity, kyphosis of rachis with stiff neck, chronic pain syndrome and aesthetic damage lead to surgical fixation. A stapling technique (2 Blount staples) (56) in 1 patient, an angular stable implant (57) in 1 patient, an 8-hole one-third tubular plate (58) in 2 patients and a 3.5/4.0 mm fixed-angle plate (59) in 3 patients were used over time with positive results. In our experience, linear titanium plate allowed to restore the normal motility and rigidity of the chest wall without sequelae. The progressive loss in tension of steel wires determined a morphological alteration of the thorax, pain and anxiety resulting in a poor quality-adjusted life years. Also, we have already demonstrated in 18 patients (46) that titanium implant gained 4 QALYs more than steel wires, justifying costs. The incremental cost-effectiveness ratio, supporting these outcomes, explained that costs should always be proportionate to the obtained health return.

Surgical approach to stabilize the rib cage after trauma must respond to the need of a minor invasiveness, to an easy and quick execution and to an overall safety, avoiding complications or recurrences. In case of flail chest, the use of Judet struts or the rigid titanium plate meets these criteria. Titanium implant is especially recommended if there is a bone loss or multiple foci of fracture, even replacing the ribs totally. In our experience we noticed the clinical advantages resulting from the association of mechanical ventilation and surgical treatment. The shorter duration of ventilatory support is aimed at gas exchange stabilization and acute respiratory distress resolution. The early surgical osteosynthesis of the fracture foci, restoring the respiratory dynamic and the lung function stability, avoids pulmonary and cardiac failures. According to the our experience, the use of linear titanium plate associated or not with demineralized bone matrix is recommended in case of isolated sternal fracture and manubriosternal dislocation. In fact, we noticed an improvement of quality-adjusted life associated with the economic sustainability of intervention. However, we believe that no technique should be subject to prejudice but rather the effectiveness of each method must be assessed in terms of adequate stabilisation and proper ventilation reflecting the anatomical and functional integrity of the chest wall. It is clear that the experience and skill of the surgeon is crucial to obtain excellent results, in order to avoid the restrictions in both the work and social life of the patient.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Liman ST, Kuzucu A, Tastepe AI, et al. Chest injury due to blunt trauma. Eur J Cardiothorac Surg 2003;23:374 -8.
2. Divisi D, Crisci R. Use of demineralized bone matrix and plate for sternal stabilization after traumatic dislocation. Gen Thorac Cardiovasc Surg 2011;59:52-6.
3. Khoriati AA, Rajakulasingam R, Shah R. Sternal fractures and their management. J Emerg Trauma Shock 2013;6:113-6.
4. Lafferty PM, Anavian J, Will RE, et al. Operative treatment of chest wall injuries: indications, technique, and outcomes. J Bone Joint Surg Am 2011;93:97-110.
5. Lardinois D, Krueger T, Dusmet M, et al. Pulmonary function testing after operative stabilization of the chest wall for flail chest. Eur J Cardiothorac Surg 2001;20:496-501.
6. Tanaka H, Yukioka T, Yamaguti Y, et al. Surgical stabilization or internal pneumatic stabilization? A prospective randomized study of management of severe flail chest patients. J Trauma 2002;52:727-32.
7. Couraud L, Bruneteau A, Durandeau A. Flail chest. Therapeutic indications in relation to the site and clinical picture. Ann Chir Thorac Cardiovasc 1973;12:15-8.
8. Pettiford BL, Luketich JD, Landreneau RJ. The management of flail chest. Thorac Surg Clin 2007;17:25-33.
9. Leinicke JA, Elmore L, Freeman BD, et al. Operative management of rib fractures in the setting of flail chest: a systematic review and meta-analysis. Ann Surg 2013;258:914-21.
10. Jones T, Richardson E. Traction on the sternum in the treatment of multiple fractured ribs. Surg Gynecol Obstet 1926;42:283-5.
11. Gardner CE Jr. Chest injuries; application of military experience to civilian practice. Surg Clin North Am 1946;26:1082-94.
12. Jancovici R, Pons F, Duberez J, et al. Traitement chirurgical des traumatismes thoraciques (II). Encycl Méd Chir (Elsevier, Paris), Techniques chirurgicales – Thorax, 42-445-B, 1997, 22 p.
13. Jaslow IA. Skeletal traction in the treatment of multiple fractures of the thoracic cage. Am J Surg 1946;72:753-5.
14. Heroy WW, Eggleston FC. A method of skeletal traction applied through the sternum in “steering wheel” injury of the chest. Ann Surg 1951;133:135-8.
15. Marcheix B, Brouchet L, Renaud C, et al. Technique de l’ostéosynthèse costale. Encycl Méd Chir (Elsevier, Paris), Techniques chirurgicales – Thorax, 42-473, 2005, 11 p.
16. Ahmed Z, Mohyuddin Z. Management of flail chest injury: internal fixation versus endotracheal intubation. J Thorac Cardiovasc Surg 1995;110:1676-80.
17. Beltrami V, Martinelli G, Giansante P, et al. An original technique for surgical stabilization of traumatic flail chest. Thorax 1978;33:528-9.
18. Mombelloni G, Fabio D. Indirizzi terapeutici dei trauma della parete toracica e del diaframma. In “I Traumi del Torace e dell’Apparato Cardiovascolare” – XXII Congresso Nazionale S.I.C.T. Bari, 10-13 Luglio 1990;9-21.
19. Borrelly J, Grosdidier G, Wack B. Traitement chirurgical de l’instabilité pariétale thoracique par l’atelle-agrafe à glissière (AAG). Rev Chir Orthop 1985;71:241-50.
20. Borrelly J, Grosdidier G, Wack B. Notre experience de 5 ans d’utilisation d’un nouveau materiel d’ostéosynthèse thoracique: l’attelle-agrafe à glissière (AAG). Ann Chir Thorac Cardiovasc 1985;39:465-70.
21. Borrelly J, Aazami MH. New insights into pathophysiology of flail segment: the implications of anterior serratus muscle in parietal failure. Eur J Cardiothorac Surg 2005;28:742-9.
22. Divisi D, Ferrera R, Montagna P, et al. Chest wall tumors. Report of 17 cases. Rev Mal Respir 1999;16:369-78.
23. Thomas PA, Brouchet L. Prosthetic reconstruction of the chest wall. Thorac Surg Clin 2010;20;551-8.
24. Judet R. Costal osteosynthesis. Rev Chir Orthop Reparatrice Appar Mot 1973;59:Suppl 1:334-5.
25. Menard A, Testart J, Philippe JM, et al. Treatment of flail chest with Judet’s struts. J Thorac Cardiovasc Surg 1983;86:300 -5.
26. Bemelman M, Poeze M, Blokhuis TJ, et al. Historic overview of treatment techniques for rib fractures and flail chest. Eur J Trauma Emerg Surg 2010;36:407-15.
27. Sánchez-Lloret J, Letang E, Calleja MA, et al. Indication and surgical treatment of the traumatic flail chest syndrome: an original technique. Thorac Cardiovasc Surg 1982;30:294-7.
28. Engel C, Krieg JC, Madey SM, et al. Operative chest wall fixation with osteosynthesis plates. J Trauma 2005;58:181-6.
29. Mouton W, Lardinois D, Ferrer M, et al. Long-term follow-up of patients with operative stabilization of a flail chest. Thorac Cardiovasc Surg 1997;45:242-4.
30. Coonar AS, Qureshi N, Smith I, et al. A novel titanium rib bridge system for chest wall reconstruction. Ann Thorac Surg 2009;87: e46-e48.

31. Landercasper J, Cogbill T, Lindesmith L. Long-term disability after flail chest injury. J Trauma 1984;24:410-4.
32. Marasco SF, Davies AR, Cooper J, et al. Prospective randomized controlled trial of operative rib fixation in traumatic flail chest. J Am Coll Surg 2013;216:924-32.
33. Bibas BJ, Bibas RA. Operative stabilization of flail chest using a prosthetic mesh and methylmethacrylate. Eur J Cardiothorac Surg 2006;29:1064-6.
34. Mayberry JC, Terhes JT, Ellis TJ, et al. Absorbable plates for rib fracture repair:preliminary experience. J Trauma 2003;55:835-9.
35. Simon BJ, Cushman J, Barraco R, et al. Pain management guidelines for blunt thoracic trauma. J Trauma 2005;59:1256-67.
36. Grau T, Leipold R, Conradi R, et al. Ultrasonography and peridural anesthesia. Technical possibilities and limitations of ultrasonic examination of the epidural space. Anaesthesist 2001;50: 94-101.
37. Carollo DS, Nossaman BD, Ramadhyani U. Dexmedetomidine: a review of clinical applications. Curr Opin Anaesthesiol 2008;21:457-61.
38. Arain SR, Ruehlow RM, Uhrich TD, et al. The efficacy of dexmedetomidine versus morphine for postoperative analgesia after major inpatient surgery. Anesth Analg 2004;98:153-8.
39. Simon B, Ebert J, Bokhari F, et al. Management of pulmonary contusion and flail chest: an Eastern Association for the Surgery of Trauma practice management guideline. J Trauma Acute Care Surg 2012;73:S351-361.
40. Boybeyi O, Bakar B, Aslan MK, et al. Evaluation of dimethyl sulfoxide and dexamethasone on pulmonary contusion in experimental blunt thoracic trauma. Thorac Cardiovasc Surg 2014;62:710-5.
41. Ocalan K, Solak O, Esme H, et al. Efficacy of budesonide and interleukin-10 in an experimental rat model with isolated bilateral pulmonary contusion created by blunt thoracic trauma. Eur J Cardiothorac Surg 2013;43:163-7.
42. McKim LH. A method of fixation for fractures of the sternum. Ann Surg 1943;118:158-60.
43. Knobloch K, Wagner S, Haasper C, et al. Sternal fractures are frequent among polytraumatised patients following high deceleration velocities in a severe vehicle crash. Injury 2008;39:36-43.
44. Harston A, Roberts C. Fixation of sternal fractures: a systematic review. J Trauma 2011;71:1875-9.
45. Khoriati AA, Rajakulasingam R, Shah R. Sternal fractures and their management. J Emerg Trauma Shock 2013;6:113-6.
46. Divisi D, Di Leonardo G, Crisci R. Surgical management of traumatic isolated sternal fracture and manubriosternal dislocation. J Trauma Acute Care Surg 2013;75: 824-9.
47. Mayberry JC, Ham LB, Schipper PH, et al. Surveyed opinion of American Traum Orthopedic, and Thoracic Surgeons on rib and sternal fracture repair. J Trauma 2009;66:875-9.
48. Molnar TF. Surgical management of chest wall trauma. Thorac Surg Clin 2010;20:475-85.
49. Song DH, Lohman RF, Renucci JD, et al. Primary plating in high-risk patients prevents mediastinitis. Eur J Cardiothorac Surg 2004;26:367-72.
50. Voss B, Bauernschmitt R, Brockmann G, et al. Complicated sternal dehiscence: reconstruction with plates, cables, and cannulated screws. Ann Thorac Surg 2009;87:1304-6.
51. Raman J, Straus D, Song DH. Rigid plate fixation of the sternum. Ann Thorac Surg 2007;84:1056-8.
52. Gallo DR, Lett ED, Conner WC. Surgical repair of chronic traumatic sternal fracture. Ann Thorac Surg 2006;81:726-8.
53. Molina JE. Evaluation and operative technique to repair isolated sternal fractures. J Thorac Cardiovasc Surg 2005;130:445-8.
54. Chou SS, Sena MJ, Wong MS. Use of sternalock plating system in acute treatment of unstable traumatic sternal fractures. Ann Thorac Surg 2011;91:597-9.
55. Ergene G, Tulay CM, Anasiz H. Sternal fixation with nonspecific plate. Ann Thorac Cardiovasc Surg 2013;19:364-7.
56. El Ibrahimi A, Smahi M, Shimi M, et al. Traumatic manubriosternal dislocation: A new method of stabilization postreduction. J Emerg Trauma Shock 2011;4:317-9.
57. Nijs S, Broos PL. Sterno-manubrial dislocation in a 9-year-old gymnast. Acta Chir Belg 2005;105:422-4.
58. Kälicke T, Frangen TM, Müller EJ, et al. Traumatic manubriosternal dislocation. Arch Orthop Trauma Surg 2006;126:411-6.
59. Gloyer MA, Frei HC, Hotz TK, et al. Osteosynthesis of traumatic manubriosternal dislocations and sternal fractures with a 3.5/4.0 mm fixed-angle plate (LCP). Arch Orthop Trauma Surg 2011;131:1261-6.

doi: 10.21037/shc.2017.05.04
Cite this article as: Crisci R, Divisi D. Chest wall surgical stabilization after thoracic trauma: indications and techniques. Shanghai Chest 2017;1:5.

Thoracic outlet syndrome: first rib resection

Cornelis G. Vos[1], Çağdaş Ünlü[1], Michiel T. Voûte[2], Rob H. W. van de Mortel[3], Jean-Paul P. M. de Vries[3]

[1]Department of Surgery, Northwest Clinics, Alkmaar, the Netherlands; [2]Department of Surgery, Erasmus University Medical Center, Rotterdam, the Netherlands; [3]Department of Vascular Surgery, St. Antonius Hospital, Nieuwegein, the Netherlands

Correspondence to: Jean-Paul P. M. de Vries, MD, PhD. Department of Vascular Surgery, Sint Antonius Hospital, Koekoekslaan 1, 3430 VB, Nieuwegein, the Netherlands. Email: j.vries@antoniusziekenhuis.nl.

Received: 27 February 2017; Accepted: 23 March 2017; Published: 30 May 2017.
doi: 10.21037/shc.2017.05.03
View this article at: http://dx.doi.org/10.21037/shc.2017.05.03

Introduction

Thoracic outlet syndrome (TOS) is caused by compression of neurovascular structures in the costoclavicular space. The symptoms of the patients depend on the anatomic structure that is being compressed. Therefore TOS is divided in three groups, neurogenic TOS (NTOS; which is most frequently encountered 90%–95%), venous TOS (VTOS; 5%) and, least commonly, arterial TOS (ATOS; 1%) (1).

Repetitive compression of the subclavian vein between the first rib, clavicle and associated muscles leads to vessel wall and intimal damage, stenosis and eventually thrombosis. Similarly the subclavian artery can be compressed leading to distal embolization, stenosis, aneurysmal degeneration or occlusion.

The objective diagnosis of NTOS is a challenge and generally accepted "golden" diagnostic criteria are lacking (1,2). The mainstay of management is nonsurgical in most patients; however, surgery is indicated for patients with persisting symptoms despite conservative management and when vascular structures are involved.

Surgical therapy consists of decompression of the thoracic outlet by performing a first rib resection with or without adjunctive vascular reconstructive procedures. First rib resection can be performed through a transaxillary (3), supraclavicular (4) and infraclavicular (5) approach. Thoracoscopic (assisted) procedures are also described in the recent literature but are beyond the scope of this book chapter.

Operative techniques

Transaxillary approach

Preparation & exposure

The patient is placed on a vacuum mattress in a 45 degrees posterolateral position on the operating table with the ipsilateral side facing upward. The hand, axilla, chest and back are scrubbed and draped to expose the axilla and the ipsilateral arm is draped in a sterile stockinet to allow manipulation by an assistant. The arm is abducted to 90 degrees and flexed at the elbow to allow positioning in a support (*Figure 1*). The operating surgeon stands on the dorsal side of the patient. Note that some surgeons prefer not to position the arm in a support to allow free manipulation by an assistant. The assistant can elevate the shoulder by applying subtle traction to increase exposure during the procedure. As long as this is performed with care the risk of injury to the brachial plexus is negligible. Due to the depth of the operating field and small working space, the use of a headlight is recommended.

It is also recommended to have two assistants available, one for manipulating the arm to improve exposure of the thoracic outlet and a second assistant to hold retractors/specula during the procedure.

Surgical technique

A transverse incision (6–8 cm is usually sufficient) is made in the skin lines along the inferior border of axillary hair (*Figure 1*, dashed line). This is usually at the level of the third rib if the patient is positioned as described above. The incision is carried directly toward the chest wall avoiding the layer of fatty tissue containing the axillary lymph nodes. The anterior border of the latissimus dorsi muscle and the dorsal border of the major pectoral muscle are released and care is taken to spare the thoracodorsal and long thoracic nerves. The dissection is carried upward directly along the chest wall to the first rib (*Figure 2*). From the second intercostal space the intercostobrachial nerve

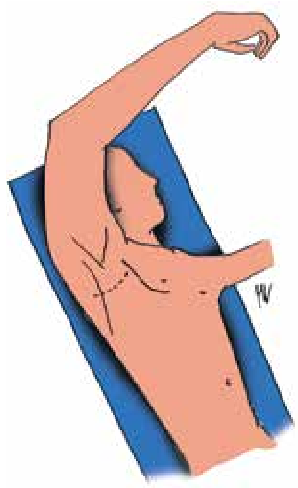


Figure 1 Patient positioning for the transaxillary approach of the first rib resection. The skin incision is marked by the dashed line.

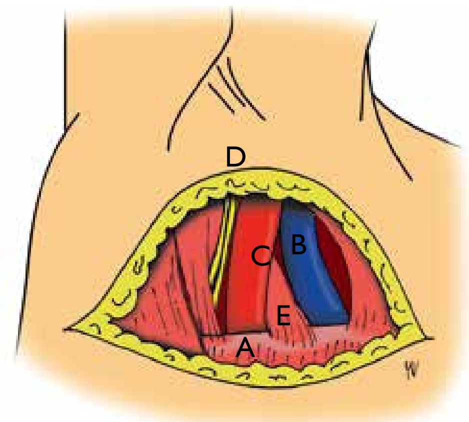


Figure 2 Exposure of the first rib (A) with the most important structures of the thoracic outlet, including the subclavian vein (B), subclavian artery (C), brachial plexus (D) and anterior scalene muscle (E).

usually crosses the operating field. It may be sacrificed although frequently it can be readily retracted and spared. The first rib has a broader and flatter shape compared to the other ribs. A retractor can be placed at this point or exposure can be improved by using sympathectomy specula. To further expose the thoracic outlet and its vital structures the shoulder can be manipulated vertically by an assistant. It is important to apply careful hemostasis during the dissection because even relative small bleedings can significantly impair visualization in the operating field.

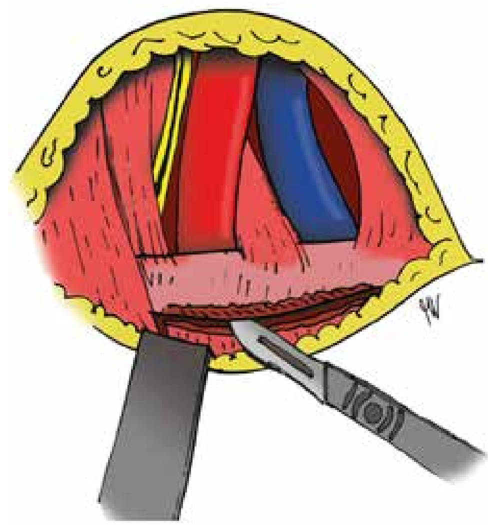


Figure 3 The intercostal muscles are dissected from the inferior border of the first rib.

The ventral aspect of the first rib can be exposed by blunt dissection and the brachial plexus is revealed posteriorly, the subclavian artery and anterior scalene muscle medially and the subclavian vein ventrally (*Figure 2*).

Before the first rib can be removed, attached structures must be dissected. The intercostal muscles can be dissected from the inferior border of the rib from the manubrium sterni anteriorly to the transverse process posteriorly using diathermia avoiding injury to the thoracodorsal and long thoracic nerves (*Figure 3*). Try to leave the parietal pleura intact, it can be digitally detached from the posterior aspect of the first rib after dissection of the intercostal muscles. Dorsal to the subclavian vein the anterior scalene muscle insertion is visualized. It can bluntly be freed from surrounding tissue on the posterior side using a dissecting forceps and divided through the insertion close to the first rib using scissors or a scalpel (*Figure 4*). Diathermia is avoided due to possible phrenic nerve injury. If present, the insertion of the scalenus minimus muscle can be detached from the posterior aspect of the first rib at this point, just dorsal to the insertion of the anterior scalene muscle insertion. In a similar fashion the middle scalene muscle insertion can be detached from the first rib, just posterior to the subclavian artery and brachial plexus. Anteriorly, the tendon of the subclavian muscle can be divided from the cartilaginous portion of the first rib taking care of the subclavian vein just posterior to this tendon. The posterior scalene muscle located more dorsally can remain in place.

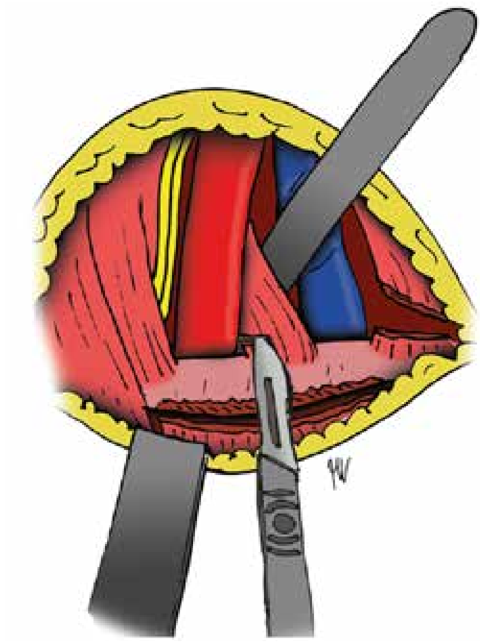


Figure 4 The anterior scalene muscle is divided through the insertion close to the first rib using scissors or a scalpel.

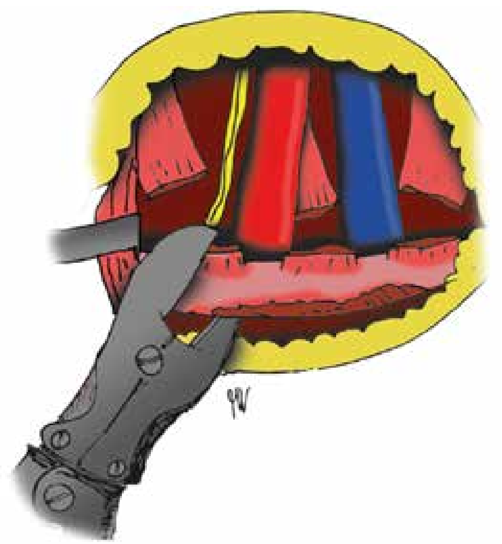


Figure 5 The first rib is cut posteriorly close to the transverse process.

An angled rib cutter (45 or 90 degrees) is used to cut the first rib close to the transverse process posteriorly and the manubrium sterni anteriorly (*Figures 5,6*). Care is taken to avoid injury to the subclavian vein and brachial plexus while cutting the rib. If a cervical rib is present it is detached from the first rib, dissected posteriorly and cut close to the transverse process. Remaining sharp edges can be smoothened using the rongeur. The brachial plexus and subclavian vessels are inspected and any remaining fibrous strands are removed.

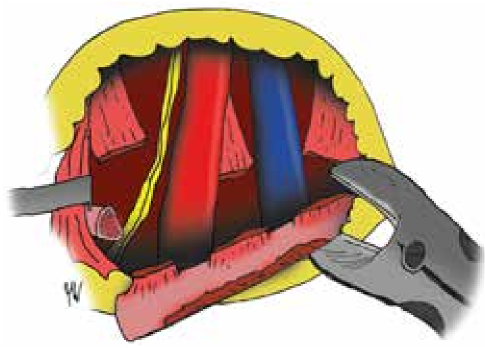


Figure 6 The first rib is cut anteriorly close to the manubrium sterni.

Completion

Wound suction drain is usually sufficient even to allow complete expansion of the lung if defects in the parietal pleura are caused during dissection. By relaxing the arm the surgical field collapses and the wound can be closed by placing a layer of subcutaneous sutures and a layer of intracutaneous sutures. A postoperative chest x-ray can be performed to rule out pneumo- or hematothorax, although this is usually unnecessary in uncomplicated procedures where the parietal pleura remained intact. Adequate postoperative pain relief and early mobilization are important for fast recovery and the drain is removed on the first postoperative day.

Supraclavicular approach

Preparation & exposition

The patient is placed in a supine position with a small pillow under and between the scapulae. The head is turned facing the contralateral side. The neck, shoulder and chest are scrubbed and draped to expose the area around the clavicle (*Figure 7*).

Surgical technique

A transverse incision is made parallel to and 2 cm above the clavicle (*Figure 7*). Supraclavicular nerves are identified and retracted using vessel loops. The platysma is divided

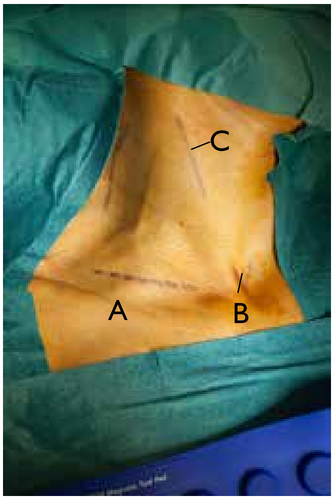


Figure 7 The area around the clavicle is exposed for the supraclavicular approach. Important landmarks are: the clavicle (A), jugulum (B) and the anterior border of the sternocleidomastoid muscle (C). The skin incision is marked by the dashed line.

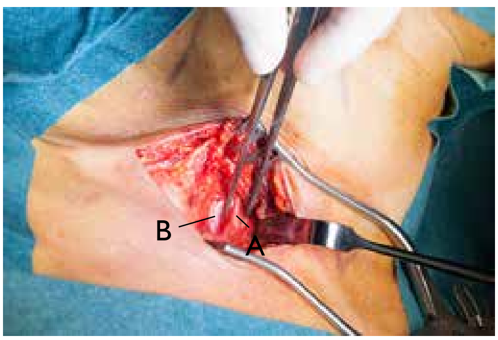


Figure 8 Phrenic nerve (A) running across the anterior border of the anterior scalene muscle (B).

followed by the clavicular head of the sternocleidomastoid muscle. The omohyoid muscle is divided and the supraclavicular fat pad is elevated. The dissection is carried toward the anterior scalene muscle and the phrenic nerve can be seen on the anterior surface of this muscle (*Figure 8*). It can be isolated and retracted using a vessel loop to prevent injury. The brachial plexus is visible posterior to the anterior scalene muscle and the long thoracic nerve runs along the posterior aspect of the middle scalene muscle (*Figure 9*). The fascia is opened and the anterior scalene muscle is divided using diathermia, or scissors. This exposes the subclavian artery directly behind the divided muscle allowing arterial reconstruction if necessary. The artery is

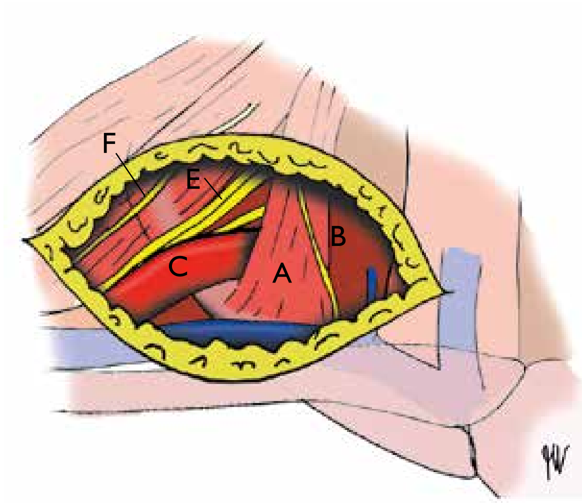


Figure 9 Overview of the supraclavicular approach showing the anterior scalene muscle (A), phrenic nerve (B), subclavian artery (C) and vein (D), brachial plexus (E) and long thoracic nerve (F).

controlled by placing a vessel loop (*Figure 10*). The trunks of the brachial plexus are mobilized and carefully retracted avoiding traction injury (*Figure 11*). The middle scalene muscle can now be divided from the first rib avoiding injury to the long thoracic nerve that runs posterior to or even through the middle scalene muscle at this level. The C8 and T1 nerve roots are seen above and below the first rib. The brachial plexus is carefully retracted to allow maximum exposure of the first rib after which the rib is cut using an angled (45 or 90 degrees) rib cutter. The rongeur is used to completely remove remnants of the first rib from its attachment to the transverse process preventing new bone formation and potential recurrence of symptoms. The anterior segment of the first rib is also removed. In a similar fashion a cervical rib can be removed using the angled (45 or 90 degrees) rib cutter (*Figures 12,13*).

Completion

Careful hemostasis is applied and the clavicular head of the sternocleidomastoid muscle may be reinserted to the clavicle. The wound is closed over a wound suction drain. The platysma is sutured followed by intracutaneous sutures for the skin. A postoperative chest X-ray can be performed to rule out pneumothorax, although this is usually unnecessary in uncomplicated procedures where the parietal pleura remained intact. Postoperative early mobilization is advised and the drain is removed on the first postoperative

Figure 10 The subclavian artery, lying directly behind the anterior scalene muscle is controlled by placing vessel loops.

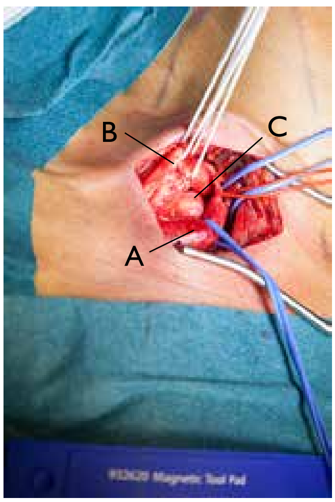


Figure 11 Trunks of the brachial plexus are identified, mobilized and carefully retracted using vessel loops.

Figure 12 The cervical rib is cut using an angled rib cutter.

Figure 13 Final overview demonstrating the subclavian artery (A), now relieved from the compression by the cervical rib that was removed.

day. Adequate pain relief is warranted.

Infraclavicular approach

Preparation & exposition

The patient is placed in a supine position with a small pillow under and between the scapulae. The head is turned facing the contralateral side. The ipsilateral arm is positioned cephalad. The neck, shoulder, chest and ipsilateral arm are scrubbed and draped to expose the area around the clavicle. The arm is draped in a sterile stockinet to allow manipulation by an assistant to improve exposure when necessary.

Surgical procedure

A transverse incision is made parallel to and 2 cm caudal to the clavicle from the medial part of the clavicle to the manubrium sterni. Fibers of the clavicular head of the major pectoral muscle are divided identifying the subclavius muscle and the subclavian vein. The subclavius muscle is divided at its insertion on the first rib and excised. The subclavian vein is mobilized freeing it from fibrous tissue on top of the vein. The first rib edges are mobilized bluntly. The insertion of the anterior scalene muscle on the first rib is located just dorsally to the vein. The phrenic nerve, running across the anterior scalene muscle, is isolated and retracted medially followed by division of the anterior scalene muscle insertion close to its attachment to the first rib. Now the subclavian artery and the brachial plexus are visualized and are retracted cranially. At this time exposure might be improved by elevation of the ipsilateral arm by the assistant. The first rib is now completely exposed. The rib is resected using an angled (45 to 90 degrees) rib cutter from its anterior attachment to the manubrium to the posterior attachment to the transverse process. The rib can be detached from the parietal pleura with blunt dissection without damaging the parietal pleura. Sharp bony remnants can be removed using the rongeur. To optimize release of the subclavian vein the costoclavicular ligament medial to the artery can be partially divided. At this point there is adequate exposure of the subclavian vein and distal part of the subclavian artery allowing vascular reconstruction of necessary.

Completion

The wound is closed over a wound suction drain. A postoperative chest X-ray can be performed to rule out pneumothorax, although this is usually unnecessary in uncomplicated procedures where the parietal pleura remained intact. Postoperative early mobilization is advised and the drain is removed on the first postoperative day. Adequate pain relief is warranted.

Comments

First rib resection for thoracic outlet syndrome can be performed through the three approaches described in this chapter. The transaxillary approach is preferred in the majority of cases because it's safe, does not require division of important muscles and has a superior cosmetic result. Drawback of this approach is the relatively narrow and deep working space. A supraclavicular approach allows better exposure and control of the subclavian artery and is the preferred approach in ATOS, while an infraclavicular approach allows superior access to the subclavian vein and is preferred for the treatment of VTOS.

To optimize exposure during the transaxillary approach it is of vital importance to keep secure hemostasis from the beginning of the procedure, since even minor bleeding can impair vision and hamper identification of vital structures. Another way to importantly improve exposure is having an assistant elevating the shoulder as this opens the thoracic outlet and enlarges the operating field. Releasing the anterior border of the latissimus dorsi muscle and the posterior border of the major pectoral muscle further improves working space and exposure.

The presence of many vital structures travelling through a relatively small and deep operating field implies the risk of injury to any of these structures. Injury to the long thoracic nerve leads to a winged scapula due to denervation of the anterior serratus muscle. Thoracodorsal nerve injury leads to denervation of the latissimus dorsi muscle. The phrenic nerve can be at risk when the anterior scalene muscle is divided and injury causes paralysis of the ipsilateral diaphragm. The majority of patients with thoracic outlet syndrome are young and active patients and nerve deficits can lead to significant functional impairment. Less impairing is the numbness of the axilla and dorsomedial aspect of the upper arm after sacrificing the intercostobrachial nerve. After a supraclavicular approach, injury to the supraclavicular nerves causes a sensible loss of the skin around the clavicle, anteromedial area of the shoulder and the proximal thorax.

The loose tissues in the axilla often fail to tamponade bleeding which therefore can cause significant hematoma formation. If the parietal pleura is damaged during dissection a hemothorax can develop. If there is accidental damage to the visceral pleura or lung parenchyma, a pneumothorax can occur and in these cases a standard wound suction drain is insufficient. Postoperative pain can be significant and adequate pain relief is important. An effective option is a preoperatively placed scalenus nerve block. Clinical success of surgical treatment for thoracic outlet syndrome is obtained in the majority of patients with vascular forms of TOS, with 90% of patients that report improvement of symptoms (1,2). For NTOS results are slightly worse with 60%–80% of patients reporting improvement of symptoms after surgery (1). This difference is in part explained by the lack of a reliable diagnostic modality to confirm the diagnosis of NTOS. Complication rates described in the literature vary between 5%–40%, with pneumothorax, nerve injury and wound infection as the most commonly occurring complications. Severe complications and death are extremely rare and therefore surgical treatment for TOS seems safe (1,2).

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Peek J, Vos CG, Ünlü Ç, et al. Outcome of Surgical Treatment for Thoracic Outlet Syndrome: Systematic Review and Meta-Analysis. Ann Vasc Surg 2017;40:303-26.
2. Povlsen B, Hansson T, Povlsen SD. Treatment for thoracic outlet syndrome. Cochrane Database Syst Rev 2014;(11):CD007218.
3. Roos DB. Transaxillary approach for first rib resection to relieve thoracic outlet syndrome. Ann Surg 1966;163:354-8.
4. Mackinnon S, Patterson GA, Colbert SH. Supraclavicular approach to first rib resection for thoracic outlet syndrome. Oper Tech Thorac Cardiovasc Surg 2005;10:318-28.
5. Molina JE. Surgery for effort thrombosis of the subclavian vein. J Thorac Cardiovasc Surg 1992;103:341-6.

doi: 10.21037/shc.2017.05.03
Cite this article as: Vos CG, Ünlü Ç, Voûte MT, van de Mortel RH, de Vries JP. Thoracic outlet syndrome: first rib resection. Shanghai Chest 2017;1:3.

Open repair of pectus deformities

Korkut Bostanci[1], Davor Stamenovic[2]

[1]Department of Thoracic Surgery, Marmara University Faculty of Medicine, Istanbul, Turkey; [2]Department of Thoracic Surgery, St. Vincentius Kliniken, Karlsruhe, Germany

Correspondence to: Korkut Bostanci. Marmara University Faculty of Medicine, Department of Thoracic Surgery, Pendik, Istanbul, Turkey. Email: kbostanci@marmara.edu.tr.

Received: 23 June 2017; Accepted: 03 August 2017; Published: 14 August 2017.
doi: 10.21037/shc.2017.08.06
View this article at: http://dx.doi.org/10.21037/shc.2017.08.06

A variety of malformations of the chest wall may be identified in childhood. The most common are the pectus excavatum and pectus carinatum deformities. Pectus excavatum is approximately 6 times more common than pectus carinatum and males are afflicted 5 times more often than females.

Pectus excavatum

Pectus excavatum, or funnel chest or sunken chest, is a congenital anomaly of the anterior chest wall characterized by a prominent posterior depression of the body of the sternum (*Figure 1*). The lower costal cartilages bend posteriorly to form a curvature. The first two ribs and the manubrium are usually normal. The most common configuration is a symmetric deformity involving the lower half of the sternum, together with costal flaring on both sides. Asymmetric deformities are common with the concavity deeper on one side and the sternum rotated to that side (1).

The pathogenesis of pectus deformities remains unclear. It has been hypothesized that the deformity results from unbalanced growth in the costochondral regions. This theory may explain the asymmetric deformity in some cases and also the development of pectus carinatum, a completely opposite type of deformity (1,2).

Pectus excavatum can be inherited through either parents, although not clearly as a recessive trait. It is believed to occur in as many as 1 in 300 to 400 live births (2,3). Other malformations may coexist, especially musculoskeletal anomalies like scoliosis—in 11% to 25% of the patients—and Marfan's syndrome (1,3). Generally the deformity is apparent soon after birth, progresses during early childhood, and becomes even more prominent in early adolescence (1-4). Regression rarely may occur spontaneously.

Most of the children are either asymptomatic in the early years, or shy and are unwilling to expose chest, especially while swimming. During adolescence easy fatigability can be seen. When the deformity is severe, the heart is displaced into the left thoracic cavity (5). Most of the patients have an asthenic habitus and poor posture. Although it was previously believed that only a few patients had respiratory or cardiac insufficiency, several recent studies have provided evidence that both cardiac and respiratory functions tend to show values that are slightly below normal. Electrocardiographic abnormalities are attributed to the abnormal configuration of the chest wall and the displacement and rotation of the heart into the left thoracic cavity (2). Mitral valve prolapse can be seen in some patients, especially with Marfan's syndrome. Conventional pulmonary function tests while at rest are mostly within normal limits or borderline, in some patients though, they can show a restrictive pattern. In general, it is difficult to obtain valid measurements in young patients (1).

Several methods and indices of quantifying the degree of the severity of pectus deformities have been proposed, although none has been widely accepted. Welch and Haller indices are the most popular ones (6,7). The distance between these two lines is the sagittal measurement. A normal chest has a Haller index of 2 or less. A Haller index between 2 and 3.2 is considered a mild deformity; between 3.2 and 3.5, moderate; 3.5 or greater, a severe deformity. Both moderate and severe deformities can be considered for corrective surgery (8).

Treatment

As most patients with pectus excavatum are asymptomatic,

Figure 1 Pectus excavatum.

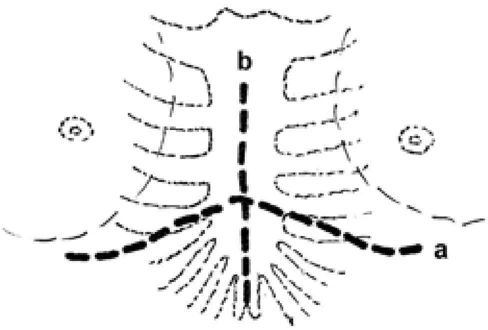


Figure 2 A transverse inframammary incision within the nipple lines is preferred for cosmetic reasons (A), especially in female patients, to avoid breast deformity, but a midline incision can also be performed (B).

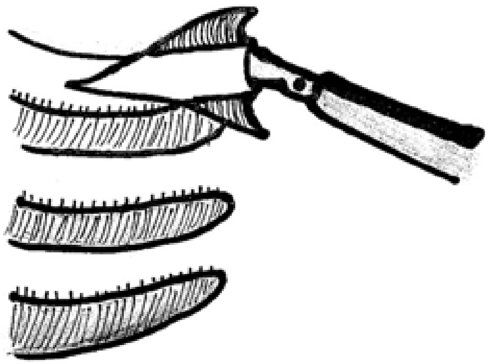


Figure 3 The lower four or five costal cartilages are resected subperichondrially for the full length of the deformed segments to the costochondral junctions.

the selection of patients for surgical repair requires good clinical judgement. The primary indication for repair is a cosmetic one. The negative self-image these patients have becomes notable especially when they go to school. They become embarrassed with the attitude of their friends about their deformity, and become withdrawn. Most are shy and have a reserved social life. Therefore, the presence of pectus excavatum in such children is an indication, especially if they have moderate to severe deformity (1,4). Surgical repair of pectus excavatum is indicated also in patients with evidence of respiratory insufficiency, especially dyspnea on exertion.

Surgical repair

Surgical repair of pectus excavatum was first reported by Meyer and Sauerbruch in 1911 and 1920, respectively (9,10). Ochsner and Brown summarized their early experience with surgical repair of this deformity, both in 1939 (11,12). Ravitch in 1949 reported his surgical repair technique, similar to Brown's, that involved excision of all deformed costal cartilages with their perichondriums, division of the xiphoid from the sternum, division of the intercostal muscle bundles from the sternum, and displacing the sternum anteriorly after transverse sternal osteotomy, using Kirschner wires or silk sutures for stabilisation (13). Current open surgical repair of pectus excavatum encompasses various modifications of the original procedure described by Brown and then modified by Ravitch. In 1958, Welch reported his modification and recommended the preservation of the perichondriums and intercostal muscle bundles (14). Shamberger added a retrosternal steel strut fixation, especially for older children with severe deformities whom complete correction is difficult to achieve by suture fixation of the sternum alone and reported that Rehbein struts could also be used for sternal fixation (2,3).

Although surgical repair of pectus excavatum is technically easier in a younger child as the chest wall is more flexible, the risk of long-term recurrence can be higher in these patients, so the operation can be delayed until the age of ten, as the chest will grow relatively less after that age and the risk of recurrence will be reduced.

Open repair technique

The preferred surgical technique uses general endotracheal anesthesia, with the patient in supine position and the arms

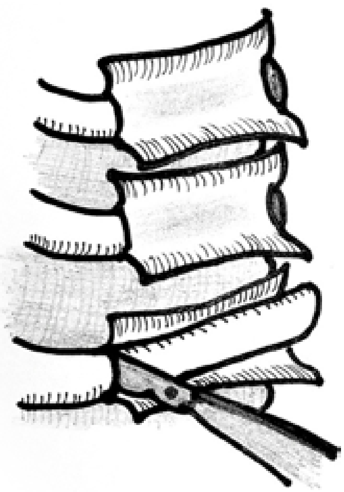


Figure 4 Perichondriums are preserved and they can be resutured when possible to create a tunnel for the new costal cartilages to regenerate within.

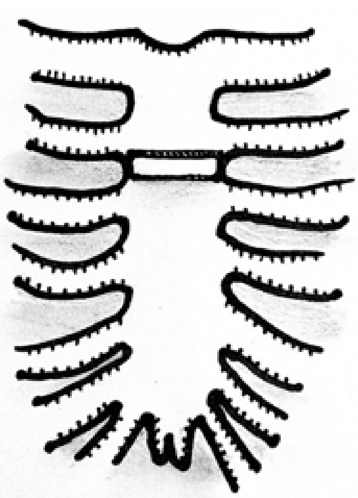


Figure 5 A transverse wedge osteotomy is performed using an oscillator blade through the anterior table of the sternum at the level of superior transition from the normal to the depressed sternum

abducted slightly. A transverse inframammary incision within the nipple lines is preferred for cosmetic reasons, especially in female patients, to avoid breast deformity, but a midline incision can also be performed (1-4) (*Figure 2*). The transverse incision is arched slightly towards the body of the sternum like a chevron in the midportion to provide better exposure of the whole sternum. Skin flaps and pectoral muscles are mobilized by electrocautery and are elevated to expose the depressed portion of the sternum and the costal cartilages. With the midline approach, the incision is extended to the periosteum of the sternum, and the pectoral muscle flaps are then elevated laterally, exposing all the costal cartilages (4).

The lateral extent of muscle elevation is the costochondral junction of the third to fifth ribs. The lower four or five costal cartilages are resected subperichondrially for the full length of the deformed segments to the costochondral junctions (*Figures 3,4*). Limited wedge chondrotomies and osteotomies to release and reshape the anterior chest wall can be preferred instead, especially in milder deformities (15,16). Longer segments of the sixth and seventh cartilages are resected to the point where they join the costal arch. Perichondriums can be resutured when possible to create a tunnel for the new costal cartilages to regenerate within. The xiphoid is divided from its attachment to the sternum and removed if projects too forward, and the mediastinal tissues are bluntly dissected digitally behind the sternum. The attachments of the costal cartilages and intercostal muscles to the sternum can be divided in order to free the lower portion of the sternum and reduce the tension especially if the deformity is too deep, but in general this step can be avoided.

A transverse wedge osteotomy is performed using an oscillator blade through the anterior table of the sternum at the level of superior transition from the normal to the depressed sternum (*Figure 5*). The posterior table of the sternum is partially fractured, and the lower sternum is then elevated to the desired position, preferably with some overcorrection, and it is secured either with interrupted nonabsorbable sutures or steel wires (*Figure 6*) (1-4). Titanium bars, titanium or absorbable copolymer plates can also be used for sternal fixation (*Figure 7*) (15,17,18).

Additionally, a retrosternal steel strut can be placed to hold the sternum forward. The strut is placed transversely behind the sternum, where it is attached on each side to the rib just lateral to the costochondral junction (*Figure 8A*). When extensive costal cartilage resection is performed and a long segment of sternum is mobilized below the osteotomy line a retrosternal support strut should be used to avoid recurrent sternal depression (1). Alternatively an anterior support strut with a large wire holding the sternum to the strut can be placed (*Figure 8B*). Struts are also helpful when there is extensive sternal rotation or a severe depression (2,3). Retrosternal support with struts is also required in patients with Marfan syndrome as the risk of recurrence is higher in them (19).

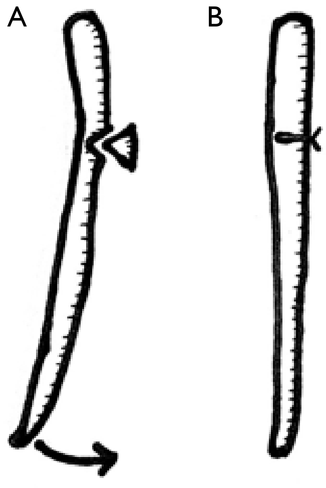


Figure 6 The posterior table of the sternum is partially fractured, and the lower sternum is then elevated to the desired position, preferably with some overcorrection, and it is secured either with interrupted nonabsorbable sutures or steel wires.

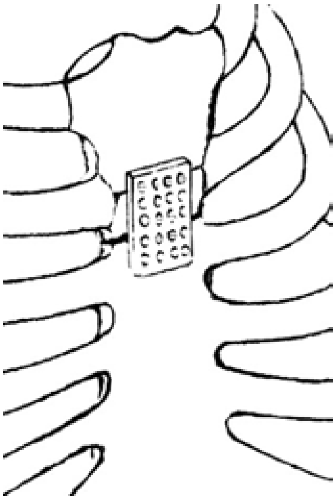


Figure 7 Titanium bars, titanium or absorbable copolymer plates can also be used for sternal fixation

An alternative material for retrosternal support can be a Marlex mesh. A sheet of Marlex mesh is spread tightly behind the sternum like a drum and attached laterally to the most anterior areas of the residual costal cartilages with nonabsorbable sutures, letting the sternum rest on the mesh in a corrected position (20).

The wound should be filled with warm saline to check if the pleural cavities were entered or not. Air can be evacuated with a small-bore suction catheter if needed. A single limb aspirative drain is then brought through the inferior skin flap and placed over the sternum and the costal cartilages. The pectoral muscle flaps are sutured to the sternum in the midline, advancing the flaps inferiorly to cover the underlying sternum. The rectus muscle flap is sutured to the tip of the sternum also, to cover the mediastinum completely. Absorbable subcuticular sutures are used in preference to skin sutures in children (*Figure 9*). The aspirative drain is removed when the drainage is less than 50 mL for 24-hour period. At the time of discharge the patients are advised to avoid body-contact sports for 3 to 6 months or until after the retrosternal steel strut is removed, if placed. New cartilage or bone regeneration within the

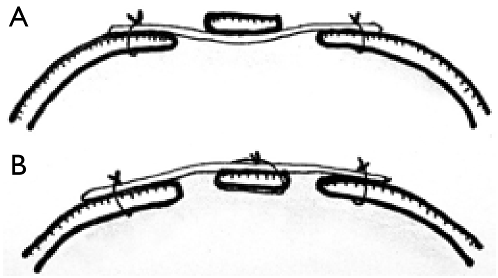


Figure 8 A steel strut can be placed to hold the sternum forward. (A) The strut can be placed transversely behind the sternum, where it is attached on each side to the rib just lateral to the costochondral junction; (B) alternatively an anterior support strut with a large wire holding the sternum to the strut can be placed.

Figure 9 Postoperative appearance of a patient with pectus excavatum, after open repair.

Figure 10 Chondrogladiolar type pectus carinatum is more common and it has the greatest prominence in the lower portion of the sternum.

Figure 11 In chondromanubrial type, also called as pectus arcuatum, the protuberance is more prominent in the upper portion of the sternum and the lower portion is short and relatively depressed.

perichondriums is usually complete within 2 months after the surgical repair and it provides a rigid support for the anterior chest wall.

Complications

Complications of open surgical repair of pectus excavatum are few and relatively unimportant. Pneumothorax may require aspiration and rarely tube thoracostomy. Wound infection can be overcome by perioperative antibiotic usage. The most important complication is the recurrence of the deformity. It is difficult to predict which patients will have a major recurrence, but mostly patients with asthenic or marfanoid habitus having poor muscle development and a narrow anteroposterior chest wall diameter are under greater risk (2,3).

The patients should be followed to full growth, until 16 years of age for girls and 19 for boys, not to miss any recurrence. The rate of recurrence is less then 2%, especially when prosthetic sternal supports are used in the repair (21).

Pectus carinatum

Pectus carinatum, or pigeon breast or keel chest, is the anterior protrusion of the sternum and it is less common than pectus excavatum (1-3). An upward curve in the lower costal cartilages results with the moving forward of the sternum (4). Pectus carinatum is more variable than pectus excavatum in subtypes. Two principal types are chondrogladiolar and chondromanubrial pectus carinatum. Chondrogladiolar type is more common and it has the greatest prominence in the lower portion of the sternum (*Figure 10*). In chondromanubrial type, also called as pectus arcuatum, the protuberance is more prominent in the upper portion of the sternum and the lower portion is short and relatively depressed (*Figures 11,12*) (1-3). Asymmetric deformities with a tilted sternum are common. Associated disorders like scoliosis, Marfanoid habitus and congenital heart diseases are more frequent than in patients with pectus excavatum (1). The deformity is generally mild in childhood and becomes prominent in early adolescence. It is often obvious and can be seen through the clothing. Symptoms are present in some patients and may include cardiac arrhythmias and dyspnea on exertion. Inability to sleep prone or pain from local trauma to the protruding deformity are the most common symptoms (3). The physiologic problem is related to the reduced flexibility of the chest wall by the anteriorly displaced sternum and deformed cartilages causing difficulty in chest wall expantion during inspiration (1,4).

Treatment

The primary indication for repair is a cosmetic one in

Figure 12 Lateral X-ray of a patient with chondromanubrial type of pectus carinatum.

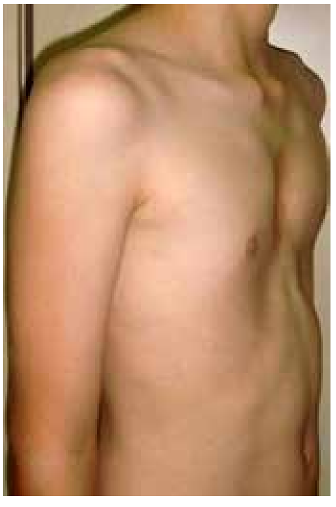


Figure 13 Postoperative appearance of a patient with chondrogladiolar type of pectus carinatum.

general as in pectus excavatum. Surgical repair is indicated also in patients with evidence of progressive symptoms of dyspnea, reduced endurance and tachypnea on exertion. Adolescents with severe pectus carinatum are often more likely to seek surgical treatment than patients with severe pectus excavatum (22).

Surgical repair

The first repair of pectus carinatum was done by Ravitch in 1952 on a chondromanubrial type deformity (23). He resected multiple costal cartilages as in open repair of pectus excavatum, and performed a double sternal osteotomy. Robicsek reported his open repair technique for pectus carinatum in 1963 (24). He resected the costal cartilages subperichondrially, performed a transverse sternal osteotomy and displacement, and resection of the protruding lower portion of the sternum. Considerable variations in surgical treatment are necessary because of the diversity of pectus carinatum.

Open repair technique

Open repair technique for pectus carinatum is more or less a variation of the open repair technique for pectus excavatum. It can be done with either a midline or a transverse submammary incision. The same exposure through the skin and muscle flaps is used with resection of the involved costal cartilages subperichondrially, leaving the perichondriums intact. Multiple reefing sutures can be placed to remove the redundancy in the perichondrial beds (4). A transverse osteotomy across the anterior table of the upper sternum is done using an oscillator blade and it is filled with a wedge of costal cartilage to secure it in an orthotopic position. Occasionally a second osteotomy may be required to displace the lower portion of the sternum posteriorly. Interrupted nonabsorbable sutures, steel wires, titanium or absorbable copolymer plates can be used for sternal fixation over the osteotomy line (16,24-26). The remainder of the repair is similar to that is done for pectus excavatum, including the closure and postoperative drainage. A retrosternal steel strut is helpful for temporary chest wall stabilization in severe deformities. Alternatively an anterior support strut with a large wire holding the sternum to the strut can be placed to avoid opening of the pleural spaces (16). Asymmetric pectus carinatum may require unilateral costal cartilage resection with transverse wedge shaped resection of the sternum only on that side, allowing anterior displacement and rotation of it (1-3). The sternal support strut can be removed 6 months after repair (*Figure 13*).

Chondromanubrial type pectus excavatum must be managed with a slightly different technique. The costal cartilages must be resected starting from the second cartilage, mostly together with third and fourth cartilages on both sides. A wide wedge osteotomy is performed at the point of maximal protrusion of the sternum, generally at

Figure 14 Postoperative appearance of a patient with chondromanubrial type of pectus carinatum.

Figure 15 Postoperative lateral X-ray of a patient with chondromanubrial type of pectus carinatum.

the level of the second costal cartilage. Sometimes a second wedge osteotomy is needed to provide a better shape of the sternum. The superior segment of the sternum can then be displaced posteriorly, and advancing the inferior fragment anteriorly the osteotomy is stabilized. Different materials can be used for this stabilisation also, such as interrupted steel wires, absorbable copolymer plates or titanium plates (*Figures 14,15*) (18,27,28).

Complications

Complications after open repair of pectus carinatum are rarely seen and they are similar to the ones seen after repair of pectus excavatum, such as pneumothorax and wound infection. Recurrence of the deformity is the most important complication again and it is less frequent than in pectus excavatum.

Conclusions

Although minimally invasive repair of pectus excavatum and carinatum has become quite popular in recent years, open repair of pectus deformities are successfully performed in many centers around the world with low morbidity, low cost, short limitation of activity and a good quality of life improvement. The optimal age for surgical treatment of pectus deformities is during adolescent years as surgery is technically easier, but adult patients should also be considered as candidates for surgical treatment if they are symptomatic.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Fonkalsrud EW. Chest wall abnormalities. In: Baue AE, Geha AS, Hammond GL, et al. editors. Glenn's Thoracic and Cardiovascular Surgery. Stamford: Appleton & Lange, 1996:581-92.
2. Shamberger RC. Chest wall deformities. In: Shields TW. editor. General Thoracic Surgery. Malvern: Williams & Wilkins, 1994:529-57.
3. Shamberger RC, Hendren WH 3rd. Congenital deformities. In: Pearson FG, Deslauriers J, Ginsberg RJ, et al. editors. Thoracic Surgery. New York: Churchill Livingstone, 1995:1189-209.
4. Sabiston DC Jr. Disorders of the sternum and the thoracic wall. Congenital deformities of the chest wall. In: Sabiston DC Jr, Spencer FC. editors. Gibbon's Surgery of the Chest. Philadelphia: WB Saunders Company, 1990:418-37.
5. Ravitch MM. Pectus excavatum and heart failure. Surgery

1951;30:178-94.
6. Welch KJ. Chest wall deformities. In: Holder TH, Ashcraft K. editors. Pediatric Surgery. Philadelphia: WB Saunders Company, 1980:162-82.
7. Haller JA, Kramer SS, Lietman A. Use of CT scans in selection of patients for pectus excavatum surgery: a preliminary report. J Pediatr Surg 1987;22:904-6.
8. Sidden CR, Katz ME, Swoveland BC, et al. Radiologic considerations in patients undergoing the Nuss procedure for correction of pectus excavatum. Pediatric Radiology 2001;31:429-34.
9. Meyer L. Zur chirurgiscen behandlung der angeborenen Trichterbrust. Verh Berl Med Ges 1911;42;364-73.
10. Sauerbruch F. Die Chirurgie der Brustorgane. J. Springer, 1920.
11. Ochsner A, DeBakey M. Chone-chondrosternon: report of a case and review of the literature. J Thorac Surg 1939;8:469-511.
12. Brown AL. Pectus excavatum (funnel chest). J Thorac Surg 1939;9:164-84.
13. Ravitch MM. The operative treatment of pectus excavatum. Ann Surg 1949;129:429-44.
14. Welch KJ. Satisfactory surgical correction of pectus excavatum deformity in childhood: a limited opportunity. J Thorac Surg 1958;36:697-713.
15. Wihlm JM. Open repair of pectus excavatum and pectus carinatum. In: Kuzdzal J, Asamura H, Detterbeck F, et al. editors. ESTS Textbook of Thoracic Surgery. Cracow: Medycyna Praktyczna, 2015:67-85.
16. Jaroszewski DE, Fonkalsrud EW. Repair of pectus chest deformities in 320 adult patients: 21 year experience. Ann Thorac Surg 2007;84:429-33.
17. Genc O, Gurkok S, Gözübüyük A, et al. Repair of pectus deformities: experience and outcome in 317 cases. Ann Saudi Med 2006;26:370-4.
18. Yuksel M, Bostanci K, Eldem B. Stabilizing the sternum using an absorbable copolymer plate after open surgery for pectus deformities: New techniques to stabilize the anterior chest wall after open surgery for pectus excavatum. Multimed Man Cardiothorac Surg 2011;2011:mmcts.2010.004879.
19. Scherer LR, Arn PH, Dressel DA, et al. Surgical management of children and young adults with Marfan syndrome and pectus excavatum. J Pediatr Surg 1988;23:1169-72.
20. Robicsek F. Marlex mesh support for the correction of very severe and recurrent pectus excavatum. Ann Thorac Surg 1978;26:80-3.
21. Fonkalsrud EW, Salman T, Guo W, et al. Repair of pectus deformities with sternal support. J Thorac Cardiovasc Surg 1994;107:37-42.
22. Fonkalsrud EW. Surgical correction of pectus carinatum: lessons learned from 260 patients. J Pediatr Surg 2008;43:1235-43.
23. Ravitch MM. Unusual sternal deformity with cardiac symptoms—operative correction. J Thorac Surg 1952;23:138-44.
24. Robicsek F, Sanger PW, Taylor FH, et al. The surgical treatment of chondrosternal prominence (pectus carinatum). J Thorac Cardiovasc Surg 1963;45:691-701.
25. Robicsek F, Watts LT, Fokin AA. Surgical repair of pectus excavatum and carinatum. Semin Thorac Cardiovasc Surg 2009;21:64-75.
26. Scarci M, Bertolaccini L, Panagiotopoulos N, et al. Open repair of pectus carinatum. J Vis Surg 2016;2:50-3.
27. Brichon PY, Wihlm JM. Correction of a severe pouter pigeon breast by triple sternal osteotomy with a novel titanium rib bridge fixation. Ann Thorac Surg 2010;90;e97-9.
28. Kim SY, Park S, Kim ER, et al. A case of successful surgical repair for pectus arcuatum using chondrosternoplasty. Korean J Thorac Cardiovasc Surg 2016;49:214-7.

doi: 10.21037/shc.2017.08.06
Cite this article as: Bostanci K, Stamenovic D. Open repair of pectus deformities. Shanghai Chest 2017;1:18.

Chest wall resection and reconstruction

Francisco Javier Moradiellos[1], Christopher W. Seder[2], Gaetano Rocco[3]

[1]Thoracic Surgery Department, Hospital Universitario Quirónsalud Madrid, Madrid, Spain; [2]Department of Cardiovascular and Thoracic Surgery, Rush University Medical Center, Chicago, IL, USA; [3]National Cancer Institute, Pascale Foundation, Naples, Italy

Correspondence to: Francisco Javier Moradiellos. Thoracic Surgery Department, Hospital Universitario Quirónsalud Madrid, Madrid, Spain. Email: dr.moradiellos@cirugiatoracica.es.

Received: 28 July 2017; Accepted: 03 August 2017; Published: 29 August 2017.
doi: 10.21037/shc.2017.08.05
View this article at: http://dx.doi.org/10.21037/shc.2017.08.05

Introduction

Chest wall resection is indicated for the treatment of most primary chest wall tumors, some locally-invasive neoplasms and, occasionally, to control infection, ulceration or pain from malignancy or radiation. A surgeon's primary goals in any chest wall resection and reconstruction should be to remove the lesion of interest, obliterate dead space, restore chest wall rigidity, preserve ventilatory mechanics, and protect intrathoracic organs, all while minimizing deformity. Although some basic tenets must be followed, innovative techniques have been described and may change the way that chest wall resection and reconstruction is performed in the future.

The work-up of a patient being considered for a chest wall resection should start with a thorough history and physical and the review of the patient's computed tomography (CT) scan or magnetic resonance imaging (MRI). Points of interest are the location of the lesion, its size, rate of growth, attachment to surrounding tissues and presence of critical adjacent structures. Patients with benign-appearing or small (<4 cm) lesions should undergo excisional biopsy, while those with larger lesions should undergo core needle or incisional biopsy. Care must be taken to orient the incisional biopsy in-line with any future operations, ensuring that the scar can be completely resected with the primary tumor. Ultrasound guidance or preoperative fiducial localization may help in planning the biopsy of non-palpable lesions. Patients with Ewing's sarcoma, osteosarcoma, and some high-grade soft tissue sarcomas should be considered for induction therapy, while plasmacytomas should be treated with radiation alone. In addition, pulmonary function tests should be obtained on all patients prior to chest wall resection for risk-stratification.

As will be shown in this chapter, chest wall reconstruction is usually more complex than the resection itself and its requirements should be foreseen from the beginning and at every step of the excisional phase of the procedure.

Operative techniques

Preparation

Most patients undergoing chest wall resection and reconstruction should receive an epidural or paravertebral catheter for pain control, depending on the laterality and location of the surgery. Single-lung ventilation using a double-lumen endotracheal tube or bronchial blocker is advised for most cases. The positioning and draping of the patient will depend on the locations of the lesion and of any autologous tissue needed to cover the resultant defect. While sometimes the donor area can be prepped in advance, patient-repositioning during surgery while maintaining sterility, is not uncommon.

Chest wall resection

The overlying skin and soft-tissues are valuable assets for the reconstruction and should be preserved if the surgeon is certain of the absence of involvement with the lesion, thus performing the initial incision directly over the mass. As much subcutaneous tissue and muscle should be spared as possible, particularly muscles that are required for reconstruction, but never at the expense of a safe oncologic margin of 2–3 cm, circumferentially, around the tumor. The site(s) of previous biopsies should be excised *en-bloc* and, if the tumor is infiltrating the skin, an ellipse of dermis with at least 2–3 cm margins is resected on all sides.

Figure 1 Specimen of a chest wall resection including the manubrium, part of the sternal body and three right costal arches.

For malignant primary chest wall tumors treated with radical intent, a 4-cm lateral margin and resection of a rib above and below the tumor is standard (1). The upper and lower intercostal spaces should be opened using electrocautery, allowing finger-palpation of the actual intrathoracic tumor margins. If the internal extent of the tumor is not clear, a thoracoscope can be inserted to help with localization. The intercostal muscle and neurovascular bundles can be sealed and cut using advanced bipolar energy or non-absorbable ligatures. The lateral rib margins are divided using guillotine rib shears. A frozen section analysis of relevant circumferential margins can be obtained during surgery and may be useful in decision-making if expanding the resection implies significant morbidity. However, this is only valid for soft tissue samples since the rib margins themselves must be decalcified prior to histologic examination. In any case, the resected specimen must be marked with threads on the sides to allow for accurate orientation by the pathologist. Pictures from several sides complement this information while showing the tissue before the fixation-induced retraction ensues.

In some cases, a partial or total sternectomy may be required to achieve adequate osseous margins (*Figure 1*). This involves performing costochondral release maneuvers to at least one rib space above and below the gross tumor margin. The internal mammary vessels should be identified and ligated. The dissection is generally performed from caudal to cephalad, as it is more convenient to lift the specimen up and dissect it off the underlying structures with electrocautery. If the manubrium is not involved, an oscillating saw can be used to divide the sternomanubrial junction. If necessary, the clavicular heads can be dissected in a sub-periosteal plane to avoid vascular injury and divided using an oscillating or Gigli saw.

If the tumor is located posteriorly, the ribs may require disarticulation from the vertebrae. This involves identifying the joint between the posterior rib and transverse process and disrupting the three costotransverse attaching ligaments (superior, lateral and posterior), using a combination of electrocautery and blunt dissection. The remaining radiate ligament attaches the head of the rib to the superior and inferior vertebral bodies and should also be divided. A downward pressure by the surgeon's assistant to the section of chest wall to be resected is helpful in the disarticulation maneuver.

Finally, in cases of tumor involvement of other underlying structures, similar appropriate clear margins must be obtained. For primary chest wall tumors, this includes achieving 2–3 cm margins on any affected non-vital adjacent organs, including lung, diaphragm, or potentially liver. This possibility should be thoroughly discussed with the patient prior to surgery.

Chest wall reconstruction

As a general principle, any defect larger than 5 cm in diameter or including more than 3 ribs should be reconstructed in order to avoid respiratory compromise from paradoxical motion of the chest wall. Reconstruction is also recommended when the defect extends lower than the 4th rib posteriorly, where the tip of the scapula is likely to become entrapped with the arm movements. There are two distinct technical steps in any reconstruction: (I) Restoring the structural and, if possible, functional rigidity of the chest wall; and (II) ensuring an adequate coverage of the defect with viable tissue (2). For the first step, there is a variety of implants and grafts which can be used.

A well-established technique involves the creation of a custom-shaped sandwich of methyl-methacrylate between two sheets of polypropylene mesh (*Figure 2*). An outline of the chest wall defect is marked on the polypropylene mesh and liquid methyl methacrylate (MMA) is poured over. The resin becomes rigid after curing, forming a cast that fills the chest wall defect. A second layer of mesh is then applied to create a sandwich (*Figure 3*). The rigid portion of the implant should be 1–2 cm smaller than the actual defect, allowing for a rim of mesh to be sutured circumferentially to the surrounding tissues. For this suture, heavy (No. 1–2) polypropylene thread is used, both in a pericostal (for the upper and lower ribs) and transcostal fashion (for the cut lateral rib margins). An alternative technique, which is

Figure 2 Polipropylene mesh being tailored to cover a chest wall defect with anchoring sutures already in place.

Figure 3 Polypropylene meshes in place with the in-between space ready to be filled with MMA.

particularly well-suited for sternal reconstruction, involves suturing a layer of mesh in place, filling it with MMA, and covering the defect with a second layer of mesh (*Figure 4*). If the polymerization of the MMA takes place *in situ*, additional care should be taken to avoid heat damage to the surrounding structures since this reaction is highly exothermic and temperatures in excess of 80 ℃ can be easily reached.

Polytetrafluoroethylene (PTFE) is another prosthetic material often used to reconstruct chest wall defects. A thick (2 mm) flexible sheet is anchored to the chest wall with heavy non-absorbable sutures. This mesh is very tightly stretched ("tight as a drum") to provide rigidity to the chest wall and prevent both paradoxical respiratory motion and lung herniation. For this last purpose, the ideal placement is inside the level of the ribs (*Figure 5*). A bone drill or sharp towel clip work well for creating rib holes for fixation (*Figure 6*).

Concerning biological implants, a variety of cryopreserved homografts and allografts are also available

Figure 4 Polypropylene-MMA sandwich after curing and ready to be covered with soft tissue.

in some centers and can be implanted using an identical technique (*Figure 7*). These grafts are usually hand milled at the time of reconstruction to cover a particular defect. In addition, any of these materials can be used in combination with bridging titanium plates to provide further structural stability. These plates can be fixed to the resected rib stumps using steel suture, cortical screws (*Figure 8*) or even simply clamping the terminal jaws which some of them include by design (*Figures 9,10*).

Chest wall reconstruction techniques have traditionally focused on restoring structural integrity by providing both rigidity and permanent covering. This is indeed enough for small to medium defects. For larger defects, or those involving sternocostal or vertebrocostal joints, biomechanical considerations apply, since maintaining the expandability and movement of the chest wall is essential to effective ventilation. In consequence, an optimal goal would be to restore as much functional integrity as possible. This could be achieved by incorporating some flexible parts and even "joints" with the attaching structures into the design of substitution implants. Metal implants have already been mentioned and can be flexed to a point during surgery, in order to accommodate different defects. This limited versatility and flexibility makes them less than ideal if we aim for a truly functional reconstruction (3).

A custom-made metal chest wall implant can be designed and molded or machine-milled but it is usually a time-consuming and costly process. More recently, an alternative based on 3D printing has been successfully applied in a few complex cases. This process involves several key steps: (I) Generating a high-resolution 3D reconstruction model of the chest wall, based on CT scans of the individual patient; (II) Planning the resection of bony structures on the 3D

Figure 5 PTFE mesh tightly attached to the edges of the rib resection in an inside position.

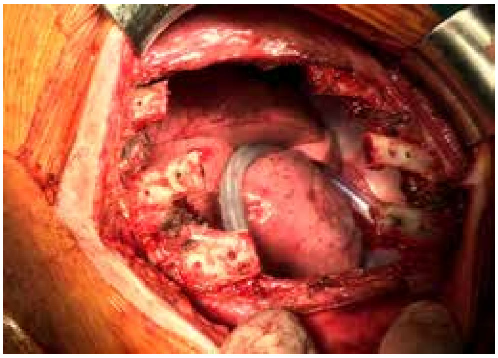


Figure 6 Chest wall resection with pleural drain in place and pre-drilled holes for anchoring sutures.

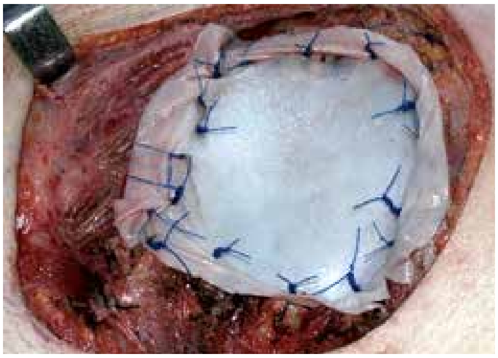


Figure 7 Chest wall defect covered with bovine pericardium.

model, according to the size and location of the lesion and accounting for safe oncologic margins; (III) Designing a single or multiple-piece implant with the desired structural and biomechanical characteristics; (IV) Prototype 3D printing in hard plastic for surgeon handling prior to the

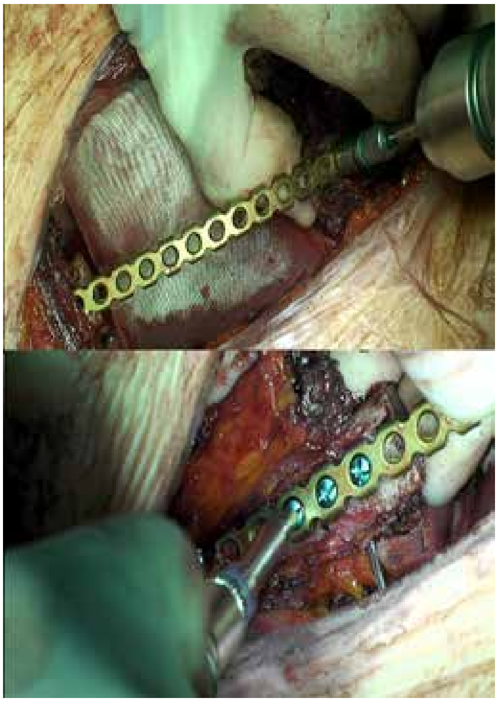


Figure 8 Titanium plate fixation with cortical screws.

procedure and refinement; (V) Final metal 3D printing of the implant, along with a cutting template (*Figure 11*), which the surgeon will find invaluable at the time of resection.

The design step is particularly crucial and has to involve both surgeons and biomedical engineers. It starts with precise functional and structural specifications and goes through several iterations until reaching an acceptable solution. Titanium is, again, the most commonly used metal for these implants, due to its excellent biocompatibility, lightness and durability. The degree and axes of flexibility of the different parts of the implant can be set by adjusting the thickness and folding of the metal (e.g., "Greek wave pattern") (*Figure 12*).

The metal 3D printing phase is usually outsourced and employs two main technologies: electron beam melting (EBM) and laser beam sintering (LBS). Both are additive 3D printing methods in with titanium alloy powder is solidified into an extremely thin layer using highly focused energy, applied within a precise shape. This layer is melted over the previous one, in a high vacuum environment. The superposition of the fused layers along the Z-axis yields the final result, consisting on a single piece of solid titanium. The spatial resolution is excellent and will

Figure 9 Titanium plate fixation with foldable jaws, over PTFP "neopleura".

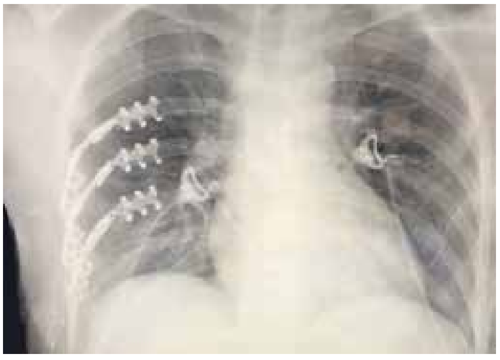


Figure 10 Chest radiography after reconstruction with titanium plates bent to the original rib curvature.

Figure 11 Three-dimensionally printed cutting template to aid during the resection phase.

Figure 12 Titanium 3D printed implant with biomechanic design.

precisely follow the digital design. Current titanium 3D printing technologies allow for the construction of very complex shapes to fulfil functional demands, as well as osseointegrable surfaces or meshes to facilitate osteoblastic migration and proliferation.

From a practical point of view, the surgeon also has to carefully consider the best way to attach the 3D implant to the resection limits at the time of surgery. Already described methods such as cortical screws, foldable jaws o even simple steel sutures have been used so far. If we wish to remain faithful to functional principles, more creative solutions will be required for attachments to the spinal transverse processes or the sternum. Attachment of a metal implant to accessory respiratory muscles is still an unreached but desirable goal in selected cases.

In any case, these implants will usually be combined with underlying PTFE patches, which will provide sealing and separation of the pleural cavity (*Figure 13*). A viable and sufficiently thick layer of soft tissue over these metal implants, including muscle, is mandatory in order to prevent skin ulceration (4).

The second step in chest wall reconstruction is the coverage of the prosthesis with viable soft tissue. This is usually a muscular or myocutaneous graft, depending on the need for skin coverage. These grafts can be either pediculated (maintaining their original blood supply) or free vascularized grafts. Free vascularized grafts allow for greater versatility but require microsurgical vascular anastomoses and these procedures, often performed by plastic surgeons, fall off the scope of this chapter. The ability to harvest and transpose pediculated grafts, on the other hand, should be among the technical armamentarium of a thoracic surgeon, in case this resource was unexpectedly needed during scheduled oncologic surgery. The four most commonly used grafts are pectoralis muscle, rectus abdominis, latissimus dorsi and omental flaps.

Concerning the pectoralis major, it should be noted that it has a double blood supply: the pectoral branch of

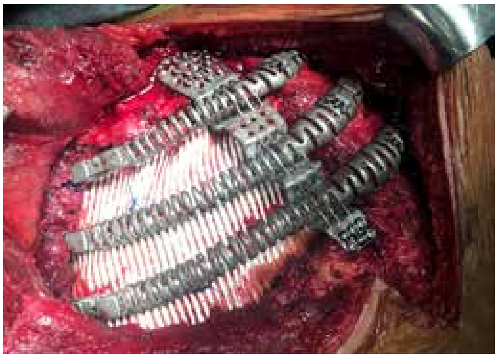


Figure 13 Titanium 3D printed implant in place, over PTFE membrane, providing structural and functional stability after sternocostal resection.

Figure 14 Pectoralis major myocutaneous flap showing donor area (cadaveric specimen).

the thoracoacromial trunk of the subclavian artery and the internal mammary 2nd through 6th perforating branches. This wide and fairly thick muscle is well-suited to cover the sternum and other antero-superior chest wall defects, and is often mobilized bilaterally. The incision used to perform an anterior chest wall resection usually allows access to the pectoralis muscle. When a skin paddle is mobilized with the muscle, it should be tacked to the underlying pectoralis fascia (*Figure 14*). This prevents shearing of the perforating blood supply with mobilization, and the subsequent skin necrosis. Electrocautery is then used to separate the muscle from the underlying chest wall and overlying subcutaneous tissue, if needed (*Figure 15*). Scissor dissection should be used near the vascular pedicles to prevent injury. The thoracoacromial pedicle can often be palpated between the thumb and forefinger on the underside of the muscle, just medial to the coracoid process of the scapula (*Figure 16*). If the thoracoacromial

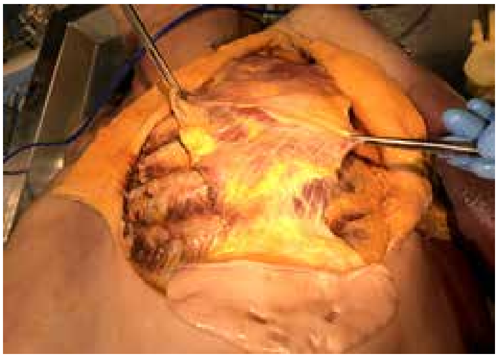


Figure 15 Extent of a pectoralis major myocutaneous flap showing a distal skin patch perfused by perforating subcutaneous vessels (cadaveric specimen).

vessels are inadequate, the pectoralis can also be used as a turn-over flap, vascularized by the internal mammary artery perforators. Division of the humeral and clavicular insertions allows extensive mobilization of the turn-over flap. Sparing 3–4 cm of muscle on the lateral aspect of the pectoralis muscle will leave the patient's anterior axillary fold intact.

Most rectus abdominis flaps that are transposed onto chest wall defects derive their blood supply from the superior epigastric artery. The overlying skin paddle can be oriented transversely (TRAM) or vertically (VRAM). The size, location, and orientation of the harvested elliptical skin island are determined by the extent of chest wall defect and the ability to primarily close the donor site. After the skin incision, electrocautery is used to circumferentially dissect around the skin paddle down to the anterior rectus sheath, veering away from the skin to preserve perforating vessels. The anterior rectus sheath is then incised in a V-shape near the pubis and temporarily sutured to the overlying skin to avoid shearing of perforating vessels. The posterior rectus sheath should be dissected off the muscle and preserved, thus decreasing the risk of herniation. The rectus muscle is divided near the pubic insertion and, along with the overlying anterior rectus sheath and skin paddle, it is mobilized towards the xiphoid (*Figure 17*). The flap is swung under the epigastric skin and subcutaneous tissue and sutured in place to the chest wall defect. During initial mobilization, the umbilicus is mobilized and re-implanted after the anterior rectus sheath and abdominal skin are closed. It should be noted that both VRAM and TRAM flaps carry significant morbidity, mostly derived from delayed eventration, and other alternatives should be

Figure 16 Fully dissected pectoralis major flap showing the thoracoacromial pedicle. The humeral insertion has already been cut for maximum reach (cadaveric specimen).

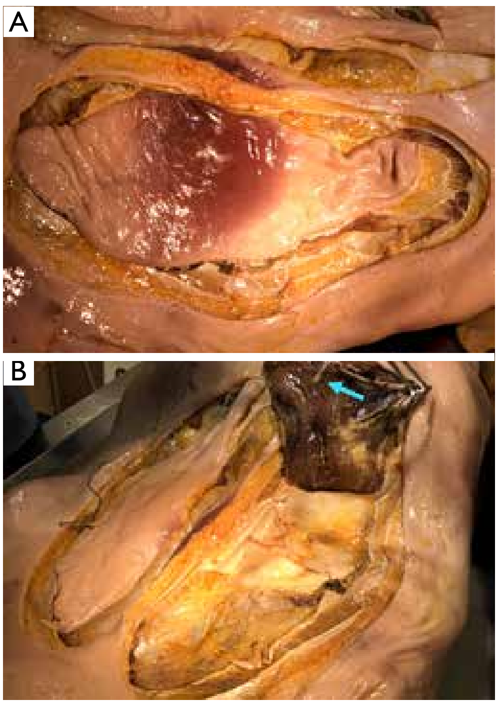


Figure 17 Vertical rectus abdominis myocutaneous (VRAM) flap (cadaveric specimen). (A) VRAM flap extending from the subcostal margin to the pubic bone; (B) VRAM flap with ligated inferior epigastric vessels (arrow) and preserved posterior fascia of the rectus abdominis.

considered first, if possible.

On the other hand, the latissimus dorsi flap is one of the muscles most commonly used for coverage of chest wall defects. It is a broad and flat muscle which is irrigated by the thoracodorsal artery, originating from the axillary

Figure 18 Latissimus dorsi myocutaneous flap. Note that the preservation of the fascial and subcutaneous perfusion with edge sutures allows for a skin patch which is wider than the muscle mass itself.

artery. Virtually any skin island overlying the muscle can be harvested, limited only by the ability to close the donor site defect (*Figures 18,19*). If the latissimus cannot be accessed through the chest wall resection incision, a counter incision along the anterior aspect of the muscle can be fashioned. Electrocautery is used to mobilize the muscle from the underlying chest wall and surrounding subcutaneous tissues. The latissimus is differentiated from the underlying serratus muscle based on the longitudinal direction of its fibers. Dissection is carried caudally towards the iliac crest and posteriorly to the paraspinous muscles, where it is divided. As dissection continues cranially, the flap is lifted and care must be taken to preserve the thoracodorsal vascular pedicle. A few inches below the humeral insertion of the latissimus, the pulse can be palpated. Flap length can be gained by dividing the humeral insertion or by carefully removing the pedicle from its investing fascia with fine scissors (*Figure 20*).

Finally, the omental flap, a vascularized fatty tissue, can reach nearly any location on the chest wall and is most often irrigated by the right gastroepiploic artery. Through a small upper midline laparotomy, the omentum should be freed from any bowel that it is adherent to and separated from the transverse colon. Small vessel ligation can be performed with silk ligatures or advanced bipolar energy. The short vessels between the greater curvature of the stomach and the gastroepiploic arch are then carefully divided and the left gastroepiploic artery is divided near the splenic hilum. If more length is needed, the omentum can be unfurled through selective division of internal vessels while preserving the vascular arcades (*Figure 21*). The omental

Figure 19 Latissimus dorsi myocutaneous flap covering an anterior chest wall defect. Final result.

Figure 20 Latissimus dorsi muscle flap prepared for eversion after ligation of the thoracodorsal pedicle and preservation of at least two perforating pedicles.

flap is brought through the diaphragm or abdominal wall into place on the chest wall defect.

Comments

Tips and tricks

- ❖ Never compromise oncologic margins to preserve soft tissue required for chest wall reconstruction. Other options will be available;
- ❖ When harvesting myocutaneous flaps, suture the skin to the muscle fascia to avoid shearing delicate perforating vessels;
- ❖ Although electrocautery is used for most of the muscle flap mobilization, scissors should be used near the vascular pedicles to avoid thermal injury;
- ❖ It is important to leave an adequate number of soft tissue drains and not remove them until the drainage is less than 25 cc per day;
- ❖ If a PTFE graft becomes infected and the patient is not septic, immediate removal is not always indicated. If incision and drainage is performed, antibiotics are administered, and prosthesis removal is delayed for 6–8 weeks, enough scar tissue often forms to support the chest wall after the infected mesh is removed.

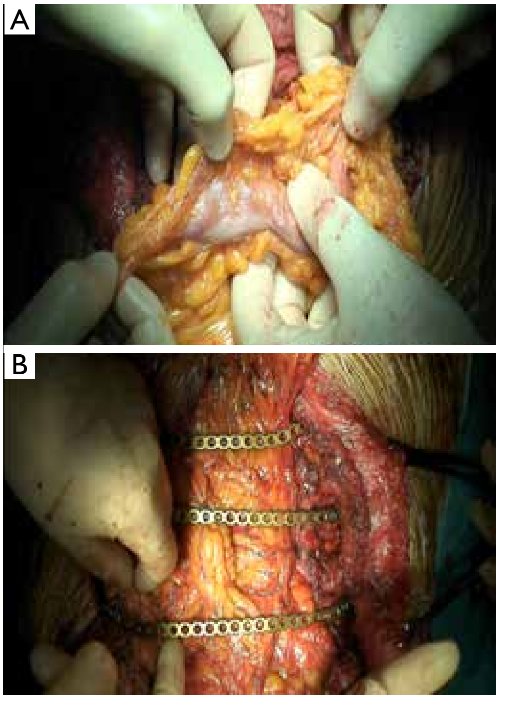


Figure 21 Omental flap for thoracic reconstruction. (A) Abdominal dissection and harvesting of the flap while preserving the vascular perfusion; (B) omental flap in a anterior thoracic position with titanium plates for structural support.

Caveats

Morbidity and mortality rates after chest wall resection and reconstruction range from 24–46% and 2–7%, respectively. The most common morbidities following chest wall resection and reconstruction relate to wound healing and pulmonary complications. Wound healing issues are more common in patients with advanced age, multiple re-do operations, combined prosthetic and bioprosthetic reconstruction, ulcerated tumors, and in those who have had soft tissue coverage with omentum. Although chest wall resection poses a considerable risk of developing postoperative pulmonary complications, without chest wall reconstruction, the incidence of flail chest and paradoxical motion, and resultant pulmonary complications, would likely be higher. In other words, reconstruction should always be carefully planned as part of the chest wall resection planning, as well as backup options.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

doi: 10.21037/shc.2017.08.05
Cite this article as: Moradiellos FJ, Seder CW, Rocco G. Chest wall resection and reconstruction. Shanghai Chest 2017;1:27.

References

1. McAfee MK, Pairolero PC, Bergstralh EJ, et al. Chondrosarcoma of the chest wall: factors affecting survival. Ann Thorac Surg 1985;40:535-41.
2. Seder CW, Rocco G. Chest wall reconstruction after extended resection. J Thorac Dis 2016;8:S863-71.
3. Rocco G. Chest wall resection and reconstruction according to the principles of biomimesis. Semin Thorac Cardiovasc Surg 2011;23:307-13.
4. Moradiellos J, Amor S, Córdoba M, et al. Functional Chest Wall Reconstruction With a Biomechanical Three-Dimensionally Printed Implant. Ann Thorac Surg 2017;103:e389-e391.

Reconstructive techniques after diaphragm resection and use of the diaphragmatic flap in thoracic surgery

Piergiorgio Solli[1], Luca Bertolaccini[2], Jury Brandolini[3], Alessandro Pardolesi[3]

[1]Department of Thoracic Surgery, Maggiore and Bellaria Hospitals, Bologna, Italy; [2]Department of Thoracic Surgery, AUSL Romagna - Forlì Teaching Hospital, Forlì, Italy; [3]Department of Thoracic Surgery, AUSL Romagna - Ravenna Teaching Hospital, Ravenna, Italy

Correspondence to: Piergiorgio Solli. Department of Thoracic Surgery, Maggiore and Bellaria Hospitals, Bologna, Italy. Email: piergiorgio.solli@gmail.com.

Received: 01 August 2017; Accepted: 03 August 2017; Published: 14 August 2017.
doi: 10.21037/shc.2017.08.04
View this article at: http://dx.doi.org/10.21037/shc.2017.08.04

Introduction

The diaphragm has been recognized as "the second most important muscle after the heart" (1).

Although a rare occurrence, the need for diaphragmatic resection and reconstruction might be dictated by secondary invasion from different tumours, including lung cancer, mesothelioma, chest wall tumours, sarcomas and metastatic lesions. Several factors must be taken into consideration when planning the approach to tumours involving the diaphragm, that accordingly to the histology, the amount and the site of involvement could be partially or completely removed. In some circumstances the resection might extend to adjacent structures such as the pericardium (mesothelioma) or the chest wall (sarcomas), thus posing supplementary challenges to the surgical procedure.

Some of the diaphragmatic resections can be repaired primarily, as long as there is adequate tissue that can be brought together without excessive tension. Larger defects or a completely resected diaphragm can be reconstructed only with synthetic or autologous tissue.

It should not be overlooked also that the diaphragm plays an important role as structure for plastic or reconstructive surgery and its use as vascularised flap in thoracic surgery has been widely documented by several reports for the treatment of multiple conditions (i.e., reinforcement of spontaneous or iatrogenic oesophageal perforations, repair after extensive pericardial resection, prophylactic bronchial stump coverage or early closure of bronchopleural fistula) (2).

Eventually large defects of one hemi-diaphragm might require reconstruction with prosthetic material in the context of a post-traumatic rupture with abdominal viscera herniation or for chronic symptomatic congenital hernia diagnosed late in adults.

Operative techniques

Surgical approaches to the diaphragm

The diaphragm provides the anatomical barrier between the pleural cavities/pericardium and the abdominal cavity. Its muscular nature is associated with the ability to sustain wide incisions without functional compromise even in the presence of bulky diseases or large defects. Surgical approach varies from classical trans-thoracic or trans-abdominal or combined thoraco-abdominal open approaches to minimally invasive thoracoscopic and laparoscopic approaches. It is impossible to establish precise criteria, surgical approaches depending on the nature of the lesion, its location, the existence of associated thoracic or abdominal abnormalities and eventually the surgeon's attitude and preference. The surgical approach should be therefore individualized and based on the clinical and radiographic findings. Vast majority of the diseases where the diaphragm is involved and needs to be resected with are thoracic in their nature, thus requiring a thoracic approach.

In general, right-sided diseases are often difficult to repair from the abdomen because of the presence of the liver and hence a right thoracotomy is preferred. On both sides the thoracotomic approach ensures optimal access to all the muscular surface facilitating adequate surgical manoeuvring and treatment of any type of diaphragmatic lesion. Moreover, the thoracotomic approach is definitely indicated in case of chronic traumatic hernias where long-standings defects usually require prosthetic replacement and division of adhesions between abdominal and thoracic structures. The incision can be performed in the 6^{th} or 7^{th} intercostals space normally through a posterior muscle-sparing thoracotomy in the auscultatory triangle or a standard postero-lateral thoracotomy. Thoracoscopy and laparoscopy are very useful to explore both cavities in the case of undiagnosed or more complicated situation and can be used in conjunction to open approaches. Thoraco-abdominal combined approaches are rarely indicated and we prefer to repair the diaphragm through thoracic approach until and unless there is clear-cut indication for concomitant laparotomy (associated abdominal organ injury).

Reconstructive techniques after diaphragm resection

The techniques of reconstruction vary according to the underlying indication.

Primary repair

For brevity, in this chapter the direct reconstruction of the diaphragm will not be discussed in details as they do not require prosthetic re-shape usually because relatively small defects that can be secured with simple re-approximation of both the edges of the muscle.

It is, however, of crucial importance emphasize the need of tension-free remodelling with adequately large and strong filament material (#0, #1, #2 suture size) in order to prevent secondary disruption, especially on left side where the absence of the liver offers less protection and predispose to iatrogenic herniation of abdominal viscera. Care should be taken to take full-thickness bites, while avoiding injury to structures below the diaphragm. A variety of suture material and technique have been successfully employed: interrupted or horizontal mattress sutures, running suture repair or one-layer interrupted stitches closure are all commonly accepted techniques in current practice, both with absorbable or non-absorbable suture material (3).

We favoured in the last decade the Maxon MT-20 1 loop suture (Polyglyconate Monofilament Absorbable, Medtronic™, USA) because of its properties: high tensile strength, 180-days absorption profile, looped structure providing adjunctive tension and smooth-shaped needle minimizing tissue drag and trauma.

Total prosthetic diaphragmatic repair (mesothelioma, complex thoracic exenterations)

Reconstruction of the diaphragm in these context is performed through the surgical approaches preferred for the whole procedure usually a thoracotomy whether a lateral or poster lateral (extra-pleural pneumonectomy or pleurectomy/decortication for mesothelioma) or combined approach like hemi clamshell incision as in the case large thymomas or large chest wall tumours.

It is crucial to secure laterally with sutures the prosthetic patch around the ribs. Posteriorly, it is sutured to the diaphragmatic crus or gently tacked with finer sutures to the wall of the oesophagus. Medially it is sewn to the edge of the pericardium with interrupted sutures. Some Authors consider extremely important to place the diaphragmatic reconstruction at the same level as the native diaphragm, namely at the 10^{th} intercostal space posteriorly and at the 8^{th}–9^{th} intercostals spaces anteriorly and laterally, in order to deliver adjuvant radiation safely, especially in the area of the posterior costo-phrenic sulcus, where the liver (right side) or the oesophagus and stomach (left side) might be exposed to an increased risk of radiation toxicity. However the modern technology with the use of Intensity-modulated radiation therapy (IMRT) technique enables a high-precision delivery, using computer-controlled linear accelerators to distribute precise radiation doses to specific areas with reduced side-effects (*Figure 1*).

The experience says that usually the attitude is to over-correct the reconstruction placing the prosthesis in a lower position than the native diaphragm and with a more steep shape, thus the goal should be to place the anchoring stitches in the appropriate site still accepting a slightly more elevated position as the final result. This makes the reconstruction easier and avoids the need to insist on stitching in un-natural areas where the anchoring points result less safe.

Specific consideration deserves the reconstruction on left site, because of the peculiar anatomy of the left posterior costo-phrenic corner. Not surprisingly the vast majority of diaphragmatic patch dehiscences reported in the literature occur on left side with an incidence as high as 5–7.6%. The special risk in this area is due to the absence of diaphragmatic tissue after the extensive resection of the whole muscle, leaving the left posterior costo-phrenic sulcus as the most critical site for diaphragmatic reconstruction especially for the proximity of the oesophageal hiatus and the descending aorta and no viable tissue that can be used

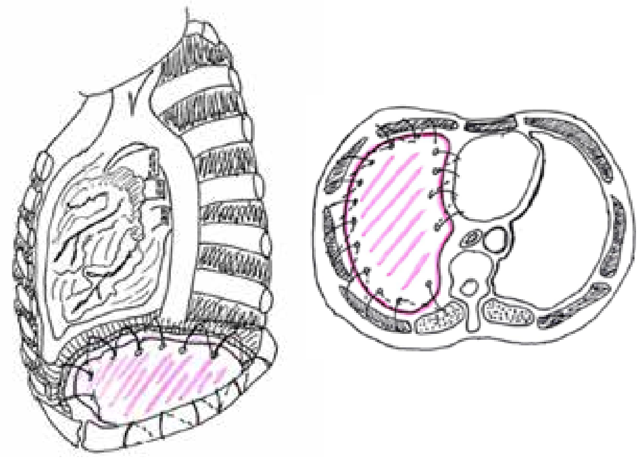


Figure 1 Technique of anchorage of the prostehesis after complete removal of the diaphragm (extra-pleurtal pneumonectomy or pleurectomy decortication). It is crucial to secure laterally the prosthetic patch around the ribs, posteriorly the diaphragmatic crus or gently tacked with finer sutures to the wall of the oesophagus, medially to the edge of the pericardium with interrupted sutures.

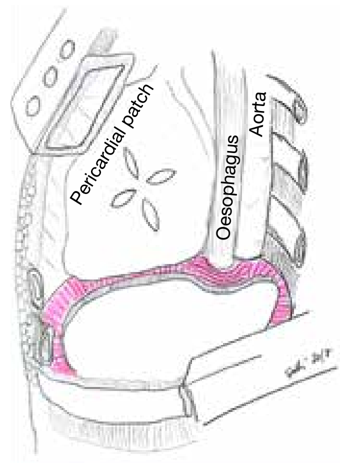


Figure 2 Specific consideration deserves the reconstruction on left site, because of the peculiar anatomy of the left posterior costophrenic corner, where the vast majority of diaphragmatic patch dehiscences occur. The special risk in this area is due to the absence of diaphragmatic tissue after the extensive resection of the whole muscle, the proximity of the oesophageal hiatus and the descending aorta and no viable tissue that can be used to fix patch. Sugarbaker *et al.* suggested to leave a 1- to 2-cm rim of left diaphragmatic crus over the gastric incisura where sutures can be placed during reconstruction preventing gastric herniation.

to fix the stitches and patch. Sugarbaker *et al.* suggested to leave a 1- to 2-cm rim of left diaphragmatic crus over the gastric incisura where sutures can be placed during patch reconstruction preventing gastric herniation (*Figure 2*) (4).

This is certainly a viable option although we believe that the technique described by Rea *et al.* (*Figure 3*) (5) with titanium plates support offers an easier and safer chance for diaphragmatic reconstruction. Titanium plates have characteristics of both endurance and flexibility, thus resulting in a valid and physiologic replacement, at the same time providing a good support for patch fixing thanks to multiple holes in its structure. Care must be taken to adequately expose the vertebral column and the posterior arch of the ribs (usually the 9th and 10th vertebra represent optimal fixing points) and to accurately identify site of screws insertion to avoid the potentially dangerous positioning into the intervertebral disc. Firstly a simulation by adapting an easy-flexible L-shaped plate model for fixation on two vertebral bodies and along the rib arch below should be done. The bone of the vertebral bodies is then exposed removing all the overlying tissue and the plate is fixed with two screws (14 mm length) on the two adjacent vertebral bodies and with one or two screws (12 mm length) on the corresponding rib. Finally, the patch is fixed to the plate with single stitches that are passed through the plate loops. The whole procedure takes about additionally 15 minutes (*Figure 4*).

For analogue reasons reconstruction has to pay attention on right side: usually a notch of the mesh had to be patterned at the level of the inferior vena cava to avoid vena cava and hepatic veins constriction. However the presence of the liver makes the reconstruction safe even in the presence of a not completely medially reconstructed diaphragm and the incidence of herniation on right side is only anecdotic.

Partial prosthetic diaphragmatic repair

Bulky diseases (thymomas or other mediastinal malignancies) or huge chest wall tumours invariably require complete resection and reconstruction of the diaphragm. More challenging is how to decide for a direct reconstruction versus a prosthetic replacement in case of partial involvement of the muscle. Most frequent clinical scenario is a lung cancers infiltrating the diaphragm, occasionally limited diaphragmatic deposits (thymoma, ovarian cancers, sarcomas). In this context the phrenotomy is normally tailored in order to ensure an oncologically adequate clear

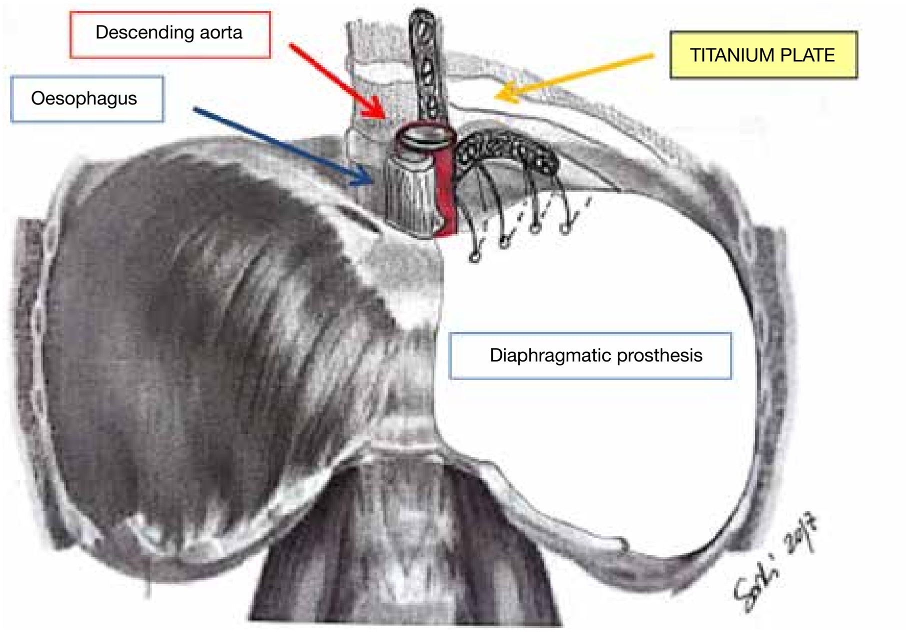


Figure 3 The technique described by Rea *et al.* with titanium plates support offers an easier and safer chance for left diaphragmatic reconstruction. Care must be taken to adequately expose the vertebral column and the posterior arch of the ribs (usually the 9th and 10th vertebra represent optimal fixing points) and to accurately identify site of screws insertion. The atch is fixed to the plate with single stitches that are passed through the plate loops (Schiavon M *et al.* A new technique of diaphragmatic patch fixation in extrapleural pneumonectomy. Eur J Cardiothorac Surg 2010;38:798-800).

margin. It could be realized circumferentially encircling the lesion or via a radial incision if a larger part of the muscle has to be resected or if the infiltration is in the periphery. It is crucial to progressively put stitches on diaphragmatic edges along with the opening of the abdominal cavity, in order to prevent muscular retraction and also to have at the end of the excision a clear delimitation of the defects and an optimal strategy to accurately plan the reconstruction (*Figure 5*).

A specific consideration deserves the case of chronic traumatic diaphragmatic hernias in adult. These are usually long-standing conditions not rarely associated with relatively moderate diaphragmatic defects. Same principles apply and when the hernia is reduced in the abdominal cavity, the edges of the defect have to be delimited with multiple separated stitches to plan the reconstruction.

There is no a general rule on what is a defect "large enough" to require a prosthetic replacement and what could be directly sutured, depending on surgeon's experience and situations. It should be considered the constant stress on the suture lines during respiration and the intra-abdominal pressure (again especially on left side) and also surgeons should remember that the real tension of the diaphragm is not that experienced during the procedure due to the anaesthetic management with curarization and muscles paralysis. In general only very limited defects can be safely repaired with direct suture and tension-free, for all the other conditions an even small prosthesis usually offers a more anatomical remodelling. The mesh is anchored through interrupted, tension-free stitches to the diaphragmatic remnants (*Figures 6,7*).

Diaphragm as vascularised flap

Diaphragmatic flaps have been successfully used to reinforce spontaneous and iatrogenic oesophageal perforations and to close chest wall defects for more than 30 years.

The diaphragmatic harvesting presents several advantages compared to other types of vascular pedicled flaps for intrathoracic transposition (i.e., serratus, intercostal, omental, pectoralis major, latissimus dorsi, parietal pleural and pericardial).

Firstly from the technical point of view: a customized flap is usually easy to prepare, to rotate, and to adapt to the

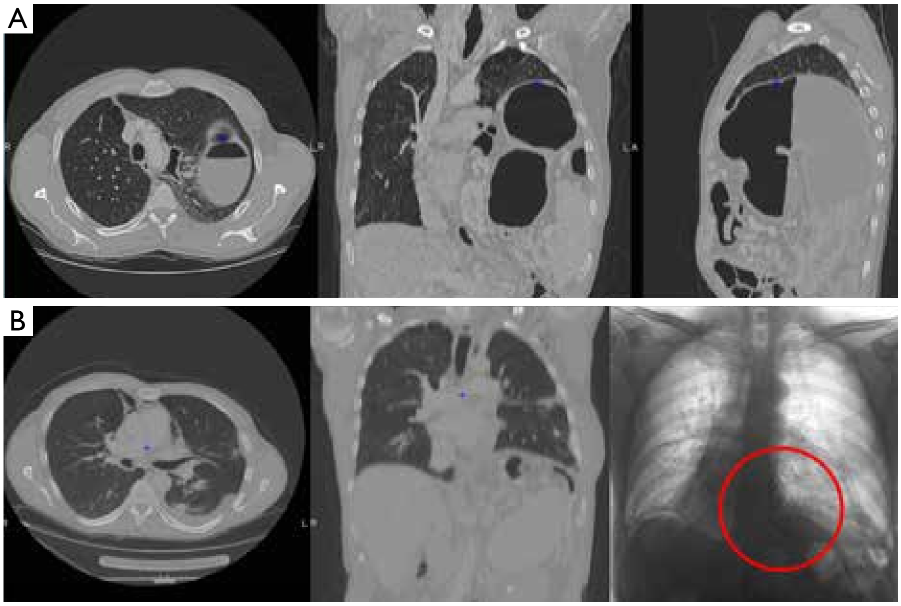


Figure 4 Case of a large chronic post-traumatica left-sided diaphragmatic hernia. The lung is almost entirely compressed. (A) CT-scan preoperative images; (B) the reconstruction on 3-month postoperative CT-scan. Red circle is spotting the titanium plate on CxR that has been utilized for left side total reconstruction of the diaphragm.

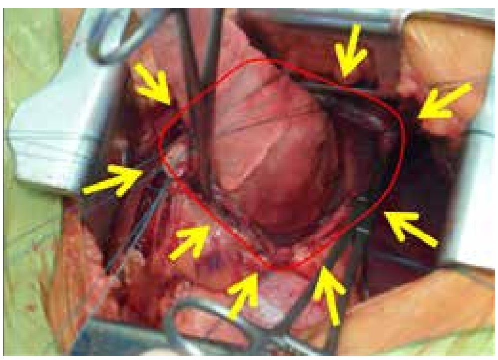


Figure 5 Case of a left-sided diaphragmatic hernia. Abdominal viscera have been already repositioned in the abdominal cavity. Stitches have been placed on the edges of the defects (red line) in order to facilitate the reconstruction (yellow arrows).

purpose. Moreover it is thick enough, resistant to necrosis and infection, very well vascularised due to the extensive blood supply to the diaphragm. A long flap can easily be tailored and can reach any area of the thoracic cavity without torsion or tension. There is usually not need to change patient's position on the operating table during the procedure, only occasionally a supplementary incision is required for harvesting.

The opening of the peritoneal cavity during phrenoplasty does not represent a real risk of propagating infection to the abdomen, nor functional disadvantages are caused by the phrenoplasty itself. As a minor functional effect after phrenoplasty, the motility of the posterior leaflet decreased with subsequent reduction of the costo-phrenic sinus. This may result in a benefit after pneumonectomy (reduction of the right post-pneumonectomy space) or after lobectomy *en-bloc* with diaphragm resection (shortening the period of air leakage, reduced basal space).

Moreover the closure of the diaphragm subsequent to flap harvesting decreases the muscle surface and reduces its paradoxical movement and may positively affect respiratory function improving the tolerance to pneumonectomy.

In this section the use of the diaphragm as flap is presented in pictures and photos in 4 different conditions: reinforcement of spontaneous or iatrogenic oesophageal perforations, repair after extensive pericardial resection (6), prophylactic bronchial stump coverage, and early closure of bronchopleural fistula (*Figures 8-10*).

Choice of prosthetic material

Many different materials (autologous or alloplastic) can be employed for the reconstruction, mostly favouring surgeon's experience, attitude and preference.

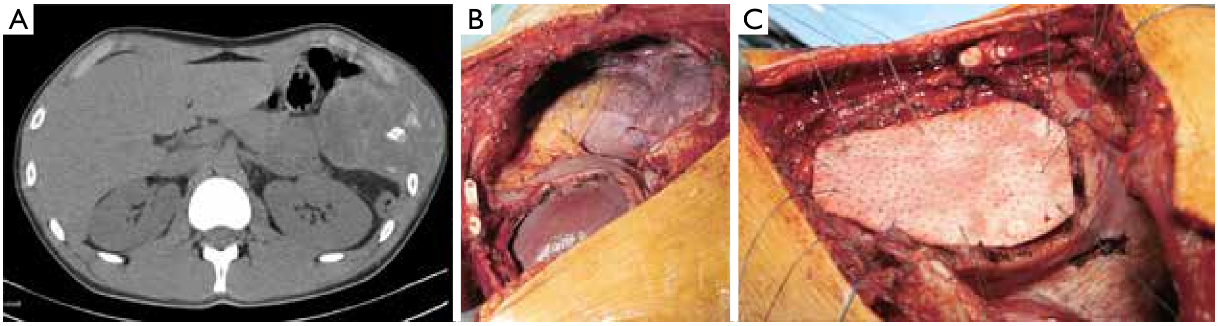


Figure 6 Partial reconstruction of the hemidiaphragm with prosthesis. (A) Chondrosarcoma of the left chest wall involving the diaphragm; (B) chest wall *en bloc* with partial diaphragm resection. Reconstruction with interrupted stitches and Permacol® (Medtronic™, USA). Courtesy Mr Marco Scarci, Thoracic Surgery, UCLH, London UK).

Figure 7 Partial resection of right hemidiaphrgam. (A,B) Case of right sided thymoma deposit (red circle) requiring a partial resection of the diaphragm with prosthetic reconstruction; (C) postoperative CT scan showing the remodelling; (D) specimen where the ideal position of the inferior vena cava (IVC) is indicated.

In the pas there has been interest for the autologous reconstruction with muscle pedicled flaps (TRAM technique, external oblique muscle flap, autologous latissimus dorsi muscle reverse flap). Among these, the technique described by Bedini *et al.* (7) with the latissimus dorsi has been consistently employed during mesothelioma surgery or for large sarcomas with interesting results. Autologous flaps offer the advantage of vascularised tissue, without a permanent foreign body and the related potential infection risk. On the other hand, the harvesting technique is generally complex and time consuming and increases potential morbidity and donor-site complications.

Nowadays, the reconstruction is typically performed with synthetic meshes. They are well tolerated, can be bio-prosthetic materials or entirely artificial mesh, either absorbable or non-absorbable.

Because of its strength and impermeability, polytetrafluoroethylene (PTFE Gore-Tex™, Gore&Assoc, Arizona, USA) is one of the most common meshes recommended for diaphragmatic reconstruction after EPP or its composite variants (GORE® DUALMESH®) with dual-surface material that encourages host tissue in-growth while minimizing tissue attachment to abdominal viscera and optional antimicrobial technology. Other options include the non-absorbable and permeable prosthetic Mersilene polyester fiber mesh (Ethicon™, Somerville, NJ, USA), Prolene double-filamented polypropylene mesh (Ethicon™, Somerville, NJ, USA), Marlex polypropylene monofilamented fiber mesh (Davol™, Cranston, RI) even though rarely used in routine practice.

Less experience exists with new biological materials: bovine pericardium, acellular porcine dermal collagen (Permacol™ Covidien, AG, USA), acellular human cadaveric dermis (AlloDerm™, Lifecell Corporation,

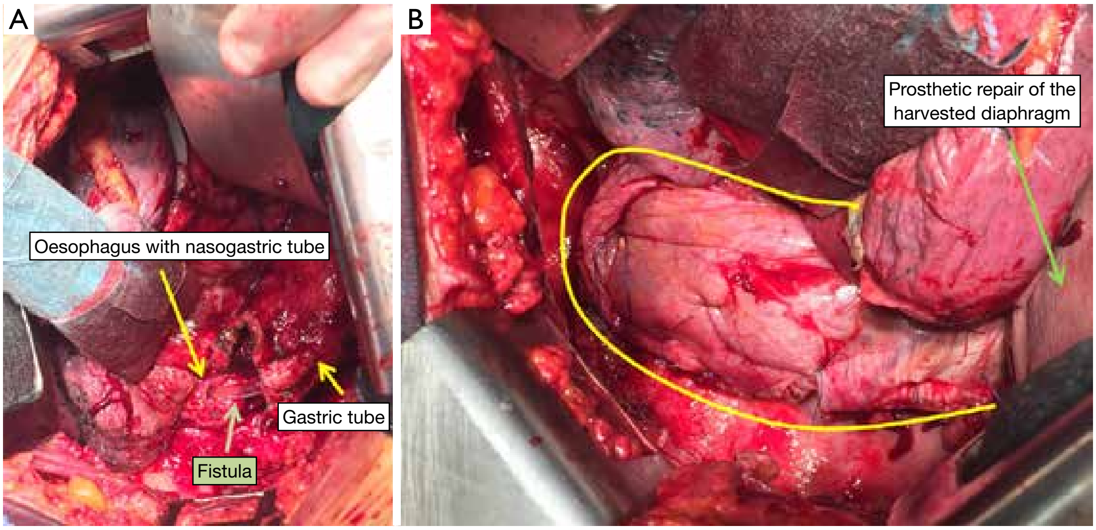


Figure 8 Use of hemidiaphrgam as vascularized flap. (A) Case of an anastomotic fistula after Ivor–Lewis esophagectomy; (B) primary repaired with the right diaphragm as vascularized flap.

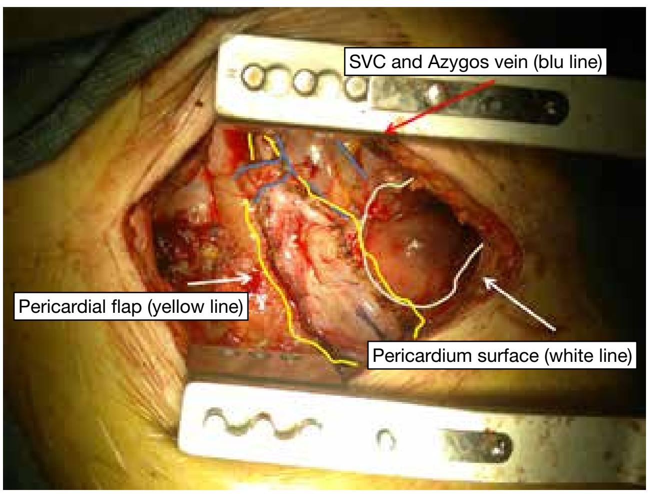


Figure 9 Harvesting of the right diaphragmatic pedicled flap utilized to reinforce the post-pneumonectomy right main bronchus stump.

Branchburg, NJ, USA) or the composite mesh AlloDerm + polypropylene with the AlloDerm facing the abdomen. Biologic meshes use a newer technology where cells and immunogenic properties are removed, leaving behind only a basement membrane framework for native tissue cells to recolonize. Subsequently, implanted extracellular matrix will be degraded and host collagen deposited. Thus, the biologic mesh should allow the strength and integrity of the repair to be maintained while this remodeling occurs.

Very recently Rolli *et al.* reported impressive results with the Surgimesh-PET 3D (Aspide Medical, La Talauderie, France), a new alloplastic mesh made of knitted multifilament polyester with 3-dimensional structure; permeable to fluid and cell migration, chemically inert, non-absorbable, highly resistant, gives a stable framework for cell migration, allowing a definitive mesh incorporation and permanent internal support (8).

Comments: tips and tricks/caveats

- Primary repair of any diaphragmatic defect should be pursued only if the final reconstruction is tension-free with excellent re-approximation of edges. Prosthetic replacement should be considered in any other circumstances regardless the entity of the defect.
- Total diaphragmatic removal on right side at the level of the inferior vena cava (IVC) hiatus could be reconstructed with some tolerance because herniation is very rare due to the liver position; at the same time attention should be paid either during resection and reconstruction to the IVC itself and the sovrahepatic veins.
- Total diaphragmatic removal on left side on the contrary should be followed by meticulous and precise reconstruction; iatrogenic hernias are between the most common postoperative complication and are usually associated to technical mistakes in reconstruction (see

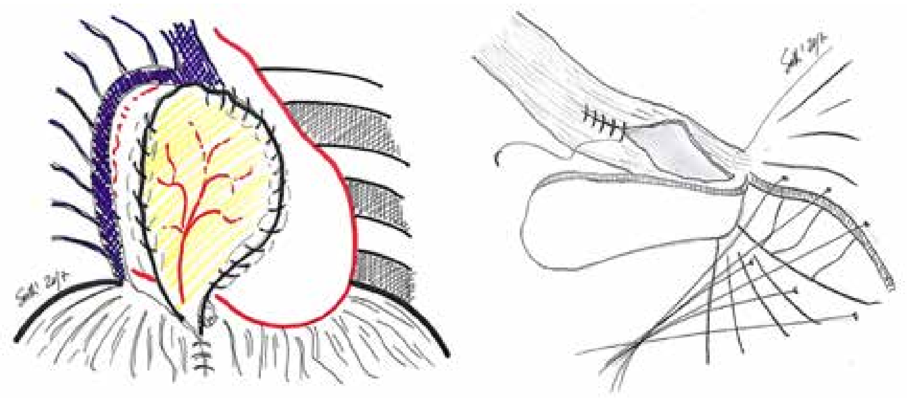


Figure 10 Use of the diaphragm as flap to repair extensive pericardial defect after an intrapericardial right pneumonectomy with wide pericardium resection (Goldstraw P, Jiao X. Pericardial repair after extensive resection: another use for the pedicle diaphragmatic flap. Ann Thorac Surg 1996;61:1112-4.) and as a reinforcement of spontaneous or iatrogenic oesophageal perforations repair.

text for details).

❖ When opening the diaphragm for a partial resection or during dissection for a chronic traumatic hernia, multiple stitches on the edges should be placed in advance in order to better plan the reconstruction and avoid abdominal viscera injuries.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Fell SC. Surgical anatomy of the diaphragm and the phrenic nerve. Chest Surg Clin N Am 1998;8:281-94.
2. Mineo TC, Ambrogi V. The diaphragmatic flap: a multiuse material in thoracic surgery. J Thorac Cardiovasc Surg 1999;118:1084-9.
3. Finley DJ, Abu-Rustum NR, Chi DS, et al. Reconstructive techniques after diaphragm resection. Thorac Surg Clin 2009;19:531-5.
4. DaSilva MC, Sugarbaker DJ. Technique of Extrapleural Pneumonectomy. Oper Tech Thorac Cardiovasc Surg 2010;15:282-93.
5. Schiavon M, De Filippis A, Marulli G, et al. A new technique of diaphragmatic patch fixation in extrapleural pneumonectomy. Eur J Cardiothorac Surg 2010;38:798-800.
6. Goldstraw P, Jiao X. Pericardial repair after extensive resection:v another use for the pedicle diaphragmatic flap. Ann Thorac Surg 1996;61:1112-4.
7. Bedini AV, Andreani SM, Muscolino G. Latissimus dorsi reverse flap to substitute the diaphragm after extrapleural pneumonectomy. Ann Thorac Surg 2000;69:986-8.
8. Rolli L, Leuzzi G, Girotti P, et al. Permeable Non-absorbable Mesh for Total Diaphragmatic Replacement in Extended Pneumonectomy. Ann Thorac Surg 2017;104:e105-7.

doi: 10.21037/shc.2017.08.04

Cite this article as: Solli P, Bertolaccini L, Brandolini J, Pardolesi A. Reconstructive techniques after diaphragm resection and use of the diaphragmatic flap in thoracic surgery. Shanghai Chest 2017;1:21.

Diaphragmatic plication for eventration or paralysis

Davide Patrini[1], Nikolaos Panagiotopoulos[1], Benedetta Bedetti[2], David Lawrence[1], Marco Scarci[1]

[1]Thoracic Surgery Department, University College London Hospitals (UCLH), London, UK; [2]Thoracic Surgery Department, Malteser Hospital, Bonn, Germany

Correspondence to: Davide Patrini. Thoracic Surgery Department, University College London Hospitals, 16-18 Westmoreland St. W1G 8PH, London, UK. Email: davide.patrini@uclh.nhs.uk.

Received: 11 June 2017; Accepted: 31 July 2017; Published: 22 August 2017.
doi: 10.21037/shc.2017.08.01
View this article at: http://dx.doi.org/ 10.21037/shc.2017.08.01

Introduction

Etiology

Diaphragmatic eventration are congenital developmental defects affecting the muscular portion of the diaphragm, while the normal attachment to sternum ribs and dorsolumbar spine are maintained. They are rare (incidence <0.05%) and more common among males, affecting more often the left hemidiaphragm. This abnormality occurs as a result of an abnormal migration of myoblasts from the upper cervical somites into two of the four embryological structures that contribute to diaphragm development. Clinically diaphragm eventration is impossible to differentiate from acquired paralysis. In contrast to true diaphragmatic eventration, diaphragm paralysis is a more common acquired condition that can result from a number of abnormalities that affect the neuromuscular axis between the cervical spinal cord and the diaphragm (*Table 1*)

Pathology—pathophysiology

Diaphragmatic eventration can be unilateral or bilateral, affecting the whole or only a portion of the hemidiaphragm. The eventrated portion of the diaphragm has an attenuated appearance with microscopically diffuse fibroelastic changes and paucity of muscle fibers. On the contrary a paralysed diaphragm has a normal (although atrophic), amount of muscle fibers. The main symptom for both categories of patients is dyspnoea. In patients with diaphragmatic eventration or paralysis the caudal movement of the diaphragm is less effective (eventration) or absent (paralysis): as a result ventilation is impaired. Among the factors that contribute to the patient's dyspnoea there is a mismatch in the ventilation/perfusion and loss of pulmonary and chest wall compliance due to impaired perfusion to the basal portion of the lung ipsilateral to the affected hemidiaphragm. This may possibly lead to regional vasoconstriction induced by alveolar hypoxia. Orthopnea develops in some patients with diaphragmatic paralysis as their hemidiaphragm (unlike that of normal persons) is unable to oppose cranial displacement of visceral organs leading to further reduction of lung volumes (1).

Diagnosis and preoperative evaluation

In most cases, patients with eventration or paralysis are asymptomatic and diagnosis is made as an incidental finding on a chest radiograph or as a diagnosis of exclusion in patient with dyspnoea. It is important to determine the start of the symptoms: generally patients with paralysis can recall the moment of the onset of symptoms or when the dyspnoea started or worsened while patients with eventration may not be able to determine a specific starting point.

Pulmonary function test (PFT)

PFT are considered to be an unreliable tool to assess diaphragm function and may not correlate with dyspnea in this setting. However PFTs are essential as they provide objective evaluation. The primary utility of PFT is to monitor changes over time (for example post surgery) (2). Diaphragmatic dysfunction reduced chest-wall compliance and a restrictive patterns is almost always seen. The restriction worsens when supine evidenced by a drop in vital capacity of 30% and 50%. The test is sensitive and has a high negative predictive value: if there is no reduction in FVC when supine, there is probably no significant

Table 1 Causes of diaphragmatic paralysis

Level	Causes
Central nervous system lesions	Cord transection above C3-4-5, including trauma and transverse myelitis
	“Hangman’s Fracture”: spinal fracture of both pedicles of the axis vertebra (C2)
	Multiple sclerosis
Motor neuron lesions	Amyotrophic lateral sclerosis
	Poliomyelitis
	Spinal muscular atrophy
Nerve root lesions	Cervical spondylosis
	Trauma—road traffic accident
Peripheral nerve lesions (phrenic)	Traumatic
	Insertion of central venous line
	Pericardial iced cold saline in cardiac surgery
	Internal mammary artery harvesting
	Thymic or thyroid surgery
	Diathermy injury or energy devices
	Deliberate phrenic nerve crush to reduce pleural space
	Systematic nodal dissection.
	Infection—viral neuritis
	Benign lymph node invasion (sarcoidosis)
	Malignant lymph node invasion
	Malignant tumors: lung, thymic, thyroid carcinoma
	Pleural plaques
Polyneuropathy	Neuralgic amyotrophy
	Guillain Barre’ like syndromes
	Chronic inflammatory polyneuropathy
	Charcot Marie tooth disease
	Acute porphyria
Other	Causes
Collagen disease or vasculitis	Systemic lupus erythematosus
	Granulomatosis with polyangitis
Radiotherapy	–
Chemotherapy	–
Diabetic Neuropathy	–
Idiopathic	–
Myopathic Lesions	Systemic lupus erythematosus
	Dermatomyositis
	Endocrine
	Intensive care myopathy
	Amyloidosis
	Idiopathic

diaphragmatic paralysis.

Imaging studies

Preoperative evaluation should include a postero-anterior and lateral chest radiograph. In normal condition the right hemidiaphragm is 1 to 2 cm higher than the left. In patients with diaphragmatic eventration or paralysis we expect to see an elevated diaphragm keeping in mind that a variety of pulmonary (i.e., atelectasis and fibrosis) and subdiaphragmatic processes (hepatomegaly, splenomegaly or gastric dilatation) can also cause diaphragmatic elevation.

A computerized tomography of the neck chest and upper abdomen is also a useful tool to distinguish hemidiaphragm elevation secondary to paralysis or eventration with any other cause of diaphragmatic palsy (intrathoracic tumors) or subphrenic process or traumatic hernia or phrenic nerve compression by cervical spinal disease.

Surgical treatment

Indications and contraindications

The only goal of diaphragmatic plication is to manage dyspnea. Therefore surgery is warranted exclusively for symptomatic patients. Indications for plication are based on the presence and severity of respiratory symptoms and their impact on quality of life in symptomatic patients where dyspnea cannot be attributed to another disease with a diaphragmatic elevation that is not caused by another pathologic process other than eventration of paralysis (3). Plication can allow for the resolution of symptoms by achieving the following specific mechanical goals.

(I) Increased total lung capacity by a more caudal displacement of the diaphragm;

(II) Decreased redundancy of diaphragmatic surface area with reduction of the paradoxical motion;

(III) Decreased diaphragmatic compliance allowing intercostal and other accessory respiratory muscles to more effectively create negative and positive intrapleural pressures;

(IV) Increased resistance to cephalad opposition of the abdominal viscera when the patient is supine.

Relative contraindications to diaphragmatic plication include body mass index (BMI) greater than 35 due to technical difficulty and for the possibility that with aggressive weight loss/bariatric surgery the overall improvement of chest wall compliance may be sufficient to improve symptoms without surgical procedure. Patient with progressive neuromuscular disorders (amyotrophic lateral sclerosis or muscular dystrophy) are usually not candidates as is not only the diaphragm to be dysfunctional but are also the other accessory muscles of respiration. Other relative contraindications include bilateral hemidiaphragmatic elevation and a calcified, non-pliable diaphragm (4).

Surgery

There are two main techniques to manage diaphragmatic elevation due to eventration or paralysis in open surgery through a thoracotomy access: central imbrication technique and radial plication technique.

Central Imbrication Technique

Under general anaesthesia with double lumen tube, an anterolateral thoracotomy is performed: the weakened diaphragmatic area is identified and lifted to determine the placement and the orientation of the suture lines. Linear rows of pledgeted nonabsorbable horizontal mattressed sutures (in our centre we use 2.0 Ethibond with Teflon pledgets) are placed through the weak part of the diaphragm (*Figure 1A*). It's important to lift the diaphragm to avoid injury to the abdominal organs with the sutures. Sutures are then tightened to flatten the diaphragmatic surface (*Figure 1B*). Sutures placed within the central tendon will not be adequate to stabilize the diaphragm long term: several other sutures are required to be placed from the edge of the diaphragmatic tendon in an antero-posterior fashion to produce substantial caudal displacement of the tendon towards the abdominal cavity allowing expansion of the ipsilateral lower lobe as well as balancing the mediastinum

Radial plication technique

Firstly described by Dr. David State in 1949, this technique implies a repair performed with interrupted horizontal mattress pledgeted sutures imbricating the muscular portion of the diaphragm in a radial manner towards the chest wall via a posterolateral thoracotomy as an unbroken band from the xiphoid process to the vertebral body avoiding the mediastinal pleura (*Figure 2*). The efficacy of this approach lies upon vigorous displacement of the edge of the muscle-tendon interface towards the lateral chest wall (5). The sutures can anchor the endothoracic fascia inside the ribs or also pass around the ribs. If a first series of stitches has been placed without achieving the desired tautness of the flaccid diaphragm, a

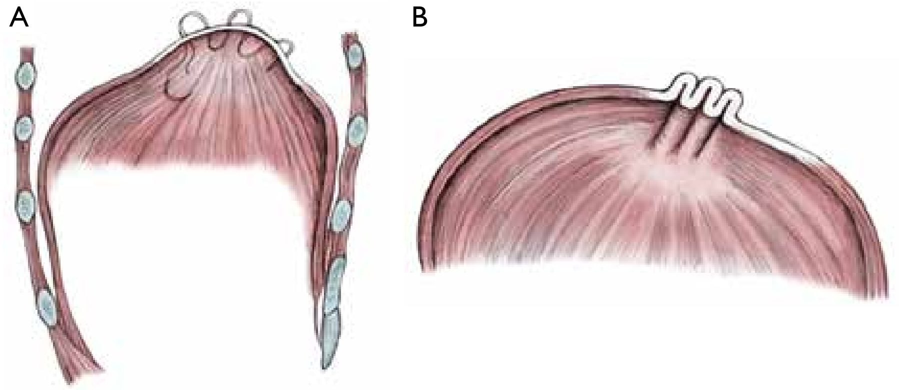


Figure 1 Central imbrication technique. (A) Several linear rows of pledgeted nonabsorbable horizontal mattressed sutures are placed through the weak spot in the diaphragm; (B) central imbrication technique: the suture is tightened and the weakened tissues are gathered into pleats, creating a tense diaphragmatic surface.

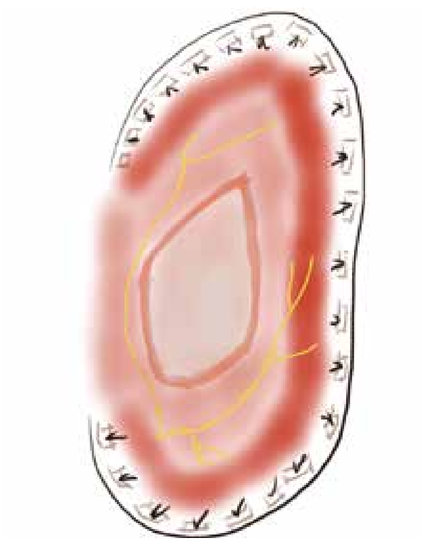


Figure 2 Radial plication technique. Several interrupted horizontal mattress pledgeted sutures imbricating the muscular portion of the diaphragm in a radial manner towards the chest wall.

second row of stitches can be placed for further tightening of the muscle.

Postoperative care

Patients are usually extubated directly in theatre unless they already required mechanical ventilation as per preoperative period. A single 28F straight drain is left on suction at a pressure of −2 Kpa. A portable chest X-ray is obtained after surgery to assess the drain position, the lung expansion and the new baseline of the plicated hemidiaphragm. Chest drain is removed usually on day 1 postoperatively unless an air leak is present. Attention should be paid to any sign of peritonitis that could represent injury to the stomach or bowels.

Once managed these and other early stage complications, patients are usually ready to be discharged in 3 to 4 days.

Complications

Many different complications have been described in different case series. In general the spectrum of surgical complications are similar to that seen in pulmonary resections (atrial fibrillation, pleural effusion, pulmonary oedema, deep venous thrombosis, pulmonary embolism etc.) but with decreased risk of air leak or broncho-pleural fistula as the lung is not intentionally involved in the plication. Nevertheless there is a higher overall risk of abdominal organs injury (spleen, stomach, liver, colon and small intestine) which can occur while taking full thickness bites without proper retraction of the local tissue. Recurrent diaphragmatic elevation can be acutely caused by excessive coughing in the early postoperative period.

Conclusions

Diaphragmatic plication should be only performed on symptomatic patients with evidence of elevated diaphragm not caused by any other pathologic process other besides paralysis and eventration. Before surgery, patients must be evaluated for any other primary cause of dyspnea. PFT and chest radiograph are essential tools to evaluate the entity of the diaphragmatic elevation. CT scan is useful to rule out any other cause of phrenic nerve involvement. Different techniques have been described to manage paralysis and eventration via open or minimally invasive approach. The choice of plication approach is up to the surgeon's expertise, training and preference. Improvement in dyspnoea is the most important measure of clinical success.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

doi: 10.21037/shc.2017.08.01

Cite this article as: Patrini D, Panagiotopoulos N, Bedetti B, Lawrence D, Scarci M. Diaphragmatic plication for eventration or paralysis. Shanghai Chest 2017;1:25.

References

1. Deslauriers J. Eventration of the diaphragm. Chest Surg Clin N Am 1998;8:315-30.
2. Ciccolella DE, Daly BD, Celli BR. Improved diaphragmatic function after surgical plication for unilateral diaphragmatic paralysis. Am Rev Respir Dis 1992;146:797-9.
3. Graham DR, Kaplan D, Evans CC, et al. Diaphragmatic plication for unilateral diaphragmatic paralysis: a 10-year experience. Ann Thorac Surg 1990;49:248-51; discussion 252.
4. Groth SS, Andrade RS. Diaphragm plication for eventration or paralysis: a review of the literature. Ann Thorac Surg 2010;89:S2146-50.
5. Mouroux J, Padovani B, Poirier NC, et al. Technique for the repair of diaphragmatic eventration. Ann Thorac Surg 1996;62:905-7.

Cardiopulmonary bypass for extended resections

Marta G. Fuentes-Gago[1], Elena Arnaiz-Garcia[2], José M. Gonzalez-Santos[2], Gonzalo Varela[1]

[1]Service of Thoracic Surgery, [2]Service of Cardiovascular Surgery, Salamanca University Hospital, Salamanca, Spain

Correspondence to: Gonzalo Varela. Service of Thoracic Surgery, Salamanca University Hospital, Salamanca, Spain. Email:gvs1@outlook.com.

Received: 10 April 2017; Accepted: 25 April 2017; Published: 30 May 2017.
doi: 10.21037/shc.2017.05.12
View this article at: http://dx.doi.org/10.21037/shc.2017.05.12

Introduction

Due to their size or location, some thoracic malignancies can involve or displace the great vessels or cardiac chambers. In these circumstances, the use of cardiopulmonary bypass (CPB) may be the only way allowing complete tumor resection, or facilitate the dissection minimising the risk of sudden, non-controllable massive bleeding during surgery. This strategy can be necessary in two clearly differentiated scenarios: the need to resect any infiltrated cardiac structure, usually left atrial wall, or prevention of massive bleeding because of the proximity of tumor to cardiac chambers or great vessels. In this chapter, we are presenting two personal cases and discuss the techniques we recommend in comparable situations. In addition, the procedure must be carefully planned by a multidisciplinary team to choose the more appropriate approach and vascular access which better conform patient characteristics and consider all possible complications. It is also necessary to consider the risks of the procedure and the advantages and inconveniences of non-surgical therapy or palliative alternatives.

Operative techniques

Preventing massive bleeding

Indications and contraindications

Tumours in close contact with vascular mediastinal structures can sometimes be subsidiary of surgery, due to lack of response to chemotherapy, sarcoma pathology type… etc. Some of these situations can make us predict a high risk of bleeding. This can be the case of a tumour which is in close contact or invading vascular mediastinal structures, such as superior vena cava o brachiocephalic trunk, making necessary remove and reconstruct them to achieve complete resection of the malignancy (*Figure 1*). We could also consider CPB in those cases of highly vascularized tumours in which endovascular embolization is not suitable. In this way CPB help us maintain hemodynamic stability -for instance, with low-flow CPB-, allowing also to cold and rewarm the patient to minimize tissue damage due to hypoperfusion. In those patients with tumours extended to aortic arch or thoracic aorta, CBP allows performing a total circulatory arrest under deep hypothermia. This technique allows us working in a bloodless field without need to control vessels difficult or impossible to access.

However, CPB should be only used in carefully selected patients. It is not a costless technique and can be associated to a high range of complications, most of them due to inflammatory response. In this way, respiratory complications can be up to 49%. Also, cardiac distension and arrhythmia can appear during and after CPB. We should not forget the postoperative risk for haemorrhage, from systemic heparinization, or even central nervous system injury due to inadequate brain protection, mainly in those patients under circulatory arrest.

Patient preparation

Patients whose arterial blood flow is provided and oxygenated by a heart-lung machine are in an abnormal state that affects most of their physiologic processes. This makes necessary to control patient variables and to achieve a great team effort, which includes not only thoracic and cardiac surgeon, but also anaesthesiologists and perfusionists.

Patient must be monitored before surgery begins. It is recommended to place a large-bore—triple lumen-intravenous cannula as well as brachial or radial arterial cannula, and a pulmonary artery flotation catheter. In addition, cerebral oximetry can be considered in some cases. Double-lumen endotracheal tube must also be located.

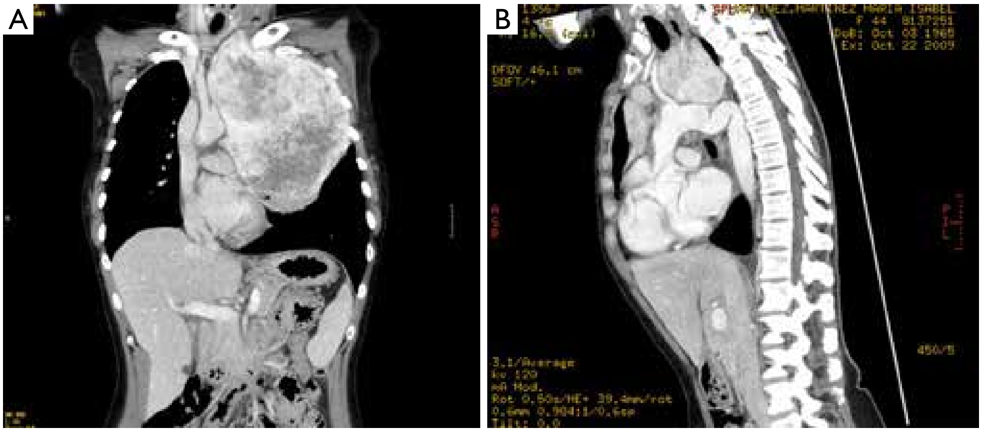


Figure 1 A patient with a left side massive fibrous pleural tumour was referred for surgery. After complete check-up, groin cannulation was indicated to facilitate dissection manoeuvres. Images of the chest contrast enhanced MR are shown below. (A) Coronal view; (B) Sagittal view.

As our patient will be anticoagulated with unfractionated heparin, heparin activity need to be closely monitored. This is commonly done through the activated clotting time (ACT).

Patient position and incision

Surgical approach must be adequate to access any structure needing to be resected and allow the vascular access necessary to establish the CPB. Depending on the location and tumour characteristics, incision could be a thoracotomy, median or partial sternotomy, hemiclamshell or clamshell incision. Mid sternotomy provides an excellent access to all cardiac chambers and great vessels, allowing an easy establishment of CPB. It also allows access to both lungs, which is especially easy as they are deflated. But we should remember that hemiclamshell incision (*Figure 2*) give us excellent access to brachiocephalic vessels, large invasive mediastinal tumours, large central pulmonary lesions and intrapericardial pulmonary vessels.

When arterial and venous access—needed to establish CPB—are not possible through the same approach for tumour resection, a peripheral vascular access is necessary. The best option is femoral vessel cannulation (*Figure 3*). However, if there is significant iliac-femoral disease, axillary artery cannulation is the one recommended (*Figure 4*).

The patient is placed in supine position for sternotomy as well as for hemiclamshell. For better exposure, we can place a roll or small pillow across both scapulae. Both groins must be prepared and included in surgical field so that femoral vessels can be accessed in case femoral cannulation has been advanced. Pump tubing is passed from the perfusionist to the operating table, completing the CPB circuit.

Detailed surgical technique

The basic premise of our surgery involves a complete en-bloc removal of the tumour. The most critical initial decision is to determine surgical approach. To control most mediastinal structures as well as pulmonary ones, we recommend hemiclamshell incision in these patients.

Patient is placed supine, and an anterior thoracotomy incision in the inframammary crease is first performed up to the sternal midline. The skin incision is then extended vertically upwards to the sternal notch and then for a short distance along the ipsilateral sternocleidomastoid muscle in the neck. The fourth intercostal space is the entrance in most cases, and the internal mammary vessels are divided and oversewn prior to sternal opening. Then sternotomy is performed from above downwards in the midline of the sternum, and curved out to the opened interspace in a J-shaped cut. Bone wax can be spread over the bone marrow, although, in excess, impairs wound healing and increases the risk of wound infection.

While placing the retractor, care should be taken to avoid undue traction on the brachial plexus. When this incision allows to access the ascending aorta and the right atrium, CPB is established through cannulation of these structures. If this is not the case, CPB need to be established through a peripheral cannulation. We must point out that if we expect a difficult access or a high risk of bleeding while thoraco-sternotomy is performed, femoral vessels cannulation should be considered before thoracic incision. CPB is usually not stablished up front but after exploring the chest conveniently.

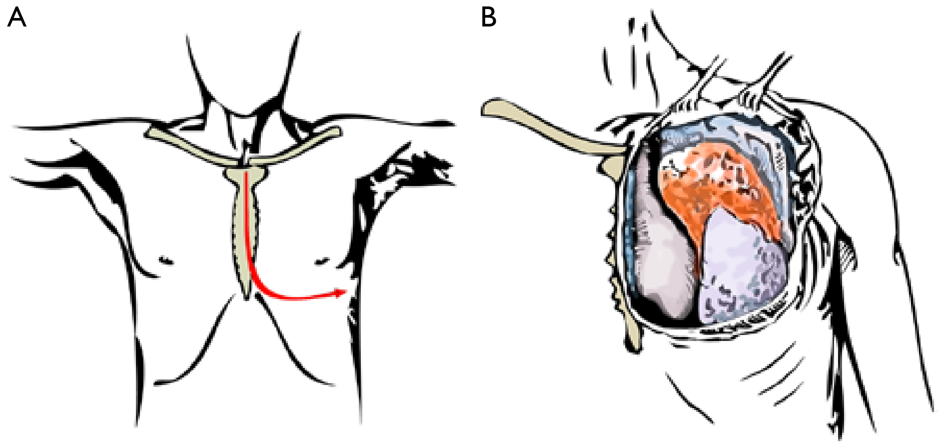


Figure 2 (A) Scheme of a left hemiclamshell approach; (B) Clamshell incision gives an excellent approach for tumour resection.

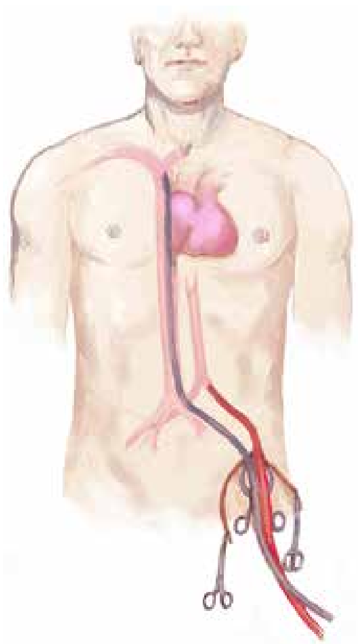


Figure 3 Femoral cannulation.

Femoral vessels cannulation

Before carrying out cannulation patient must be anticoagulated. A single bolus of unfractionated heparin is commonly administered on a weight-based protocol (300–400 units per kilogram), with the goal of achieving an ACT greater than 480 seconds prior to initiation of CPB. Additional heparin bolus is administered periodically during the intervention to maintain desired ACT levels.

The femoral vessels are exposed through an incision in the right triangle of Scarpa, inferior to inguinal ligament. Femoral artery pulse can be helpful to locate vessels placement (1). A curved, oblique or craneo-caudal skin incisions are possibilities to access to femoral vessels. However, a craneo-caudal incision is recommended to improve exposition. As an alternative, J-shaped incision can be done slightly lateral to vessels location to avoid the lympho-ganglionic pad. In any case, it is necessary to perform a meticulous opening and closing technique to avoid a possible lymphorrage.

Common femoral artery and vein are dissected and a vessel-loops are placed around each of them at proximal and distal levels (*Figure 5*). Whether common femoral artery is short, it may be necessary to control the superficial and femoral profundal arteries with vessel-loops, in order to gain enough access. For femoral artery cannulation, small atraumatic vascular clamps are applied both above and below the intended arteriotomy site. Superficial and profunda artery may either be clamped or snared. A small transverse arteriotomy is made where the arterial wall appears to be relatively normal. A 14–18 F tapered cannula is gently introduced into the arterial lumen and secured in place with a stich joining it to the proximal skin or tying it to the loop already placed around the artery to prevent the cannula to slip out because of perfusion pressure or involuntary movements. The surgeon should always look for a column of pulsating blood in the femoral cannula; in the absence of obvious pulsation, it is very likely that the cannula tip is not in the lumen of the vessel.

For femoral venous cannulation, a longitudinal venotomy is performed on anterior aspect of common femoral vein.

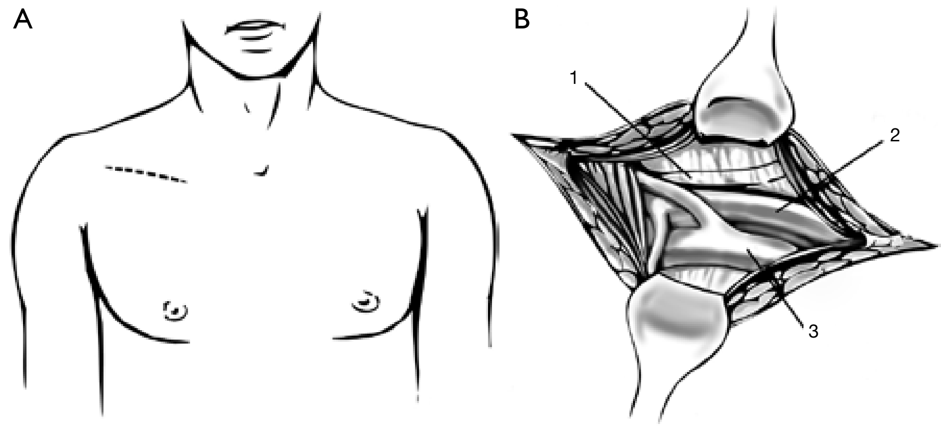


Figure 4 Axillary cannulation. (A) Location of the skin incision; (B) Axillary vessels. (1: Plexus; 2: Artery; 3: Vein).

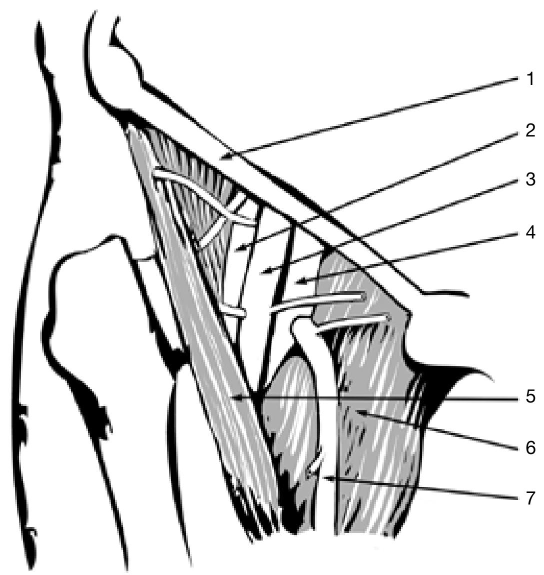


Figure 5 Location of the vessels at the groin. (1: Ligament, 2: Femoral nerve; 3: Femoral artery; 4: Femoral vein; 5: Sartorius muscle; 6: Adductor Muscle; 7: Saphenous vein).

A long 22 o 28 F femoro-atrial cannula with multiple side holes is directly inserted into the vein and advanced, preferably under echocardiographic control, until the distal tip is located into the right atrium. Alternatively, a venous cannula pre-mounted on a tapered dilator core is advanced over a guide wire, previously inserted through a needle puncture in the middle of a 5/0 purse-string polipropilene suture.

In this moment, we can start CPB, and continue with our procedure. We would recommend isolation of the mass from possible adhesions to parietal pleura, resecting it whenever possible, and going on with mediastinal dissection.

Aortic or supra-aortic trunks invasion

In this point, we should inspect the way aorta and the supra-aortic trunk are affected.

Depending on the way aorta is affected, tumour resection can be managed in different forms. Whenever the aortic wall is not infiltrated by malignancy, it is enough to perform a subadventitial dissection. However, when invasion is deeper, partial resection of the aortic wall is mandatory. Although en-bloc excision is recommendable, when aortic wall is invaded or when tumour is of great size, it is safer to leave a tumour piece in contact with the vessel. Its resection will be completed after removing most of the mass. In this situation, and depending on the extension of aortic wall invasion, several options are available. When aortic infiltration area is not extensive and affects a small segment of the aortic circumference, the area to be resected can be excluded through a lateral exclusion with a Satinsky clamp. Aortic wall defect must be repaired with a patch of pericardium or of some synthetic material whose form and size must be properly tailored. Whether this approach is not possible, it is necessary to control the aorta proximally and distally to the lesion. After occluding the aorta with two vascular clamps, the involved segment is completely resected with safety margins, and replaced by a tubular vascular prosthesis of adequate size. For this purpose, a polyester double velour, collagen impregnated, low-porosity prosthesis is recommended. The sutures can then be reinforced with a sealant to ensure hemostasis. Whenever control and occlusion of the aorta are not possible, or are extremely dangerous, the only option is to establish a deep hypothermic circulatory arrest—at an esophageal temperature of 16–18 ℃—to perform an open tumour resection and aortic reconstruction in a bloodless field.

When brachiocephalic trunk is the one affected and aorta is not involved, patency of left carotid artery and sufficiency of the Circle of Willis must be evaluated before carrying on its resection. This can be done by checking the effect of temporary occlusion of the innominate artery or right carotid artery in the oxygen saturation of the corresponding cerebral hemisphere, measured by transcranial cerebral oximetry. Once the Circle of Willis competence has been checked, occlusion of the innominate artery proximally and distally to the zone we are going to replace can be performed, even if tubular resection is needed. If we are just going to replace any other supra-aortic trunk, CBP is not compulsory to carry on.

Usually patches and prosthesis used for these purposes are made of woven polyester or PTFE (polytetrafluoroethylene), and we should choose proper size, depending on the artery to be replaced has. Antiagregation is recommended after a patch is placed.

After the procedure, when our mass has been taken out and all these bleeding-risk maneuvering completed, we must stop CBP. Then, venous cannula is withdrawn from the femoral vein and the purse-string suture is tied or venotomy is sutured. Once the arterial cannula has been withdrawn, the arteriotomy is closed with several separated 5-0 polypropylene stitches.

Following discontinuation of CPB and decannulation, heparin is reversed with protamine sulfate in a dose of 1 mg of protamine for every 100 units of heparin. We must remember in this point that protamine administration may be responsible for systemic hypotension or anaphylactic and anaphylactoid reactions, as well as certain grade of pulmonary hypertension.

After positioning drain, meticulous closure involves perfect sternal re-approximation with Nº 6 stainless steel wires and the use of pericostal sutures for the intercostal space incision, all of which are closed in multiple layers, as well as suturing the thoracotomy as usually done.

Extending lung resection to the atrium

Indications and contraindications

Whether left atrium is involved (*Figure 6*), partial clamping for resection may cause hemodynamic instability and tumour embolization, depending on tumour size. All this can be avoided with the use of CPB. CPB allows a direct inspection of cardiac chambers, posibilitating to extend the limits of resection to a safer margin.

Patient preparation

Patient preparation is like the previously described. Groins must be also prepared in case any problem appears at the time of central cannulation.

Detailed surgical technique

When tumour is minimally invading the atrium, it could be approached from a thoracotomy, without CPB. In this situation, the interatrial groove must be widely dissected to allow a large Satinsky clamp be placed as centrally on left atrium as possible. In this way, tumor may be completely resected with sufficient safety margins. This maneuver allows a primary closure of the atrial defect with a double 4/0 polypropylene running suture, applied below the clamp

However, when we face a pedunculated lesion or tumor invading the whole atrial wall, CPB is required, to get a complete tumour resection and minimize the risk of embolism, arrhythmias and bleeding. Sternotomy or hemiclamshell are the preferable approaches.

Surgical approach is developed as previously explained and cannulation centrally performed whenever possible. An arterial cannula is placed in distal ascending aorta and single two-staged venous cannula is inserted in right atrium. Two separate venous cannulas—to the superior and inferior vena cava—are necessary when both atrial cavities are to be entered (*Figure 7*).

When left atrium needs to be opened, that should be done under cardiac arrest. Cardiac arrest is induced by clamping the aorta proximally to arterial cannula and infusing a high-potassium solution (cardioplegia) in the ascending aorta and/or coronary sinus, through previously placed catheters. For that purpose, an aortic root needle is inserted through a 4/0 polipropilene purse-string stitch in mid ascending aorta and a balloon-tiped catheter is inserted in the coronary sinus through the right atrial wall. Cardioplegia is infused for 3 minutes, at a flow of 150 mL/min.m^2 for a total dose of 400–750 mL for an average adult (2).

After that, left atrium is opened and tumour is resected, leaving enough free margins. Left atrium closure should be performed with a double-armed 4/0 polipropilene suture with large half-circle needles. When the atrial wall defect is large, it must be reconstructed with a patch of autologous

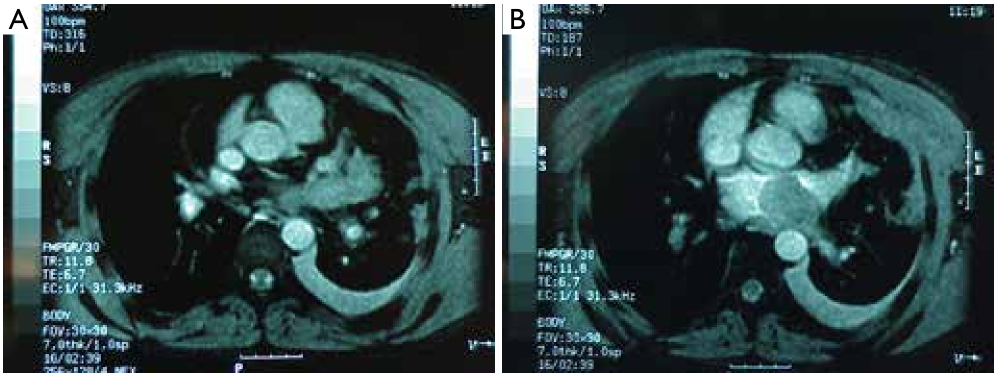


Figure 6 Squamous lung carcinoma invading the left atrium in a young patient. No distant metastases or clinical evidence of nodal involvement was found. Surgery was indicated under CPB. (A) Hilar mass surrounding the left main bronchus; (B) Atrial invasion.

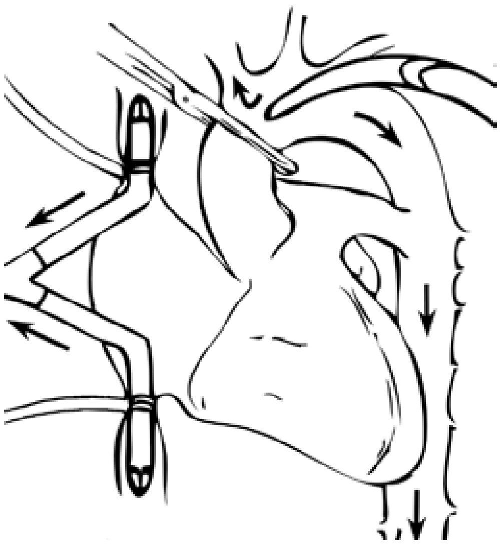


Figure 7 Standard central cannulation for CPB.

or synthetic pericardium. sutured with the same material.

As soon as we finish atrial reconstruction, we must de-air cardiac chambers to prevent air embolism. We should de-air it through the atrium suture before tying it up. To accomplish it, we recommend the following steps:

- ❖ The heart is filled with fluid (blood or electrolyte solution) before closing sutures, to minimize air entrapment.
- ❖ Heart must be reperfused and beating.
- ❖ Residual air is aspirated from the heart before allowing it to eject.
- ❖ Lungs are intermittently ventilated to express air from the pulmonary veins.
- ❖ A slotted vent needle is introduced into the aortic opening used to apply cardioplegia, and high suction is applied to it.

An effective way to minimize air embolism is to flood operative field with carbon dioxide during all the procedure. This is achieved by introducing a constant flow of carbon dioxide through a tube anchored to the pericardium above right pulmonary veins.

Heart sometimes starts to beat spontaneously soon after clamp is removed. Nevertheless, in a large majority of cases, a defibrillator can be needed to restore heart rhythm. Asystolia can also be found, and solved using right ventricular epicardial electrodes connected to an external pacemaker.

Apart from atrium excision, to ensure complete tumour resection, sometimes intrapericardial pneumonectomy may be required.

Comments

- ❖ It is highly important to identify these patients and schedule step by step this surgery in a multidisciplinary team including cardiothoracic surgeons, anaesthesiologists, and perfusionists.
- ❖ En-bloc resection is highly recommended; however, sometimes it is safer to divide the tumour, to dissect mediastinal structures properly.
- ❖ When aortic cannulation is needed, we must place purse-string sutures, somewhere with no atherosclerotic or calcified plaques.
- ❖ It is also important to choose an appropriate cannula size: if it is too small, it may create a significant gradient in the perfusion pressure while CPB; whereas a large aortic cannula can tear aortic wall or even dissect it.

- ❖ Securing femoral cannulas during by-pass is paramount to avoid cannula slippage with perfusion pressure and displacements.
- ❖ Despite high range of complications associated to CPB and combined procedures, it is a safe strategy in selected patients (3).

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

doi: 10.21037/shc.2017.05.12
Cite this article as: Fuentes-Gago MG, Arnaiz-Garcia E, Gonzalez-Santos JM, Varela G. Cardiopulmonary bypass for extended resections. Shanghai Chest 2017;1:9.

References

1. von Segesser LK. Peripheral cannulation for cardiopulmonary bypass. Multimed Man Cardiothorac Surg 2006;2006(1009):mmcts.2005.001610.
2. Konsary S. Cardiac Surgery. Safeguards and pitfalls in Operative Technique. 4th edition. Philadelphia: Wolters Kluwer Lippincott Williams & Wilkins, 2007.
3. Muralidaran A, Detterbeck FC, Boffa DJ, et al. Long-term survival after lung resection for non-small cell lung cancer with circulatory bypass: a systematic review. J Thorac Cardiovasc Surg 2011;142:1137-42.

Superior vena cava resection and reconstruction

Antonio D'Andrilli, Camilla Poggi, Erino A. Rendina, Federico Venuta

Department of Thoracic Surgery, University of Rome Sapienza, Rome, Italy

Correspondence to: Federico Venuta. Department of Thoracic Surgery, University of Rome Sapienza, Policlinico Umberto I, Cattedra di Chirurgia Toracica, V.le Del Policlinico 155, 00161 Rome, Italy. Email: federico.venuta@uniroma1.it.

Submitted Apr 16, 2017. Accepted for publication Apr 29, 2017.
doi: 10.21037/978-988-77840-5-0.1

Introduction

Superior vena cava (SVC) may be infiltrated by mediastinal tumors or by right upper lobe lung cancer. Among the mediastinal neoplasms, Thymoma and Thimic Carcinoma are the histologic types more frequently responsible of direct SVC involvement (1). Vascular invasion by lung cancer may be caused by direct extension of primary tumor or by mediastinal lymph node involvement (2-4). The majority of these lesions are unresectable, and when feasible the resection usually includes Pneumonectomy (PN) or sleeve PN.

Infiltration of SVC is able to influence the oncologic prognosis of the disease and it also increases the technical complexity of the operation, with an extended resection and a demanding reconstructive procedure in order to achieve complete resection. In fact, completeness of resection is one of the most important factors affecting outcome. Increasing experience in the last years has contributed to improve the results of such complex operations. However, the diffusion of these operations still remains limited, due to the concern for higher perioperative complication and mortality rates.

Technical aspects and intraoperative management

Options for reconstruction include direct suture if a minimal portion of the circumference is involved, patch reconstruction (usually with biological material), and prosthetic conduit (biological or synthetic material) reconstruction. Extended resections and reconstructions of the SVC represent a technical challenge for the potentially detrimental effect of clamping a patent vessel (5). Partial caval clamping or clamping of an already obstructed SVC is usually well tolerated. During complete clamping of a patent SVC there is a marked hemodynamic imbalance with modifications of the mean venous pressure and mean arterial pressure and consequent reduction of the brain arterial-venous gradient; it may also cause cerebral edema and damage, intracranial bleeding, and a potentially lethal reduction of the cardiac output. This hemodynamic derangement could be minimized with several intraoperative technical and pharmacologic solutions. The use of intra- or extraluminal shunts may reduce the detrimental effects of clamping, although thrombosis of the shunt has been observed; furthermore, these devices occupy space in the operative field.

Clamping time should be reduced as much as possible, especially if the SVC is not completely obstructed. A complete vessel clamping is usually tolerated up to 45 to 60 minutes when an appropriate pharmacological support is administrated (5). Intraoperative pharmacologic neuroprotection includes administration of steroids before clamping, and optimization of circulatory parameters during clamping by fluid administration and vasoconstrictive agents in order to increase the arterial pressure. Anticoagulation with intravenous sodium heparin (0.5 mg/kg) is administered before clamping and is continued after surgery, taking into account the characteristics of the graft material used for reconstruction.

Reconstructive strategy may vary on the basis of tumor location and extension. Vascular reconstruction can be performed by a SVC trunk replacement if a disease-free confluence of both the innominate veins is present. After clamping and vascular resection, the anastomosis between the superior caval stump and the prosthetic conduit is performed first (5-0 or 6-0 polypropylene suture). To avoid kinking of the prosthesis, the length of the conduit is adapted so that the distal anastomosis can be put under tension. In case of neoplastic infiltration of the SVC at the confluence with the innominate veins, the revascularization is usually performed between the left innominate vein and the inferior SVC stump (or the right atrium) with closure of the right innominate vein, or alternatively between the right innominate vein and the inferior SVC stump (or the right atrium) with closure of the left innominate vein, according to local invasion. These types of reconstruction are almost always performed using synthetic materials (usually ringed PTFE grafts) or heterologous (usually bovine) pericardium. Minimal dissection, especially at the level of the left innominate vein is mandatory to avoid rotation above the anastomosis. The risk of kinking is lower for revascularization of the right innominate vein because the residual venous stump is shorter and the direction of the graft is almost vertical.

Revascularization of both the innominate veins implanted independently on the right atrium are generally not performed, because blood flow through the graft is too low and exposes at high risk of thrombosis (6). Resection of the SVC and both the innominate veins followed by reconstruction with a Y-shaped prosthesis (Dacron or PTFE) have been successfully realized and reported in the literature only in few patients (7).

Reconstructive materials

Different materials have been used for prosthetic reconstruction of the SVC, including biological (autologous or heterologous) or synthetic options. PTFE is the preferred material for syntetic graft reconstruction. This synthetic material shows the highest long-term patency rate, and after implantation it is quikly reepithelialized with autogenous epithelial cells. PTFE grafts have a low infection risk, less platelet deposition, and less thrombogenicity compared with Dacron grafts (8). The risk for thrombosis of the PTFE prosthesis has been reported between 14% and 24% in some of the largest published series (9-12). The synthetic grafts are usually reinforced with external rings.

Oizumi and coll. have reported the surgical results of 12 patients undergoing replacement of the SVC with PTFE graft (6). The SVC pathway was reconstructed separately for the innominate veins in 9 patients; two patients received a single conduit replacement, while one patient had a Y-shaped bypass. Overall long term patency rate was 86.4%. The 3 graft occlusions occurred in patients receiving bilateral innominate veins reconstruction.

Biological materials have gained large acceptance in the reconstruction of thoracic vessels at low pressure due to a higher biocompatibility, lower infection risk and thrombosis, and reduced costs if compared with synthetic materials. Among the biological materials, autologous pericardium has been extensively used for either patch or conduit vascular reconstruction in thoracic surgery. Although positive results have been obtained with both these options, the large amount of tissue required for the replacement of a long vascular tube makes this material unsuitable in most of the patients requiring complete caval reconstruction. Conversely, autologous pericardium can be considered an ideal option for patch reconstruction of the SVC. Its harvesting does not require a separate procedure and offers a sufficient amount of tissue. However, despite the high number of favorable characteristics (biocompatibility, adequate thickness and resistance, no-cost), pericardium show some limits because it shrinks and curls, making the adaptation of the patch to the defect more difficult. To minimize this problem, it has been described an original method of fixation of the autologous pericardium with glutaraldehyde to increase the stiffness of the patch (13). Among the heterologous biological materials, bovine pericardium, at present, is certainly the most frequently used. It shows some advantages such as the presence of even and stiff edges and the limited tendency to retract, facilitating its adaptation and suturing to the vascular wall. When complete SVC replacement is to be performed, bovine pericardium should be preferred. Porcine pericardium has been more recently available, but it shows lower rigidity compared to the bovine one, and is therefore less suitable for conduit caval reconstruction. Based on still limited literature data, the pericardial conduit shows a lower infection and thrombosis risk (*Table 1*) (6,10-12,14-21), and does not require long-lasting anticoagulation compared with synthetic materials. We have proposed an original technique to contruct a pericardial conduit (22). The bovine pericardial leaflet is trimmed to a rectangular shape of the resected vessel length, wrapped around a syringe (5 mL or 10 mL) and sutured longitudinally by a linear stapler. The mechanical suture recently introduced in this technique (instead of the previously used manual suture) enables a quicker, easier, and more precise procedure, allowing a more regular shape of the graft. In a series of 16 consecutive patients with lung or mediastinal malignancies undergoing SVC reconstruction using this technique, a 100% patency rate of the prosthetic conduit at long term has been observed (21,23). Patency and endoluminal blood flow of the biologic conduit have been assesed by magnetic resonance imaging after 1 year from the operation in a recent study. We have calculated mean blood flow and area

Table 1 Major studies reporting superior vena cava (SVC) prosthetic reconstruction after oncologic resection

Author (year)	SVC resection patients	Diagnosis	Prosthetic reconstruction, n [%]	Material	Long-term patency, (%)
Shargall *et al.* (14) (2004)	32	Lung	9 [60]	PTFE	85
Suzuki *et al.* (15) (2004)	15	Lung	11 [27]	PTFE	82
Spaggiari *et al.* (16) (2004)	40	Lung	28 [25]	PTFE	89
Shintani *et al.* (17) (2005)	109	Mediastinal	18[a] [100]	PTFE	62
Spaggiari *et al.* (10) (2007)	18	Lung, mediastinal	25 [35]	PTFE, bovine pericardium	76
Lanuti *et al.* (18) (2009)	70	Lung, mediastinal	12 [63]	PTFE	90
Picquet *et al.* (19) (2009)	19	Lung, mediastinal	23 [95]	PTFE	100[b]
Okereke *et al.* (20) (2010)	24	Lung, mediastinal	38 [100]	PTFE	90[c]
Sekine *et al.* (12) (2010)	38	Lung, mediastinal	20[d] [100]	PTFE	70
Leo *et al.* (11) (2010)	20	Lung, mediastinal	28 [38]	PTFE	85
D'Andrilli *et al.* (21) (2013)	72	Lung, mediastinal	17 [100]	Bovine pericardium	100
Oizumi *et al.* (6) (2016)	12	Lung, mediastinal	12 [100] [22 grafts][e]	PTFE	86.4

[a], Double or Y grsft replacement in 8 patients; [b], Only clinical assessment without graft check; [c], Graft check performed in only 53% of patients; [d], Double graft replacement in 11 patients; [e], Bilateral separate innominate veins reconstruction in 9 patients. NR, not reported; PTFE, polytetrafluoroethylene.

of the biological conduit lumen section and compared these data with those of a control group of patients with normal SVC founding no significant differences (21).

Other biological options such as autologous venous grafts (saphenous, jugular, superficial femoral) have a limited diameter that is sufficient only for the reconstruction of the brachiocephalic vein, and are not suitable for SVC replacement. Saphenous vein graft of adequate diameter has been created by suturing the venous wall in a spiral fashion around a stent or a chest tube of appropriate size, but its use in the clinical practice is anecdotal and historical (24).

Prosthetic materials and patency rates of main series of oncologic SVC reconstruction published in the literature are reported in *Table 1*.

Results of surgical treatment

SVC resection and reconstruction for lung cancer

The largest series of SVC resection and reconstruction include patients with Non-Small Cell Lung Cancer (NSCLC). There are more than 10 studies published in the literature, including a relatively large number of patients undergoing resection and reconstruction of the SVC. Prosthetic reconstructions have been performed in variable proportions, ranging between 0% and 49%. Five-year survival rates have been reported between 21% and 31% with a perioperative mortality rate of 7% to 14% (*Table 2*) (10,14-16,25,26). There are very few long-term survivors in the group of N2 lung cancer patients.

The largest published series included data from four international centers and analysed the results of 109 patients with NSCLC invading the SVC by the primary tumor in 72% of cases and by metastatic lymph nodes in 28% of cases (16). Fifty-five patients underwent pneumonectomy (20 with carinal resection), while the remaining underwent lobar resection. Prosthetic caval replacement was required in 26% of them (27), while a partial resection was done in the remaining cases with running suture in 53% of them, with vascular stapler in 13%, and patch repair in 7%. Major postoperative morbidity was 30% and postoperative mortality 12%. Pathological N2 involvement was observed in 50% of the cases. Five-year survival was 21%. At multivariate analysis, both PN and complete SVC resection with prosthetic replacement were associated with an increased risk of death.

Yildilzeli and colleagues (26) have reported the results of 39 patients with T4 lung cancer undergoing SVC resection and complete prosthetic reconstruction. The actuarial 5 and 10-year survival were 29.4% and 22.1%. However, survival reached 37.5% at 5 years in patients with N0/1 disease.

Table 2 Reconstruction of the Superior Vena Cava for lung cancer

Authors, year	Patients	Conduit (material)	Patch (material)	Mortality (%)	5-year survival (%)
Bernard *et al.* (25), 2001	15	4 (PTFE)	2 (PTFE)	NR	25
Spaggiari *et al.* (16), 2004[a]	109	28	8 (5 peric., 3 PTFE)	12	21
Shargall *et al.* (14), 2004	15	9 (7 PTFE, 1 jugular vein, 1 bov. peric.)	2 (peric.)	14	57 (3-Y)
Suzuki *et al.* (15), 2004	40	11 (PTFE)	8 (aut. peric.)	10	24
Spaggiari *et al.* (10), 2007	52	13 (8 PTFE, 5 bov. peric., 3 n.s.)	4 (aut. peric.)	7.7	31
Yildizeli *et al.* (26), 2008	39	39 PTFE	–	7.7	29.4

[a], multicenter study. Abbreviations: aut. peric., autologous pericardium; bov. peric., bovine pericardium; NR, not reported; n.s., not specified; peric., pericardial; PTFE, polytetrafluoroethylene.

Carinal resection and squamous cell carcinoma have been found to be the most significant negative prognostic factors in patients who have undergone en bloc SVC resection for lung cancer. Patients receiving carinal PN had a 13.1% 5-year survival compared with 43.2% of patients who underwent other lung resections. Survival at 5 years was 51% in patients with non-squamous cell carcinoma and 12.1% in patients with squamous cell carcinoma.

A review by the American College of Chest Physicians analyses the results of the 4 largest studies published between 2000 and 2007, including 189 patients undergoing SVC reconstruction A mean cumulative postoperative mortality of 12% and a mean cumulative 5-year survival of 25% (range: 21%–31%) is reported (28).

A recent Italian study (11) has shown no increased risk for overall postoperative morbidity and mortality in patients undergoing complete prosthetic replacement of SVC when compared with patients receiving direct suture repair of the vessel. However, graft reconstruction was related to a higher incidence of surgical complications in this series (17.8% *vs.* 4.5%).

SVC resection and reconstruction for mediastinal tumors

There are only few large series in the literature reporting the results of extended resections of invasive anterior mediastinal tumors invading the great vessels and other neighboring structures. Moreover, some of them provide cumulative data referring to results obtained with the treatment of different histologic neoplasms and heterogeneous oncologic multimodality protocols.

In 1998, the Marie Lannelongue Hospital group in Paris reported a 17-year experience including 89 patients with primary mediastinal tumors (74% of which in the anterior compartment) resected with at least part of an adjacent structure (27). There were 35 thymomas, 12 thymic carcinomas, 17 germ cell tumors, 16 lymphomas, 3 neurogenic tumors, 3 thyroid carcinomas, 2 radiation induced sarcomas, and 1 mediastinal mesothelioma. Median sternotomy was used in almost all the patients with anterior mediastinal tumor and in some with tumor of the middle mediastinum (79% of all patients). A clamshell approach was chosen in three cases with large chemoresistant germ cell tumors. The pericardium was the most frequently excised structure (73% of patients). Pulmonary resections (including 28 wedge resections, 16 lobectomies and 5 pneumonectomies) were performed in 55% of cases. Forty percent of patients underwent resection of great vessels including SVC in 21 cases and innominate vein in 13. Replacement of SVC was performed in all cases by a PTFE graft. Vascular replacement was not done in patients undergoing innominate vein resection. Radical excision was achieved in 79% of patients. Major complications occurred in 17% of patients, requiring reoperation in four cases (4.5%). Surgical mortality was 6%. All SVC grafts but one were patent at 3 months. There was one late graft occlusion at 15 months. Postoperative adjuvant radiation therapy was used in 85% of patients with thymoma and in 58% of those with thymic carcinoma. Postoperative chemotherapy was administered in 67% of patients with thymic carcinoma. Fourteen out of 17 patients with germ cell carcinoma underwent cisplatin-based preoperative chemotherapy. Ten of these patients underwent postoperative chemotherapy. 5-year survival rate was 63%. It was 69% for patients with thymoma (stage III or IV), 42% for those with thymic carcinoma, 48% for germ cell tumor, and 83% for patientswith lymphoma. Recurrence rate was higher in patients with thymic carcinoma (75%).

More recently, data from a Chinese group has been published, including 15 patients with malignant tumors of the anterior mediastinum involving the SVC or its branches (7). There were nine patients with malignant thymoma and one patient each with thymic carcinoma, teratoma, embryonal carcinoma, Hodgkin's lymphoma, non-Hodgkin's lymphoma, and mixed teratoma with thymoma. All the operations were performed through median sternotomy. In two cases, the left innominate vein was removed without any reconstruction. In seven patients, partial resection of the SVC or innominate vein was performed and repaired by direct suture with lateral SVC clamping. In three other patients, a pericardial patch reconstruction was performed using a total caval clamping. In the three remaining patients, complete resection of the SVC with both the innominate veins was performed with reconstruction by a Dacron graft. In one patient, a Y-shaped prosthesis was used. In the other two cases, a single lumen conduit was inserted between the right innominate vein stump and the right atrium with closure of the left innominate vein stump. Major complication rate was 13%, without perioperative mortality. Preoperative chemotherapy was administered in four patients (26%). At the time of publication, all patients but one were alive with a 35-months median follow-up and a disease-free survival ranging between 10 and 43 months.

In 2003, we reported a series of 45 patients with stage III thymic tumors, 11 of whom with thymic carcinoma (29). Thirty of these patients (66.6%) with a resectable stage III lesion (invasion of the SVC, pericardium, or limited invasion of the mediastinal pleura and lung) underwent primary surgery. The other 15 patients with tumors considered not completely resectable due to the extensive invasion of the surrounding organs underwent induction chemotherapy followed by surgical resection. All the operations were performed through median sternotomy. After the operation, patients received adjuvant chemotherapy and radiotherapy at a dose of 40 Gy in case of complete resection or at a dose of 50 to 60 Gy in case of incomplete resection. A vascular reconstruction was performed in 11 patients by a bovine pericardial conduit interposition. In nine cases, it was made after resection of the SVC and in two after the resection of the left innominate vein. Complete resection was feasible in 82% of patients with thymic carcinoma and in 91% of patients with other histologic diagnosis. Major complications occurred in 6.7% of patients. There was no operative mortality. The 10-year overall actuarial survival was 78%, whereas the cumulative disease-free survival was 53%. Ten-year survival for patients undergoing complete resection was 80%, while it was 60% for patients with incomplete resection. Ten-year survival after induction chemotherapy was 90%, compared with 71% after primary surgery.

In the largest surgical experience of thymoma and thymic carcinoma (179 patients) published by the Massachusetts General Hospital group (30), the recurrence rate in 17 patients with great vessels invasion (30%) was significantly higher than that found in the remaining patients. Recent reports have suggested a survival advantage of induction therapy for stage III thymomas when compared with adjuvant treatment (29,31,32).

When considering only invasive thymic tumors (Masaoka stage III and IV) the completeness of surgical resection is generally reported as one of the most significant factors influencing prognosis (30). Incomplete resections or surgical debulking usually do not modify long-term survival (31-33). Unfortunately, the presence of too extended involvement of the surrounding anatomic structures makes radical surgery unfeasible in 30% for 40% of cases of invasive thymic tumors (1).

SVC reconstruction under cardio-pulmonary bypass

In the last years, some interesting experiences have appeared in the literature reporting limited series of patients undergoing resection of thoracic malignancies, mostly located in the anterior and middle mediastinum, requiring the use of cardiopulmonary bypass (CPB). The need for CPB was principally due to the direct invasion of cardiac structures or great vessels.

Vaporciyan and colleagues (34) have published a study of 19 patients with intrathoracic invasive tumors, most of which were metastatic lesions, showing direct involvement of cardiac chambers or great vessels requiring CPB to allow resection. Primary mediastinal tumors were present only in 20% of patients. The surgical approach was median sternotomy in 68% of cases, clamshell incision in 16% and posterolateral thoracotomy in 16%. Reconstructive procedures were performed by direct suture whenever possible. Conduit or patch vascular reconstruction was required in eight patients (42%) with the use of autologous pericardium, bovine pericardium, Dacron graft, and PTFE patch or graft. Complications occurred in 58% of patients and perioperative mortality was 11%. The overall complete resectability (R0) rate from the cardiac structures was 79%. The overall median survival was 62.4±25.4 months and it was significantly higher in patients who underwent radical resection.

Another similar series from the Memorial Sloan Kettering Cancer Center has been reported in 2004 including 10 patients with malignant tumors invading the heart and great vessels, seven of which requiring CPB (35). In three of these patients, the tumor was in the anterior mediastinum and determined SVC obstruction. The anterior mediastinal tumors included one thymoma, one synovial cell sarcoma, and one malignant teratoma.

These tumors were approached by median sternotomy in two cases and by a hemiclamshell incision in one (stage IV thymoma). SVC reconstruction was made by a ringed PTFE graft. Among these 3 patients, CPB was required only in the one with malignant teratoma. There were not postoperative deaths. Although the patient with thymoma received a radical (R0) resection, he died due to brain relapse of the disease after 29 months. On the contrary, the other two patients with anterior mediastinal malignancy were still alive at the time of publication after 69 months (synovial sarcoma) and 33 months (teratoma), although they presented microscopically infiltrated margins (R1). The latter two patients did not receive any postoperative oncologic treatment, while the patient with malignant teratoma received preoperative chemotherapy.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. D'Andrilli A, Venuta F, Rendina EA. Surgical approaches for invasive tumors of the anterior mediastinum. Thorac Surg Clin 2010;20:265-84.
2. D'Andrilli A, Venuta F, Menna C, et al. Extensive resections: pancoast tumors, chest wall resections, en bloc vascular resections. Surg Oncol Clin N Am 2011;20:733-56.
3. D'Andrilli A, Maurizi G, Poggi C, et al. [T4 lung cancer: results of surgical treatment]. Minerva Chir 2010;65:569-75.
4. Rendina EA, Venuta F, De Giacomo T, et al. Induction chemotherapy for T4 centrally located non-small cell lung cancer. J Thorac Cardiovasc Surg 1999;117:225-33.
5. Gonzalez-Fajardo JA, Garcia-Yuste M, Florez S, et al. Hemodynamic cerebral repercussions arising from surgical interruption of the superior vena cava. Experimental model. J Thorac Cardiovasc Surg 1994;107:1044–9.
6. Oizumi H, Suzuki K, Banno T, et al. Patency of grafts after total resection and reconstruction of the superior vena cava for thoracic malignancy. Surg Today 2016;46:1421-6.
7. Chen KN, Xu SF, Gu ZD, et al. Surgical treatment of complex malignant anterior mediastinal tumors invading the superior vena cava. World J Surg 2006;30:162-70.
8. Brewster DC. Prosthetic grafts. In: Rutherford RB, editor. Vascular surgery. Philadelphia: WB Saunders, 1995:492-521.
9. Dartevelle PG, Chapelier AR, Pastorino U, et al. Long-term follow-up after prosthetic replacement of the superior vena cava combined with resection of mediastinal-pulmonary malignant tumors. J Thorac Cardiovasc Surg 1991;102:259-65.
10. Spaggiari L, Leo F, Veronesi G, et al. Superior vena cava resection for lung and mediastinal malignancies: a single-center experience with 70 cases. Ann Thorac Surg 2007;83:223-9.
11. Leo F, Bellini R, Conti B, et al. Superior vena cava resection in thoracic malignancies: does prosthetic replacement pose a higher risk? Eur J Cardiothorac Surg 2010;37:764-9.
12. Sekine Y, Suzuki H, Saitoh Y, et al. Prosthetic reconstruction of the superior vena cava for malignant disease: surgical techniques and outcomes. Ann Thorac Surg 2010;90:223-8.
13. D'Andrilli A, Ibrahim M, Venuta F, et al. Glutaraldehyde preserved autologous pericardium for patch reconstruction of the pulmonary artery and superior vena cava. Ann Thorac Surg 2005;80:357-8.
14. Shargall Y, de Perrot M, Keshavjee S, et al. 15 years single center experience with surgical resection of the superior vena cava for non-small cell lung cancer. Lung Cancer 2004;45:357-63.
15. Suzuki K, Asamura H, Watanabe S, et al. Combined resection of superior vena cava for lung carcinoma: prognostic significance of patterns of superior vena cava invasion. Ann Thorac Surg 2004;78:1184-9; discussion 1184-9.
16. Spaggiari L, Magdeleinat P, Kondo H, et al. Results of superior vena cava resection for lung cancer. Analysis of prognostic factors. Lung Cancer 2004;44:339-46.
17. Shintani Y, Ohta M, Minami M, et al. Long-term graft patency after replacement of the brachiocephalic veins combined with resection of mediastinal tumors. J Thorac

Cardiovasc Surg 2005;129:809-12.
18. Lanuti M, De Delva PE, Gaissert HA, et al. Review of superior vena cava resection in the management of benign disease and pulmonary or mediastinal malignancies. Ann Thorac Surg 2009;88:392-7.
19. Picquet J, Blin V, Dussaussoy C, et al. Surgical reconstruction of the superior vena cava system: indications and results. Surgery 2009;145:93-9.
20. Okereke IC, Kesler KA, Rieger KM, et al. Results of superior vena cava reconstruction with externally stented-polytetrafluoroethylene vascular prostheses. Ann Thorac Surg 2010;90:383-7.
21. D'Andrilli A, De Cecco CN, Maurizi G, et al. Reconstruction of the superior vena cava by biologic conduit: assessment of long-term patency by magnetic resonance imaging. Ann Thorac Surg 2013;96:1039-45.
22. D'Andrilli A, Ciccone AM, Ibrahim M, et al. A new technique for prosthetic reconstruction of the superior vena cava. J Thorac Cardiovasc Surg 2006;132:192-4.
23. Ciccone AM, Venuta F, D'Andrilli A, et al. Long-term patency of the stapled bovine pericardial conduit for replacement of the superior vena cava. Eur J Cardiothorac Surg 2011;40:1487-91; discussion 1491.
24. Doty DB. Bypass of superior vena cava: six years experience with spiral vein graft for obstruction of superior vena cava due to benign and malignant disease. J Thorac Cardiovasc Surg 1982;83:326.
25. Bernard A, Bouchot O, Hagry O, et al. Risk analysis and long-term survival in patients undergoing resection of T4 lung cancer. Eur J Cardiothorac Surg 2001;20:344-9.
26. Yildizeli B, Dartevelle PG, Fadel E, et al. Results of primary surgery with T4 nonsmall cell lung cancer during a 25-year period in a single center: the benefit is worth the risk. Ann Thorac Surg 2008;86:1065-75.
27. Bacha EA, Chapelier AR, Macchiarini P, et al. Surgery for invasive primary mediastinal tumors. Ann Thorac Surg 1998;66:234-9.
28. Shen KR, Meyers BF, Larner JM, et al. American College of Chest Physicians. Special treatment issues in lung cancer: ACCP evidence-based clinical practice guidelines (2nd edition). Chest 2007;132: 290S-305S.
29. Venuta F, Rendina EA, Longo F, et al. Long-term outcome after multimodality treatment of stage III thymic tumors. Ann Thorac Surg 2003;76:1866-72.
30. Wright C, Wain J, et al. Predictors of recurrence in thymic tumors: importance of invasion, World Health Organization histology and size. J Thorac Cardiovasc Surg 2005;130:1413-21.
31. Jaxkson MA, Mall DL. Postoperative radiotherapy in invasive thymoma. Radiother Oncol 1991;21:77-82.
32. Okumura M, Ohta M, Tateyama H, et al. The World Health Organization classification system reflects the oncologic behavior of thymoma. Cancer 2002;94:624-32.
33. Wilkins KB, Sheikh E, Green R, et al. Clinical and pathological predictors of survival in patients with thymoma. Ann Thorac Surg 1999;230:562-74.
34. Vaporciyan AA, Rice D, Correa AM, et al. Resection of advanced thoracic malignancies requiring cardiopulmonary bypass. Eur J Cardiothorac Surg 2002;22:47-52.
35. Park BJ, Bacchetta M, Bains MS, et al. Surgical management of thoracic malignancies invading the heart or great vessels. Ann Thorac Surg 2004;78:1024-30.

Cite this article as: D'Andrilli A, Poggi C, Rendina EA, Venuta F. Superior vena cava resection and reconstruction. Open Thoracic Surgery. doi: 10.21037/978-988-77840-5-0.1

Complex Procedures

Open surgery for posterior mediastinal neurogenic tumors

Erkan Kaba[1], Mazen Rasmi Alomari[2], Alper Toker[2]

[1]Department of Thoracic Surgery, Istanbul Bilim University Medical Faculty, Istanbul, Turkey; [2]Group Florence Nightingale Hospitals, Istanbul, Turkey

Correspondence to: Erkan Kaba, MD. Department of Thoracic Surgery, Istanbul Bilim University Medical Faculty, 34381 Sisli, Istanbul, Turkey. Email: erkankaba@hotmail.com

Received: 11 June 2017; Accepted: 04 July 2017; Published: 25 July 2017.
doi: 10.21037/shc.2017.07.01
View this article at: http://dx.doi.org/10.21037/shc.2017.07.01

Introduction

Although most of the posterior mediastinal masses are found incidentally in adults, neurogenic tumors are the most common mediastinal tumors in children. The rate of malignancy may be as high as 50% in children, whereas, neurogenic tumors are almost always benign in adults. They are usually symptomatic when they are malignant. It was reported that the tumor extends into the neurogenic canal in 10% of the patients, which are named as "dumbbell tumors" (1). Besides there is an association between von recklinghausen disease and thoracic neurogenic tumors in about 14% of the cases. But this ratio is nearly 50% in adult patients with malignant tumors (2).

In general a chest computed tomography (CT) is helpful in radiological evaluation. Beside giving information about the presence of a capsule or a cleavage plane, CT scan can also reveal a possible intraspinal extension by demonstrating bony erosion of vertebral pedicles or laminae, or enlargement of an intervertebral foramen. In case of a suspicion about an intraspinal extension of the tumor, magnetic resonance imaging (MRI) is necessary to evaluate the accurate description of the presence and longitudinal extension of the intraspinal component of the tumor (*Figures 1-4*). Also some particular patients require preoperative angiograph to demonstrate the relation of the tumor with the Adamkiewicz artery.

Thurer and Herskowitz specified that "dumbbell tumors" located at lower thorax require more attention during surgery because of the blood supply to the spinal cord (3). During the management of such lesions originating below T6 level, the location of the Adamkiewicz artery must be identified carefully to avoid a possible spinal cold ischemia. This artery supplies the largest part of blood for anterior and posterior spinal arteries at lumbar area. It usually arises between T7 and L4, and mostly between T8-10 intercostal arteries. Spinal angiography may be performed before the surgery. An alternative method is the somatosensory evoked potential measuring during surgery.

Several authors tried to differentiate schwannomas from sarcomas by evaluating preoperative based on the positron-emission tomography/computed tomography (PET/CT) scans, and proposed a cut off standard uptake value (SUV) max of 4.8 (4). Some studies revealed significantly higher values in patients with benign schwannomas and concluded to still consider the diagnosis of schwannoma despite higher fluorodeoxyglucose (FDG) avidity (*Figure 5*) (5). Neurofibrosarcomas located at the posterior mediastinum have also demonstrated significant FDG avidity, like sarcomas located elsewhere.

Access to the posterior mediastinum is mostly provided with posterolateral (auscultatory triangle) or anterolateral thoracotomy. Video-assisted thoracoscopic surgery (VATS) has been introduced as a safe and effective method of minimally invasive surgery in the past 15 years. Robotic surgery gained popularity in the past 5 years due to 3 dimensional vision and high technical capabilities of the arms. Open surgery is indicated in large-sized tumors (>6 cm), in the presence of a previous thoracic surgery, or when the tumor is presumed to invade the spinal canal or spinal artery, or is apically located (close to the satellite ganglion, and great vessel). This is because such cases have an increased risk of perioperative complications including avulsion of dumbbell component in the vertebral foramen, bleeding from spinal arteries, cerebrospinal fluid (CSF) leak, injury to the recurrent laryngeal nerve and Horner

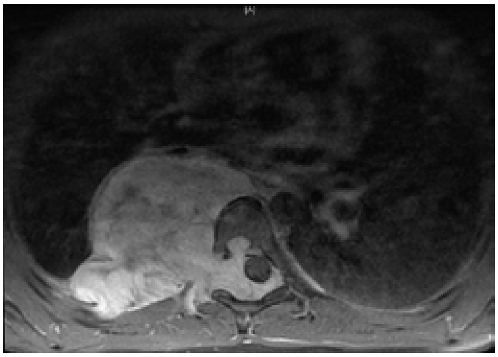


Figure 1 Axial MRI images of a tumor with intraspinal extension in a patient with large-sized tumor (7 cm × 6 cm), spreading through 7th and 8th intercostal spaces.

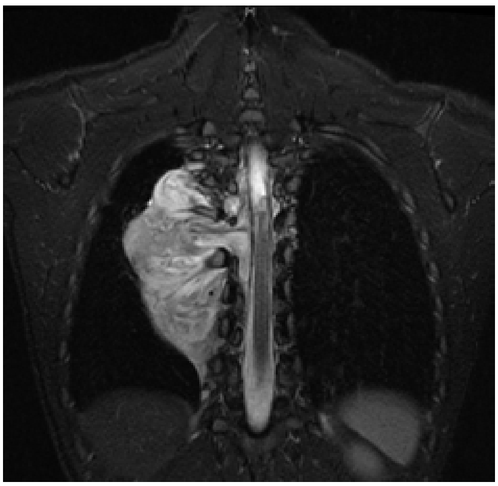


Figure 2 Coronal MRI images of a large tumor (11 cm) with the invasion the right nerve roots T5, T6, and T7.

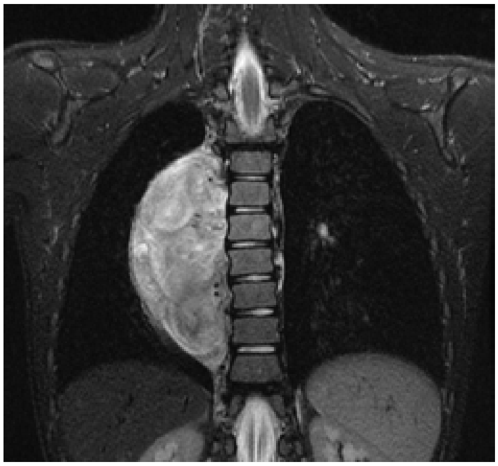


Figure 3 Tumor invading the spinal cord.

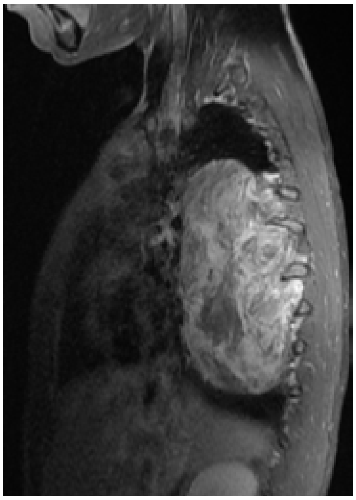


Figure 4 Sagittal images of tumor.

syndrome. However, in our institution we prefer robotic surgery in every case after excluding a possible intraspinal extension.

Operative techniques

Level of the location, the size of the tumor and its relations to neural foramina and spinal canal are used to determine the incisions and surgical approach.

- ❖ Mass without obvious clinical or radiological signs of spinal canal involvement:

After lung isolation by double lumen endotracheal intubation, the patients is placed in standard posterolateral thoracotomy position. The parietal pleura over the lesion is excised using electrocautery or electrothermal bipolar-activated vessel sealing systems, which can be LigaSure (Valleylab, Boulder, CO) or harmonic scalpel (Johnson & Johnson Medical Products, Ethicon Endosurgey, Cincinnati, OH, USA). During the blunt dissection, care must be taken to both intercostal and vertebral vessels, which should be divided by clipping, if required. The tumor is released from the neural tissue after securing the feeding vessels as demonstrated in the *Figure 6*.

When extrapleural dissection and resection is difficult or impractical technically, intracapsular resection has been proposed for apically located tumors, around the T2 and T3 nerve root closer to larger arteries, veins and stellate

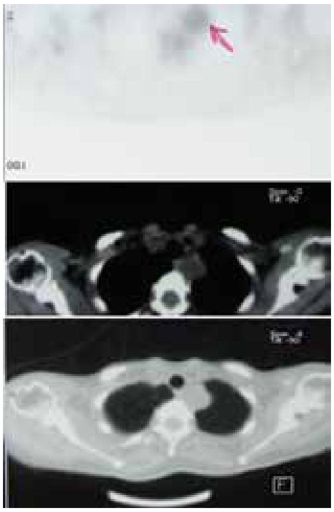


Figure 5 PET CT images: neurogenic tumor involvement of left upper posterior mediastinum.

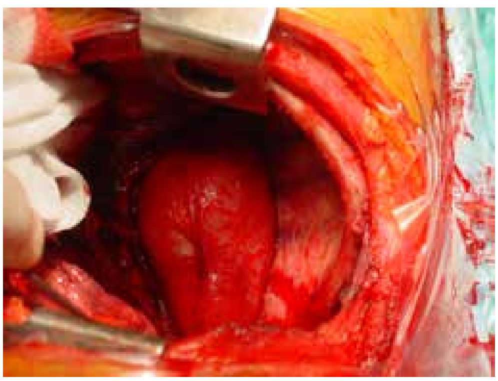


Figure 6 Exposure after lung releasing from the neurogenic tumor.

ganglion during VATS. In most cases, mass enucleation from subpleural attachment could be performed. The nerve root may be preserved with difficulty in schwannomas, while, in neurofibromas the nerve root is taken en bloc with the tumor. Therefore some authors recommend open surgery instead of intracapsular resection via minimally invasive surgery.

❖ Mass with clinical or radiological signs of spinal canal involvement.

Two different methods were described for these tumors.

(I) Akwari defined a combination of posterior and posterolateral approaches. In this method, posterior laminectomy is performed for intraspinal extension

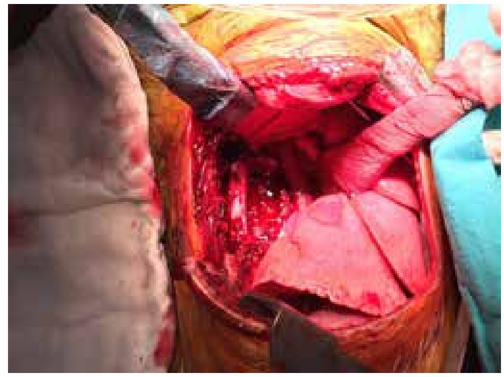


Figure 7 Division of the nerve roots by ligation.

of tumor first, then posterolateral thoracotomy is performed for removal of tumor.

(i) Spine surgery: Neurosurgeons (spine surgeons) perform posterior laminectomy for "dumbbell tumors". The patient is positioned prone. Posterior laminectomy is completed at the corresponding levels via a posterior midline incision. Originating nerve roots are divided by ligation in case of a totally extradural tumor (*Figure 7*). Intradurally extended tumors necessitate further care and experience in spinal surgery. In such case, the dura is opened and the tumor is dissected from the spinal cord. After freeing the intraspinal component of the tumor, it is pushed into the thoracic cavity. The procedure is then completed in posterolateral thoracotomy position. Instrumentation at necessary levels are completed at this stage of surgery (*Figure 8*).

(ii) Intrathoracic part of the surgery: After skin closure of median posterior incision in prone position, patient is converted to lateral thoracotomy position. We generally prefer a separate thoracotomy incision which approximates the midline of the posterior incision (*Figure 9*). Sometimes, due to technical difficulties, we combine the incisions to have a wider exposure.

(iii) The dissection of the mass: The thoracotomy is opened in the mid-part of the tumor. By allowing tumor free margins, posterior part of the ribs are divided according to the corresponding planned vertebral resection.

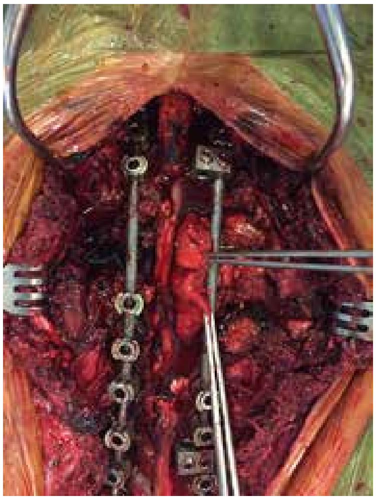


Figure 8 Image of mediastinum after vertebral instrumentation.

Figure 10 CT-scan image after instrumentation.

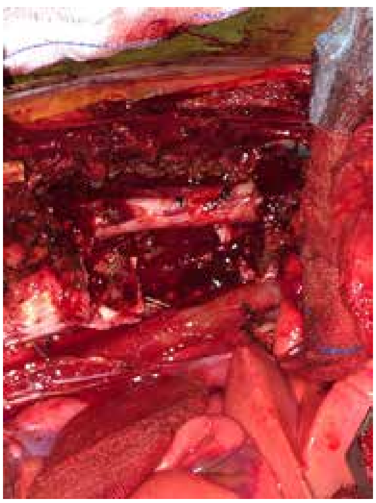


Figure 9 Operation area's view through thoracotomy incision.

The tumor is dissected from the lung (almost always there is not any adhesion), esophagus, aorta, posterior pericardium and main bronchi. A benign tumor never invades the abovementioned structures. Vertebrae are resected after completion of the mobilization of the intrathoracic part of the tumor. Then the prosthetic replacement of the resected vertebrae is completed by spine surgeons (*Figure 10*).

(II) Patient is placed in the lateral decubitus position in Grillo's technique. Rotating ventrally should help accessing to the thorax and spine. In Grillo's method, a hockey-stick shaped skin incision is performed beginning from vertical mid vertebral area and extending horizontally to the tip of scapula. A flap that consists of skin subcutaneous tissue is lifted over muscle layer, and thoracotomy is performed under this flap tissue. After the exploration and the mobilization of the thoracic portion are completed, resection of intraforaminal extension starts as second part of surgery. Authors suggest that en bloc resection of the tumor with a foraminotomy is possible with thoracotomy incision.

However, approaches depend on surgeon's preferences and experiences. Theoretically one posterior incision is appropriate for small size tumors. When tumors are larger or multiple vertebral foramens are involved Akwari method is preferable according to our experience.

Complications

Postoperative morbidity rate of neurogenic tumor surgery is around 20% to 30%. Pneumonia and atelectasis are among the commonest complications (6). Nowadays, many surgeons prefer to perform these operations using VATS. Although we believe that the conversion to thoracotomy is an oncological must, rather than a complication, 22% to 30% of the patients necessitate conversion because of the intraspinal extension, tumor size, difficult locations of the tumor, or the presence of pleural adhesions. For tumors with intraspinal extension, CSF leak is a frightening complication. Management and identification of these complications needs experience.

Mostly there is no need for a lung resection thus in air-leak and migration of air into intradural space. Increased amount of drainage may be the only symptom. Beta-2 transferrin level in the pleural fluid may help in diagnosis of CSF leakage. The first aim in the treatment is to decrease the intradural pressure by placing a catheter into dura and drainage CSF outside instead of into the thoracic cavity. Revision and closure of dural leak may be alternative if the drainage continues.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

doi: 10.21037/shc.2017.07.01

Cite this article as: Kaba E, Alomari MR, Toker A. Open surgery for posterior mediastinal neurogenic tumors. Shanghai Chest 2017;1:15.

References

1. Akwari OE, Payne WS, Onofrio BM, et al. Dumbbell neurogenic tumors of the mediastinum. Diagnosis and management. Mayo Clin Proc 1978;53:353-8.
2. Inoue M, Mitsudomi T, Osaki T, et al. Malignant transformation of an intrathoracic neurofibroma in von Recklinghausen's disease. Scand Cardiovasc J 1998;32:173-5.
3. Thurer RJ, Herskowitz K. Open approaches to posterior mediastinal tumors and the spine. Chest Surg Clin N Am 1996;6:117-38.
4. Nose H, Otsuka H, Otomi Y, et al. Correlations between F-18 FDG PET/CT and pathological findings in soft tissue lesions. J Med Invest 2013;60:184-90.
5. De Waele M, Carp L, Lauwers P, et al. Paravertebral schwannoma with high uptake of fluorodeoxyglucose on positron emission tomography. Acta Chir Belg 2005;105:537-8.
6. Go T, Macchiarini P. Open approaches to posterior mediastinal tumor in adults. Thorac Surg Clin 2010;20:285-95.


ISSN 2072-1439
Vol 9, No 6 June 2017
2016
IMPACT FACTOR
2.365
JOURNAL of
THORACIC
DISEASE
jtd.amegroups.com
The Official Publication of
AME
Journal of Thoracic Disease