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Subxiphoid Video-Assisted Thoracic Surgery

Editors: Lei Jiang
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Subxiphoid Video-assisted Thoracic Surgery (FIRST EDITION)

EDITORS

Lei Jiang
Department of Thoracic Surgery, Shanghai Pulmonary Hospital affiliated to Tongji University School of Medicine, Shanghai 200433, China

Giuseppe Aresu
Department of Cardiothoracic Surgery, Papworth Hospital, Cambridgeshire, UK

ASSOCIATE EDITORS

Diego Gonzalez-Rivas
Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University School of Medicine, Shanghai 200433, China; Department of Thoracic Surgery, Coruña University Hospital and Minimally Invasive Thoracic Surgery Unit (UCTMI), Coruña, Spain

Alan D. L. Sihoe
Department of Surgery, The University of Hong Kong, Hong Kong, China; Department of Surgery, The University of Hong Kong Shenzhen Hospital, Shenzhen 518053, China; Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University, Shanghai 200433, China

Gaetano Rocco
Department of Surgery, Memorial Sloan Kettering Cancer Center, 1275 York Avenue, New York, NY, USA

Jason M. Ali
Thoracic Surgery, Royal Papworth Hospital NHS Foundation Trust, Papworth Everard, Cambridge, UK

Gening Jiang
Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University, Shanghai 200433, China

CONTRIBUTORS

Amr Abdellateef
Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University, Shanghai 200433, China

Firas Abu Akar
Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University School of Medicine, Shanghai 200433, China

Jason M. Ali
Thoracic Surgery, Royal Papworth Hospital NHS Foundation Trust, Papworth Everard, Cambridge, UK

Giuseppe Aresu
Thoracic Surgery, Royal Papworth Hospital NHS Foundation Trust, Papworth Everard, Cambridge, UK

Zhigang Chen
Department of Thoracic Surgery and Anaesthesia, Shanghai Pulmonary Hospital, Tongji University, Shanghai 200433, China

Jian Chen
Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University School of Medicine, Shanghai 200433, China

Chih-Tao Cheng
Department of Medical Research, Koo Foundation Sun Yat-Sen Cancer Center, Taipei, Taiwan, China

Serena Concina
Department of General Surgery, Santa Maria della Misericordia University Hospital, Udine, Italy

Aman Coonar
Department of Thoracic Surgery, Papworth Hospital NHS Foundation Trust, Cambridge, UK

Wojciech Czajkowski
Department of Thoracic Surgery, Pulmonary Hospital, Zakopane, Poland

Joel Dunning
Department of Cardiothoracic Surgery, James Cook University Hospital, Middlesbrough, UK

Haiyang Fan
Department of Thoracic Surgery, The Seventh Hospital, Sun Yat-sen University, Shenzhen City, Guangdong Province 518107, China

Mario Ferrante
Department of Anaesthesia, Royal Papworth Hospital, Cambridge, UK

Matthew Fok
Department of Thoracic Surgery, Papworth Hospital NHS Foundation Trust, Cambridge, UK

Edward Fryzlewicz
Department of Anaesthesiology and Intensive Care, Pulmonary Hospital, Zakopane, Poland

Diego Gonzalez-Rivas
Department of Thoracic Surgery, Coruña University Hospital and Minimally Invasive Thoracic Surgery Unit (UCTMI), Coruña, Spain; Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University School of Medicine, Shanghai 200433, China

William Guido Guerrero
Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University School of Medicine, Shanghai 200433, China; Department of Thoracic Surgery, Rafael Angel Calderón Guardia Hospital, San José, Costa Rica

Luis Angel Hernandez-Arenas
Department of Thoracic Surgery, Shanghai Pulmonary Hospital affiliated to Tongji University School of Medicine, Shanghai 200433, China

Jing Huang
Department of Respiration, Shanghai Pulmonary Hospital, Tongji University School of Medicine, Shanghai 200433, China

Mahmoud Ismail
Department of Thoracic Surgery, Erns Von Bergmann hospital, Potsdam, Germany

Shruti Jayakumar
Department of General Surgery, Santa Maria della Misericordia University Hospital, Udine, Italy

Lei Jiang
Department of Thoracic Surgery, Shanghai Pulmonary Hospital affiliated to Tongji University School of Medicine, Shanghai 200433, China

Gening Jiang
Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University, Shanghai 200433, China

Jay Karunanantham
Department of Thoracic Surgery, Papworth Hospital NHS Foundation Trust, Cambridge, UK

Pradeep Kaul
Thoracic Surgery, Papworth Hospital NHS Foundation Trust, Papworth Everard, Cambridge, UK

Sylweriusz Kosinski
Department of Anaesthesiology and Intensive Care, Pulmonary Hospital, Zakopane, Poland

Lei Lin
Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University, Shanghai 200433, China

Francisco Lirio
Department of Thoracic Surgery, Hospital General Universitario Alicante, Alicante, Spain

Chia-Chuan Liu
Division of Thoracic Surgery, Department of Surgery, Koo Foundation Sun Yat-Sen Cancer Center, Taipei, Taiwan, China

Yun-Hen Liu
Division of Thoracic Surgery, Chang Gung Memorial Hospital, College of Medicine, Chang Gung University, Keelung, Taiwan, China

Zhen-Ying Liu
Department of Medical Research, Koo Foundation Sun Yat-Sen Cancer Center, Taipei, Taiwan, China

Enrico Melis
Division of Thoracic Surgery, Department of Surgical Oncology, Regina Elena National Cancer Institute, Rome, Italy

Jacobo Moreno Garijo
Department of Anesthesia & Pain Management, Toronto General Hospital, Toronto, Canada

Tomasz Nabialek
Department of Anaesthesiology and Intensive Care, Pulmonary Hospital, Zakopane, Poland

Juliusz Pankowski
Department of Pathology, Pulmonary Hospital, Zakopane, Poland

Chinmay Patvardhan
Department of Anaesthesia, Royal Papworth Hospital, Cambridge, UK

Adam Peryt
Department of Thoracic Surgery, Papworth Hospital NHS Foundation Trust, Cambridge, UK

Jichen Qu
Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University School of Medicine, Shanghai 200433, China

Andrew Roscoe
Department of Anaesthesia, Royal Papworth Hospital, Cambridge, UK

Mariusz Rybak
Department of Thoracic Surgery, Pulmonary Hospital, Zakopane, Poland

Julio Sesma
Department of Thoracic Surgery, Hospital General Universitario Alicante, Alicante, Spain

Chih-Shiun Shih
Division of Thoracic Surgery, Department of Surgery, Koo Foundation Sun Yat-Sen Cancer Center, Taipei, Taiwan, China

Alan D. L. Sihoe
Department of Surgery, The University of Hong Kong, Hong Kong, China; Department of Surgery, The University of Hong Kong Shenzhen Hospital, Shenzhen 518053, China; Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University, Shanghai 200433, China

Katarzyna Solarczyk-Bombik
Department of Thoracic Surgery, Pulmonary Hospital, Zakopane, Poland

Sandro Sponga
Department of Thoracic Surgery, Santa Maria della Misericordia University Hospital, Udine 33100, Italy

Takashi Suda
Division of Thoracic Surgery, Fujita Health University School of Medicine, Toyoake, Aichi, Japan

Malgorzata Szolkowska
Department of Pathology of the Tuberculosis Institute, Warsaw, Poland

Sara Volpi
Thoracic Surgery, Royal Papworth Hospital NHS Foundation Trust, Papworth Everard, Cambridge, UK

Helen Weaver
Department of Cardiothoracic Surgery, Papworth Hospital, Cambridgeshire, UK

Michal Wilkojc
Department of Thoracic Surgery, Pulmonary Hospital, Zakopane, Poland

Liang Wu
Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University, Shanghai 200433, China

Huan Xu
Department of Thoracic Surgery and Anaesthesia, Shanghai Pulmonary Hospital, Tongji University, Shanghai 200433, China

Chenlu Yang
Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University School of Medicine, Shanghai 200433, China

Yang Yang
Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University School of Medicine, Shanghai 200433, China

Yunsong Zhang
Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University, Shanghai 200433, China

Zhigong Zhang
Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University, Shanghai 200433, China

Marcin Zieliński
Department of Thoracic Surgery, Pulmonary Hospital, Zakopane, Poland

Executive Typesetting Editor

Beibei Chen, AME Publishing Company

Cover Image Illustrator

Anthony P. Yim, HongKong, China

The *Annals of Cardiothoracic Surgery*, one of AME's peer-reviewed journals, is lucky to have an author from Rochester, USA. He is left-handed. When he began his training in surgery, he encountered he encountered a particularly intractable obstacle: when using… when using scissors or doing knotting during a surgery, his actions were the mirror opposite of what was described in textbooks. Therefore, he often "took a beating" from his mentors when performing a surgery.

Later, he summarized his experience and published it in a journal in an attempt to find other surgeons that "suffer from the same fate". Surprisingly, after his article was published, many surgeons e-mailed him, asking him how left-handed doctors should undergo surgical training, and so on. Then he met Professor Tristan D. Yan, the editor-in-chief of *Annals of Cardiothoracic Surgery*, who also happens to be a left-handed doctor. Tristan encouraged him to become a heart surgeon because there are steps in cardiac surgery that require the use of the left hand to complete the suture threading technique. Tristan's view was that it was better if surgeons were trained to use both their left and right hands.

A few days ago, on my daughter's first day of kindergarten, I chatted with her teacher for a while; finally, she asked me if there was anything about my daughter that she should take note of . "Please do not correct my daughter's left-handedness," I said, "Just let it be." "Why?" the teacher asked in wonder.

On December 7th, 2013, we held the second AME Academic Salon in the Hospital Affiliated to Nantong University. After dinner, Dr. Shen Yaxing from the Department of Thoracic Surgery of Shanghai Zhongshan Hospital invited several attendees to have tea in his room. The elevator was in the middle of the hotel. After we walked out of the elevator, he led us to the left, then to the left, then to the left, then to the left, and finally to the door of his room. Although we were confused and disoriented, some of us figured out out that the door was just diagonally across the elevator. We all burst into laughter. Yaxing divulged that he took this route the first time he entered his room, and so he decided to bring us on the same route the second time. Yaxing then said that this was the behavior of a "typical" surgeon!

During the training to be a surgeon, each step and each action are done under the strict direction and supervision of a senior surgeon. Thus, many surgeons like to affectionately address their mentors as their "masters".

How, then, can you become a master of surgery? In addition to your own intelligence and diligence, the expertise and mentorship offered by a "master" is also very important. Just like in the world of martial arts, there are many different schools that are independent from each other and have their own strengths and weaknesses, and the surgical world is very much the same.

Therefore, it is important for a young surgeon to gain knowledge and skills from different masters by taking in only the essence and discarding the dregs. With this in mind, we have here determined to publish the AME Surgery Series, in an attempt to share with our readers the surgical skills of some of the prominent surgical teams in China and from abroad, as well as their philosophical thinking and some interesting stories. We sincerely hope that our colleagues in the surgical departments find these books insightful and helpful.

Stephen D. Wang
Founder and CEO,
AME Publishing Company

Subxiphoid approach, a new prospective to see the minimally invasive thoracic surgery

In 1995 the treatment guidelines of the American Society of Clinical Oncology considered an improvement in Quality Of Life to be a necessary objective in justifying the recommendation of a new therapeutic strategy for patients with cancer.

In this view the development of the minimally invasive thoracic surgery had the purpose to achieve the same oncological results in a less traumatic way leading to an improvement of several post operatory quality of life determinants.

From the first thoracoscopic procedures introduced in the first years of the 20th century, we have assisted a constant evolution of techniques and technologies but the real revolution started in the early 90's when the first VATS major anatomic lung resection was performed by Roviaro.

From that point a new way has opened and, after a slow diffusion plenty of difficulties and detractors, in the last fifteen years the VATS techniques have spread worldwide.

Many studies have shown the minimally invasive approach benefits and in the last years even the official guidelines have recommended it the preferred option even in the case of lung cancer resection.

In parallel with the increased experience in this field an important number of variations have come to light especially regarding the number, the position and the size of the ports. Needlescopic, biportal and uniportal VATS have been introduced with the aim to reduce the invasiveness and the traumatic injury of the intercostal bundles and therefore to improve the outcome. However, analyzing the results, we can recognize that we have room to improve as patients undergoing VATS still complain of some acute and chronic postoperative pain.

In this context the promise land of an almost painless incision has been the new aim of a group of pioneer minimally invasive thoracic surgeons that have proposed to reach the chest cavity and operate into it without passing through the rib cage giving birth to the subxiphoid video-assisted thoracic surgery.

The subxiphoid approach has been proposed as a less invasive alternative for minor and major procedures such as lung lobectomies and segmentectomies thymectomies and bilateral lung resections.

This book provides a summary of different procedures carried out using the subxiphoid approach. Furthermore we have given space to hot topics in this field like lymphadenectomy, bilateral procedures and learning curve.

Some of the best world experts in this technique have been involved in this book edition, I hope that their experience and their futuristic vision will help to spread subxiphoid VATS all over the thoracic surgery community making our work less invasive and less painful for our patients.

Giuseppe Aresu, MD, PhD
Department of Cardiothoracic Surgery, Papworth Hospital, Cambridgeshire, UK
(*Email: aresugiu@gmail.com*)

Subxyphoid VATS represents an additional approach in the armamentarium of a thoracic surgeon. It may indeed be considered a potential evolution of Uniportal VATS (UniVATS) in that the geometry of the approach to the target intrathoracic lesion can be similar. However, the perspective and the anatomic view are somewhat different – not only due to the restricted space in the substernal cylinder that accommodates optic and operative instruments but also to the development of planes according to a longitudinal axis perpendicular to the major broncho-vascular structures as opposed to the frontal axis of UniVATS and Multi VATS. As a result, the surgeon dissects around hilar structures like slaloming around poles which he/she approaches in a stepwise fashion following a direct line like in a downhill ski race. Deviation from the main dissecting strategy is of course possible, but entails a level of familiarity with lung anatomy and tridimensional representation which requires considerable experience.

As with Uniportal VATS, there has been a rapid demonstration of the safety and feasibility of this surgical approach which seems to provide the main advantage of a reduced pain compared to intercostal incisions. Favorable anthropometric features also appear to facilitate this approach which has gained remarkable consensus in Asia. The addition of subcostal as well as intercostal ports is recommended when the dissection is impeded by underlying factors like perivascular fibrosis or seemingly fixed hilar or mediastinal adenopathies. And, as with Uniportal VATS, we might be facing the implicit danger of a sterile exhibition of surgical expertise without a clear demonstration of the potential benefits that this surgical approach may provide. Hence, my encouragement to the subxyphoid VATS advocates at gathering a consensus around the basics of this technique and instituting an international database including all procedures in order for this approach to be evaluated according standard quality metrics and determine possible training pathways. Until then, the subxyphoid approach is likely to suffer the same fate of Uniportal VATS and could be considered as another acrobatic surgical exercise with little or no additional advantage offered in the surgical management of patients with intrathoracic conditions. This work by Aresu *et al.* has the merit to shed some light on the technicalities of subxyphoid VATS thereby contributing to defining the ground rules of this complex but fascinating approach.

Gaetano Rocco, MD, FRCS, FEBTS, FCCP
Attending, Thoracic Surgery Service, Department of Surgery,
Memorial Sloan Kettering Cancer Center,
New York, USA

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General Aspects

From video-assisted thoracoscopic surgery to the uniportal subxiphoid robotic approach

Diego Gonzalez-Rivas[1,2]

[1]Uniportal VATS Training Program, Shanghai Pulmonary Hospital, Shanghai 200000, China; [2]Minimally Invasive Thoracic Surgery Unit (UCTMI) and Coruña University Hospital, Coruña, Spain

Correspondence to: Diego Gonzalez-Rivas, MD, FECTS. Director Uniportal VATS Training Program, Shanghai Pulmonary Hospital, Shanghai 200000, China; Minimally Invasive Thoracic Surgery Unit (UCTMI) and Coruña University Hospital, Coruña, Spain. Email: Diego.Gonzalez.Rivas@sergas.es.

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"*Our future in surgery lies not in blood and guts, but in bits and bites*". —Colonel Richard Satava, pioneer of robotic telesurgery 2000

Developments in minimally invasive thoracic surgery begun one century ago by the hand of Hans Christian Jacobaeus. Diagnostic procedures, such as pleural biopsies, were performed mainly by pulmonologists and thanks to the introduction of the video-assisted surgical scope in 1991, the minimally invasive technique applications expanded to include major anatomic resections among other thoracic procedures. Since then, these techniques have evolved and improved all around the world.

The initial practice of three port technique in a 'baseball diamond' pattern was modified to suit surgical needs, and gradually developed into 'next generation' less invasive approaches, such as the double port video-assisted thoracoscopic surgery (VATS). Thereafter the logical progression of reducing the number of incisions ended with the single port VATS approach. In the last decade, this technique generated considerable interest within the field of minimally invasive thoracic surgery due to several reasons. Because this approach is less invasive, the uniportal technique has emerged as an innovative technique, applicable to a large variety of thoracic diseases, from easy diagnostic procedures to the most complex resections for lung cancer, including bronchial, vascular sleeves or even carinal resections.

There are many studies that show that the intercostal, uniportal approach can reduce the surgical trauma when compared with multiport thoracoscopic surgery. However, the risk of possible injury to the intercostal nerve and the consequent acute and, or chronic pain cannot be completely ruled out. Avoiding the incision through the intercostal space could be a potential advantage to reduce postoperative pain and to improve the postoperative course of patients.

Recent innovations in single-incision approach include the use of subxiphoid and subcostal approach for major anatomic pulmonary resections. The subxiphoid and subcostal approach has been used during the last two decades initially for different minor thoracic procedures such as pericardial window, thymectomies, pulmonary metastasectomy and bilateral resections.

In 2013, Liu CC, with previous experience in uniportal transthoracic surgery, reported the first case of thoracoscopic lobectomy with mediastinal lymph node sampling through a single subxiphoid incision in a patient with lung cancer. Since then the technique has been refined and improved in only few centers around the world with the largest experience at the Shanghai Pulmonary Hospital. The volume of surgery at this center includes the largest number of subxiphoid and subcostal cases reported in the world. These include upper and lower lobectomies, pneumonectomies and all kind of segmentectomies.

One of the most important advantages of the subxiphoid approach is that it can reach both sides of the chest through a single incision. This is very useful for bilateral resections, anterior mediastinal resections and thymectomies. However, the access through the subxiphoid space has several limitations. One of the most important is the handling of major bleeding. When an emergent conversion to open surgery is necessary, an extension of the subxiphoid incision is unlikely to be useful and an additional chest incision or even thoracotomy should be performed.

In addition, a radical lymph node dissection is very difficult to achieve via subxiphoid approach and there is limited access to posterior anatomy, so the upper posterior and lower anatomic segmentectomies are really challenging. From the xiphoid to the hilum, there is an oblique and longer distance than transthoracically so the instrument fighting problem during uniportal surgery will be even more challenging than through the transthoracic approach. The manipulation of instruments over the beating heart is also inconvenient, especially during left side procedures where extra care must be taken to avoid cardiac problems during surgery. The use of a sternal retractor improves the access and particularly reduces compression of the heart. The subcostal approach on the left side diminishes a bit the heat compression and could improve also the view.

So, the question that arises is how can we solve these subxiphoid limitations.

Parallel to the development of thoracoscopic approaches, a new concept of surgery was born almost 20 years ago—robotic surgery. Since the first robotic resection was reported in 2002, the popularity of this approach is slowly gaining clinical and research interest all over the world. Like other minimally invasive techniques, the robotic system offers the advantages of reduced postoperative pain, faster recovery and decreased hospital stay compared to open surgery. Most of the robotic platforms include a system with several arms so a minimum number of 3 to 4 incisions are always performed.

Supporters of robotic surgery claim several advantages over VATS, such as improved three-dimensional visualization, better ergonomics and more degrees of freedom of motion. However, to date, not one single study has shown clear advantages of the robot over VATS approaches. Therefore, the superiority of multiportal robotics cannot be demonstrated yet, especially when compared with the uniportal approach which is cheaper, faster and less invasive.

So why not try to apply the robotic technology through the subxiphoid approach?

We have now reached the moment when the subxiphoid approach and robotic surgery converge to develop a system that allows greater maneuverability and precision as well as avoidance of acute or chronic paid due to intercoastal nerve damage. The robotic surgery allows a greater range of instrumentation so the areas that were previously limited through the subxiphoid space (posterior segments and subcarinal and paratracheal space) are now accessible thanks to the advanced movement of the robot and the use of angulated cameras.

A couple of years ago we started a project with an important robotic company to develop this concept into thoracic surgery. After the visit of the engineers to our Uniportal VATS training program at Shanghai Pulmonary Hospital we followed with visits to the factory to improve this new robotic thoracic platform. A robotic system that accesses the chest through the subxiphoid space

We could say now that the future of the subxiphoid approach is promising with the recent development of the uniportal robotic equipment designed to minimize the surgical access trauma. We used a 2.5-cm diameter insertable arm which opens up within the operating cavity into a steerable 3D camera and three effector arms for tissue handling and suturing. The initial anatomic thoracic procedures we performed with this system in the cadaveric model were excellent showing feasibility of all kind of lobectomies and thymectomies. One of the advantages of this new platform could be the visualization of the subcarinal and paratracheal space to accomplish extensive lymph node dissection.

We are now waiting for studies to document the applicability in patients and compare clinical outcomes of the subxiphoid robotic technology versus the transthoracic and subxiphoid uniportal thoracoscopic approaches, in order to show clear benefits for this new exciting system. Once again, we are facing a new revolution in thoracic surgery that will definitely change the way we treat lung cancer and other thoracic surgical diseases.

"*It is very difficult to slow down. The practice of medicine is like the heart muscle contraction—it's all or none*" —Alexis Carrel (1873–1944).

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Footnote

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General Aspects

Reasons not to perform subxiphoid video-assisted thoracic surgery

Alan D. L. Sihoe[1,2,3], Joel Dunning[4]

[1]Department of Surgery, The University of Hong Kong, Hong Kong, China; [2]Department of Surgery, The University of Hong Kong Shenzhen Hospital, Shenzhen 518053, China; [3]Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University, Shanghai 200433, China; [4]Department of Cardiothoracic Surgery, James Cook University Hospital, Middlesbrough, UK

Correspondence to: Alan D. L. Sihoe, MBBChir, MA (Cantab), FRCSEd (CTh), FCSHK, FHKAM, FCCP. Department of Surgery, The University of Hong Kong, Hong Kong, China. Email: adls1@hku.hk.

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The title of this paper can be read in two ways. Many readers will first think it is meant to say "these are the reasons that one should not perform subxiphoid VATS". Another reading is that "these should not be the reasons for one to perform subxiphoid VATS". The authors' intention is decidedly in line with the latter.

There is no doubt that video-assisted thoracic surgery (VATS) is the greatest step forwards in general thoracic surgery in the past quarter of a century (1,2). The introduction of minimally invasive surgical approaches to operations in the chest has not only reduced morbidity for each individual patient, but allowed safe, effective surgery to be offered to patients previously deemed unfit or unwilling to undergo open thoracotomy. Since the gradual establishment of VATS in the 1990s, thoracic surgeons have endeavoured to look for the next big breakthrough. First, robotic-assisted surgery gathered much interest, but rates of adoption worldwide have been limited by issues of cost (3). Subsequently, 'next generation' VATS approaches have been introduced—including needlescopic and 2-port VATS techniques (2). Uniportal VATS in particular has created much enthusiasm around the globe, with thoracic surgeons in many countries now keen to learn this approach (4). The ability to restrict surgical access trauma to just one small incision via one single intercostal space appealed to many—even if the clinical evidence supporting this as being advantageous has so far not been consistent (5).

One of the newest attempts to produce a novel technical innovation has been to perform single port VATS via a subxiphoid approach. This was first described for thymic resections (6), and has since been developed to permit anatomical and bilateral lung resections (7-9). Even though this approach may seem technically challenging to perform, its proponents claim many benefits. It allows great access to the anterior mediastinum for thymectomy, and access to both sides of the chest with only a single incision. Most importantly, it is claimed that by avoiding the intercostal space altogether, the subxiphoid approach completely negates trauma and compression to the intercostal nerves: often quoted as the major source of post-operative pain and paresthesia after thoracotomy and VATS (9,10).

Is there evidence to support the claims?

The theoretical benefits of subxiphoid VATS sound very attractive. Is this now the time to start jumping on the bandwagon? The answer to that certainly requires a look at the current evidence. As with Uniportal VATS, it is prudent to look beyond the hype and bold claims regarding any new surgical technique, and see whether boasts of clinical advantage are supported by hard clinical data (5,11).

To this end, the authors undertook a simple search of the PubMed database using the National Center for Biotechnology Information website on October 7, 2018. Searching for the word "subxiphoid" in the article title, 67 unique articles were identified that pertained to subxiphoid VATS for pulmonary and mediastinal/thymic surgery (those dealing with cardiovascular and pericardial indications were excluded). These are listed in Supplementary files. These papers included 42 papers on pulmonary surgery, and 25 on mediastinal/thymic surgery.

On closer scrutiny, the vast majority of the papers on subxiphoid VATS for pulmonary surgery were simple case reports, commentaries, reviews, how-to-do-it technique articles, and animal studies. Such papers provide little or no original clinical data on the outcomes of the technique. There were only 8 papers reporting case series that gave clinical data on the use of this approach, and only 2 papers that compared this to conventional VATS. The latter 2 comparative studies suggested that subxiphoid VATS gave lower post-operative pain scores (10,12)—but such scores are not necessarily reliable given the small cohorts, subjectivity of pain reporting, and lack of standardized pain control protocols used in these studies (5,11). No other differences favouring the subxiphoid approach were found. Moreover, 22 (52%) of the 42 papers were produced by merely 3 centers alone. This reflects the likelihood that subxiphoid VATS is currently being practiced only by a handful of specialists, high-volume centers.

Regarding the 25 papers on subxiphoid VATS thymectomy, there were 6 papers reporting case series that gave clinical data on the use of this approach, and 3 papers that compared this to conventional VATS or open sternotomy. The latter 3 comparative papers reported results that favoured the subxiphoid approach (13-15), but all were small retrospective studies in which peri-operative management was not well standardized and bias has not been excluded. Of the 25 papers, 15 (60%) were produced by 3 centers alone.

What the above simple analysis shows is that there is currently very little hard clinical data illustrating the use of the subxiphoid VATS approach. Two issues arise from this. First, the reasonable number of case series published apparently suggests that the technique can be feasibly performed. However, with so many subxiphoid papers coming from only a few centers, it is open to question whether there was overlap of the patient numbers reported between the papers, and whether the fairly good results reported were only achievable by those few high-volume centers that particularly focused on developing this technique. Indeed, other VATS experts have already questioned the reproducibility of such results by the 'average' thoracic surgeon (16,17). Second, with only a few very limited comparative studies available, there is actually insufficient volume of evidence to convincingly support superiority (or even non-inferiority) of the subxiphoid approach over other approaches.

It is appropriate at this time to mention the work of Dr. João Carlos Das-Neves-Pereira's team. Using a bespoke peri-operative regime that includes a novel topical analgesic solution, dietary control, massage, aromatherapy, and other simple techniques, this team was able to achieve oral feeding and full ambulation within the first hour in over 90% of patients (18). Remarkably, these results were attained in patients who received lobectomy exclusively via an open incision and with full general anesthesia. Such recovery is at least as good as anything reported after any minimally invasive approach. This would cast doubt on whether it is reasonable to attribute any 'advantages' solely to the use of subxiphoid VATS—or any other approach for that matter.

The news is not all bad for proponents of subxiphoid VATS. There is similarly little evidence to support the criticisms of opponents of the technique (16). Their concerns about safety and of inadequacy of resection (including lymph node dissection) have thus far not been confirmed. It is also too early to tell if this is a result of most of the data coming from leading specialist centers only, too little overall data accumulated thus far, or bias against submitting/publishing negative results.

It is customary in such situations to suggest that "future randomized studies are needed". However, what would this really achieve? In the history of VATS itself, only a few such randomized trials have ever been completed (19,20), and their impact has been limited due to misjudged inferences being drawn or their confirming only what surgeons already knew. That has not stopped VATS becoming established in clinical practice today. It has been argued that randomized trials to compare minimally invasive thoracic surgical approaches are not feasible, expensive, and have little to no impact on actual clinical practices (21). Clearly, more clinical evidence on subxiphoid VATS is required to define its place in thoracic surgery—although randomized trials may not be the panacea many think they are.

Are we forgetting to care about the evidence?

However, it is perhaps of even greater importance to appreciate another more worrying trend. That is that clinical evidence itself seems to be increasingly ignored by many thoracic surgeons today. The fever-pitch fervour for Uniportal and now perhaps subxiphoid VATS appears to continue in spite of the lack of good clinical evidence supporting claims of advantage (5,11).

Conventional VATS lobectomy was first described in the early 1990s, and yet it was not until the last 10 years or so that it became established as the preferred approach for early stage lung cancer management (2,5). Along the way, the pioneers of VATS overcame widespread initial scepticism by producing ever better quality of clinical evidence to validate their approach (5). Regrettably, it appears that this lesson is becoming forgotten. Many are rushing to embrace the 'next generation' VATS approaches today without responding to constructive criticism with good clinical research. Worryingly, proponents of the latest techniques have a tendency to portray potential advantages as actual advantages (22). Many unsuspecting followers then mistakenly believe them to be proven advantages despite the lack of good comparative studies to show this. In this way, 'fake news' is born about how 'good' a new technique is.

The dangers of falling for such news that is 'too good to be true' have been witnessed in cardiothoracic surgery before. In the 1990s, reduction left ventriculoplasty (the 'Batista operation') received international attention as an exciting new 'cure' for end-stage dilated cardiomyopathy (23). Many around the world (including this author as a young surgeon) were caught up by the hype and rushed to learn about this fantastic new technique that promised to offer so much to patients (24), until later studies confirmed that the procedure was associated with high early and late failure rates (25). In more recent times, reports of using a patients' own stem cells to grow trachea transplants on biological and synthetic scaffolds received global attention (26). This 'breakthrough' was feted and widely hailed when reported at surgical meetings around the world. The hype reached a crescendo amongst 'fans' of the approach, before the scandalous—and sadly terrible—truth was finally revealed (27). The authors by no means suggest that subxiphoid VATS would lead to such unpleasant outcomes! However, the message is that surgeons can easily get caught up by the latest 'fashionable' techniques, and sometimes become too mesmerized to evaluate them objectively.

Part of the reason that surgeons fall for the alluring siren call of a new surgical technique is that its advocates are often very prolific in their speech-giving and article-writing (28). The exposure that a new technique receives at international meetings and in the pages of journals often misleads surgeons into thinking that 'everyone else is doing it' and hence 'so should I'. In reality, as shown above, many if not most of the reports come from just a few specialist centers. The average surgeon may not appreciate that a technique is 'safe and feasible' only in the expert hands at such centers, and may mistake potential benefits for proven ones as said above. If the average surgeon then proceeds to try such a technique because of an "if they can do it, why can't I" attitude, it is the patient who may be put at risk. This is when hype can lead to harm.

The authors wish to emphasize that the intent of this article is not to discourage all surgeons from exploring new surgical techniques—including subxiphoid VATS. On the contrary, the need for more clinical evidence requires that pioneers must first boldly innovate with their operations (28). The authors suggest that perhaps 5% of the surgical community are true pioneers, with innovative ideas and the proven operative and research skills needed to explore new ways to advance patient care. We believe such pioneers with good track records should be applauded for their pathfinding efforts and amply supported with research funding. But we also appreciate another 5% of the surgical community who are inevitably conservative sceptics, whose voices of caution should be duly respected and not casually dismissed by the pioneers. Our concern is rather with the remaining 90% of surgeons. This majority of surgeons need to remember that the surgeon's first obligation is to offer the safest, evidence-proven practices for their patients at all times. Recognizing whether you yourself are a true pioneer or a lemming-like follower of fashions is a keen test of insight versus ego, but nonetheless a vital step whenever a surgeon contemplates pursuing any new surgical technique.

Surgery as a drug

Perhaps the problem with new operative techniques exposes an inherent flaw in how surgery is governed.

In medicine, when a new pharmaceutical drug is developed, it must first undergo three phases of clinical trials to determine: the safety and dose-ranging; the biological activity versus side-effects profile; and the clinical effectiveness compared to current 'gold standard' therapy, respectively (29). At every step, the trials are governed by Institutional Review Boards (IRB) to ensure safety and ethical practice at the centers where they are conducted. Following trials, governmental regulatory bodies scrutinize all aspects of the evidence before allowing the drug to be made available for public consumption. A classic example is the cancer immunotherapy drug pembrolizumab (30). This was invented in 2006. Phase I trials were conducted in 2011. Results were first published in the *New England Journal of Medicine* in 2013 (28). It was only after that that the US Food and Drug Administration (FDA) provisionally approved pembrolizumab under the FDA Fast Track Development Program. In 2015, the FDA approved pembrolizumab for treating metastatic lung cancer patients in whom other chemotherapeutic agents have failed (30). Finally, in 2017, it was approved for use in any unresectable tumor with DNA mismatch repair deficiencies or a microsatellite instability-high state, with no limitation on the site of the cancer or the kind of tissue in which it originated. This entire process took over 10 years to progress from bench to bedside, reflecting the care with which a new therapy was handled to ensure patient safety and well-being.

In contrast, any new surgical approach receives no such rigorous oversight. The first operations using the approach and any prospective study may undergo IRB assessment, but generally any new idea can be tried by a surgeon almost immediately. There is today little to stop a surgeon watching a video of a subxiphoid VATS operation on the Internet, and then deciding to try it out the next day. If a surgeon decides to learn a new technique, there is often no certified course to teach it, no defined benchmarks to demonstrate he/she has attained a 'required level of competence', no process of accreditation to show that the institute's program has reached recognized safety standards, and very little government regulatory oversight in most countries. In other words, there is relatively little to protect the patient from a surgeon's personal belief that a new-fangled technique is 'safe' and 'has advantages'. In the UK, the British National Formulary (BNF) operates a central body to which all adverse reactions from pharmaceutical drugs in the country must be reported. There is no equivalent national agency to which adverse events from surgery need to be similarly reported.

As surgeons, we must ask ourselves why each new surgical technique in this day and age is not subject to the same scrutiny as each new drug. The potential for harm with a major thoracic procedure is certainly no less than with a pharmaceutical agent, and yet the difference in terms of governance can be very great. What harm could be caused—and what harm may be avoided—if the subxiphoid (or any other) approach was required to undergo thorough trials before being made generally available to the public?

Conclusions

In conclusion, the authors reiterate that it is not our intent to dissuade readers from practicing the subxiphoid VATS approach. Indeed, it is important for pioneer surgeons to constantly seek ways to improve their practice, and each new idea has the potential to bring great rewards for patients. Both authors themselves are also exploring the subxiphoid approach.

The key message is rather that if any surgeons do decide to explore subxiphoid VATS, they must be under no illusions about what that decision is based on. It is not a decision based on the subxiphoid approach being irrefutably 'safe and feasible', because most case series data come from only a handful of very specialized centers. It is not a decision based on the so-called 'advantages' of the approach, because any such 'advantages' are—at the time of this writing—only theoretical ones, and have not yet been validated by a body of robust clinical evidence. Whether such potential advantages may outweigh the potential disadvantages remains to be determined by future studies. Until then, surgeons should be careful not to tell patients that a subxiphoid strategy is being used because it is necessarily 'better' surgery.

If a surgeon proceeds with subxiphoid VATS in the spirit of a pioneer, it is still prudent to view it as a new technique that requires more clinical data to define its proper place in thoracic practice. With this exploratory mindset, it is advisable to consider framing one's early experience as a clinical trial with IRB oversight. This would provide some degree of regulatory protection for surgeon and patient, reduce the chance of the surgeon 'over promising, under delivering', and increase the likelihood that the experience may get properly collected and shared with the thoracic surgical community. That experience may (or may not) one day provide the reasons for why one should perform subxiphoid VATS.

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Footnote

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Anesthesia and enhanced recovery in subxiphoid video-assisted thoracoscopic surgery

Zhigang Chen[1#], Jason M. Ali[2#], Huan Xu[1], Lei Jiang[1], Giuseppe Aresu[2]

[1]Department of Thoracic Surgery and Anaesthesia, Shanghai Pulmonary Hospital, Tongji University, Shanghai 200433, China; [2]Thoracic Surgery, Royal Papworth Hospital NHS Foundation Trust, Papworth Everard, Cambridge, UK

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[#]These authors contributed equally to the work.

Correspondence to: Lei Jiang, MD. Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University, Shanghai 200433, China. Email: jiangleiem@aliyun.com.

Abstract: Subxiphoid video-assisted thoracoscopic surgery (VATS) is a surgical approach in minimally invasive thoracic surgery that aims to aid enhanced recovery by reducing postoperative pain by avoiding instrumentation of the intercostal spaces. Access through a subxiphoid port presents challenges for both the surgeon and anaesthetist. Particularly for left sided procedures, the heart can be compressed resulting in arrhythmia and haemodynamic compromise. The anaesthetic team play an important role in ensuring the success of subxiphoid VATS procedures. The key is continuous and comprehensive monitoring for circulatory disturbance and arrhythmia intraoperatively. Should arrhythmia develop it is important that it is managed rapidly and effectively in such a manner to minimize haemodynamic disturbance. In this article, important considerations for anaesthesia in subxiphoid VATS procedures is presented and solutions presented.

Keywords: Anaesthesia; subxiphoid; video-assisted thoracoscopic surgery (VATS); subxiphoid VATS (SVATS); enhanced recovery

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Anaesthesia and enhanced recovery in subxiphoid video-assisted thoracoscopic surgery (VATS)

Thoracic surgery is evolving. A large thoracotomy is no longer the standard surgical access to the pleural cavity. VATS has become the norm and with it, improved patient outcomes and faster return to normal activity (1-3). However, VATS surgery is still associated with significant pain, and a risk of developing chronic pain due to instrumentation of the intercostal space. In an attempt to further improve outcomes in terms of pain and recovery from thoracic surgery a more recent development has been the use of the subxiphoid approach. In this approach, a vertical incision is made in the subxiphoid space and the pleural cavity is entered at this level (*Figure 1*). This approach then avoids any instrumentation of the intercostal spaces avoiding the potential for nerve compression and injury (4). To date, there has been one randomised controlled trial comparing subxiphoid VATS (SVATS) to standard VATS—in patients undergoing bullectomy and pleurectomy. They observed a significant reduction on postoperative pain in the SVATs group which was associated with earlier mobilisation and reduced risk of complication (5). The SVATS approach has become increasingly popular, and there are reports of a wide range of operations being performed from anatomical segmentectomies to pneumonectomies (6-15).

Thoracic surgery is usually performed in the context

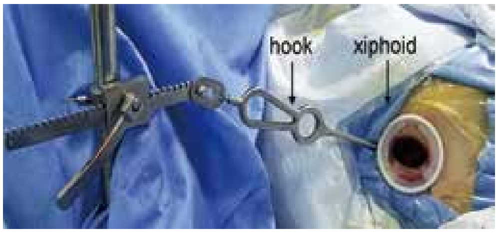

Figure 1 Subxiphoid access port for surgery with a patient in the right lateral decubitus position.

Table 1 Contraindications for subxiphoid VATS surgery

Absolute
Significant cardiomegaly
Severe arrhythmia
Impaired left ventricular function
Relative
Body mass index >30 kg/m^2
Age >80 years
More complex and prolonged surgery

VATS, video-assisted thoracoscopic surgery.

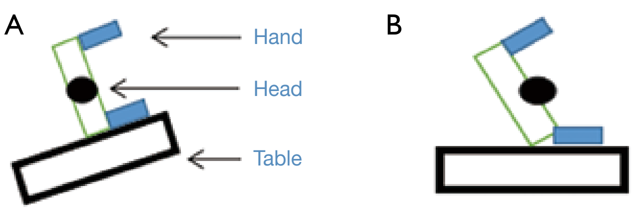

Figure 2 Optimal patient positioning with the patient tilted away from the lateral decubitus position which can be achieved by either tilting the operating table (A), or tilting the patient (B).

of well-developed enhanced recovery programs which further aids the benefit of the SVATS approach (16,17). However, SVATS presents certain perioperative challenges for the thoracic anaesthetic team. Particularly in left sided procedures, the patient's heart may need to be displaced which can cause haemodynamic compromise and dysrhythmia.

Preoperative preparation

As for all surgical patients, pre-operative assessment is an important stage in preparation for surgery. Patients should be assessed by experienced thoracic anaesthetists with focus on documenting past medical history and performing physical examination. Basic laboratory investigations and pulmonary function tests are performed to ensure operability (18).

In the context of SVATS, the anaesthetic team should ensure additional attention is placed on assessing cardiovascular function. We would advocate that patients should have an electrocardiogram performed to assess for any dysrhythmia, and if there is any concern over cardiovascular function, echocardiography and exercise testing should be considered. In patients with compromised cardiovascular function, the operative approach should be reconsidered to minimize the risk to the patient (*Table 1*).

Intraoperative anaesthesia

Anaesthesia

The choice between total intravenous anaesthesia or combined anaesthesia should be determined by the preference and experience of the anaesthetic team. Anaesthesia should be induced, and patients intubated with a double-lumen endotracheal tube. The maintenance of sedation, analgesia and muscle relaxation during the surgery should the same as for standard VATS procedures.

Patient positioning

There are two commonly employed positions on the operating table for patients undergoing SVATS. To have adequate exposure of the subxiphoid region the patient needs to be tilted away from the lateral decubitus position. This can be achieved either by adjusting the angle of the operating table with the patient in the lateral decubitus position (*Figure 2A*) or positioning the patient tilted on the horizontal operating table (*Figure 2B*). It is important to pay attention during positioning of the patient to prevent injury to the brachial plexus and cervical spine—by preventing excessive head extension and/or rotation by using appropriate support devices.

Intraoperative monitoring

Standard monitoring should be performed including electrocardiogram, oxygen saturations, end-tidal CO_2 and central temperature. For SVATS, we would advocate insertion of an arterial line and, especially in case of left sided procedures, central venous line in order that arterial blood pressure and central venous pressure can be monitored during the procedure, and blood gas analysis can be performed. These additional measures are employed to allow monitoring of the potential haemodynamic instability that can occur (19).

Intraoperative fluid management

Patients should receive intravenous fluid throughout the procedure, however they should be administered conservatively. In SVATS, occasionally there may be greater traction and compression of the lung parenchyma due to the challenging angles sometimes required to perform the surgery, which can lead to higher risk of lung injury and postoperative pulmonary oedema. The fluid strategy employed should also consider the duration of pre-operative dehydration the patient has experienced and be titrated to intraoperative cardiovascular monitoring and operative blood losses.

Ventilatory settings

A protective ventilation strategy should be utilized—with the aim of minimizing tidal volume (tidal volume of 6 mL/kg) with a low positive pressure (positive end expiratory pressure 5–10 cmH_2O) (20). The benefit of this strategy is not only to minimize the risk of lung injury, but also there is a reduced oscillation of the mediastinum during single-lung mechanical ventilation. This aids surgical access by providing a stable and optimal space for the procedure which reduces the pressure of the surgical instruments on the heart.

Perioperative complications and their management

Arrhythmia

Due to the hearts position in relation to the subxiphoid access, arrhythmia is a frequent occurrence in SVATS—particularly in left sided procedures. The various surgical instruments are designed with angles to minimize cardiac interference, but some compression of the heart is inevitable and can result in a range of arrhythmias. The majority of encountered arrhythmias recover spontaneously and rapidly following temporary suspension of the surgery. Due to the location of the heart, the arrhythmias experienced in left sided procedures tend to be more severe and may result in hypotension.

A range of arrhythmias are encountered. The most benign arrhythmias experienced are single atrial (*Figure 3A*) or ventricular (*Figure 3B*) ectopic beats. Occasionally, ventricular ectopic beats are followed by an escape rhythm and a more sustained arrhythmia (for example, *Figure 3C,D*). It is also possible to observe a mixture of atrial and ventricular ectopics (*Figure 3E*), and occasionally patients will go into atrial fibrillation which can lead to hypotension (*Figure 3F*). It has also been observed for patients to develop ventricular tachycardia (*Figure 3G*).

The aim intraoperatively is to prevent haemodynamic compromise and/or progression of any arrhythmia experienced—aiming to reduce the frequency of ectopy and treat haemodynamic compromise experienced as a result of tachy/brady arrhythmias. The majority of arrhythmias experienced are easily reversed by pausing the surgery. Occasionally, it may be necessary to administer anti-arrhythmic drug treatment, although this does not need to be continued following the surgery. It may also be necessary to cardiovert a patient out of a rhythm such as atrial fibrillation—although this can be performed at the end of surgery with the patient supine unless there is an urgent need to treat the arrhythmia. If the patient becomes hypotensive then more aggressive management may be required and the surgery should be paused to allow for recovery and/or treatment to be administered—as this will then reduce the compression on the heart that likely is precipitating the arrhythmia. If the patient remains hypotensive then fluid resuscitation may be required, guided by the central venous pressure and the next step would be to consider introduction of vasoactive drug therapy. At this point, it would be advisable to convert from SVATS to a standard approach in order to safely complete the surgery.

Continuous monitoring of arterial blood pressure and electrocardiography is essential during SVATS in order that the anaesthetic team can remain vigilant to diagnose and respond rapidly to any arrhythmia and/or haemodynamic compromise that develops during the course of the procedure.

Hypoxemia

Similar to the situation in standard VATS, desaturation is a common problem faced by patients on single lung ventilation. The commonest problem is malposition of the double lumen tube due to migration. Other problems include ventilation/perfusion mismatch due to single lung

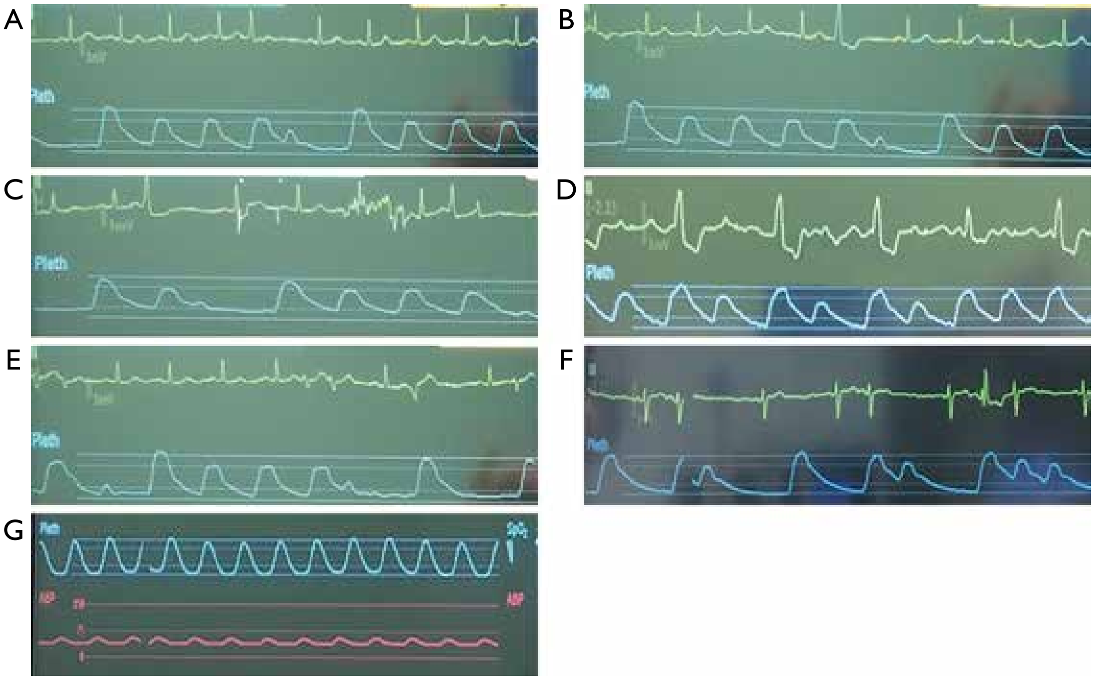

Figure 3 Example arrhythmias experienced during subxiphoid VATS procedures. (A) Atrial ectopy, (B) ventricular ectopy, (C,D) ventricular ectopy leading to escape rhythms, (E) mixture of atrial and ventricular ectopy, (F) atrial fibrillation and (G) ventricular tachycardia. VATS, video-assisted thoracoscopic surgery.

Table 2 Management of patients desaturating during subxiphoid VATS surgery

Gradual desaturation
Confirm the position of DLT is correct with fiber bronchoscopy
Recruitment maneuver of the ventilated lung
Increase FiO_2 to 1.0
Increase blood pressure if it too low
Apply 5 cmH_2O PEEP
CPAP to the nonventilated lung
Acute desaturation
Two lung ventilation immediately and then identify the reason for hypoxemia

VATS, video-assisted thoracoscopic surgery; DLT, double-lumen tube; PEEP, positive end-expiratory pressure ventilation; CPAP, continuous positive airway pressure.

ventilation and the lateral decubitus position and underlying pulmonary disease in the ventilated lung. A series of steps is recommended when facing desaturation during SVATS procedures (*Table 2*).

Postoperative extubation and analgesia

At the end of the surgery, two-lung ventilation is restored, and an airway pressure of 35 cmH_2O is applied for 10 seconds as a lung recruitment manoeuvre. If muscle relaxant has been used and remains active, an anticholinesterase such as neostigmine can be administered as reversal. Once the patient regains consciousness and is able to maintain an airway, they can be extubated and transferred to the recovery room and eventually discharged to the ward.

Although the aim of SVATS is to minimize the postoperative pain incited, it is essential that pain management is optimized as after all surgery to observe the maximal benefit and facilitate enhanced recovery. A range of approaches is adopted but usually includes combination of intravenous analgesia and regional nerve blocks, for example thoracic epidural or more commonly, paravertebral infusions (21,22). Adequate antiemetic should be prescribed in order to minimize the complications associated with opiate analgesia. For patients with a history of vomiting or vertigo, the preventive use of dexamethasone and reducing intraoperative related drugs can be advantageous in preventing vomiting and nausea.

Table 3 Example postoperative analgesia protocol to facilitate enhanced recovery following subxiphoid VATS procedures

Day 0 in recovery
Flurbiprofen axetil 50 mg IV after arrival in recovery
Start IV PCA: sufentanil 50–100 μg + flurbiprofen axetil 100 mg + tropisetron
If patients remain in pain, give bolus of IV sufentanil 5–10 μg but observe for respiratory depression
Reduce or avoid flurbiprofen axetil in patients who have hypertension
Day 0 HDU
Continue PCA
IV metoclopramide 5–10 mg if nausea and vomiting
If severe nausea or vomiting then convert to transdermal fentanyl patch
Day 1 ward
Continue PCA
IV metoclopramide 5–10 mg if nausea and vomiting
Day 2 ward
Step down to oral analgesia if tolerated: oxycodone hydrochloride 5 mg and acetaminophen 325 mg (Tylox) QDS
Day 3 ward
Continue Tylox QDS
Patient remains on this post-discharge
If ongoing pain, reviewed by anaesthetic team for escalation of therapy

VATS, video-assisted thoracoscopic surgery; PCA, patient controlled analgesia; HDU, high dependency unit; QDS, quaque die.

An example post-operative analgesia protocol that is utilized in Shanghai Pulmonary Hospital, China, is presented in *Table 3*. It has been designed to reduce the rate of complications and accelerate mobilization of the patient following surgery.

Summary

Subxiphoid VATS is a recent development in thoracic surgery that aims to aid enhanced recovery by reducing postoperative pain. The anaesthetic team play an important role in ensuring the success of these surgeries. The key is continuous and comprehensive monitoring for circulatory disturbance intraoperatively. Should arrhythmia develop it is important that it is managed rapidly and effectively in such a manner to minimize haemodynamic disturbance.

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Footnote

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The role of anaesthesia and enhanced recovery in the future of thoracic surgery

Jacobo Moreno Garijo[1], Andrew Roscoe[2]

[1]Department of Anesthesia & Pain Management, Toronto General Hospital, Toronto, Canada; [2]Department of Anaesthesia, Royal Papworth Hospital, Cambridge, UK

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Correspondence to: Dr Andrew Roscoe. Department of Anaesthesia, Royal Papworth Hospital, Cambridge CB23 3RE, UK. Email: a.roscoe@nhs.net.

Abstract: The development of enhanced recovery after surgery (ERAS) for thoracic surgery has created new challenges for the anaesthetist. The preoperative phase is critical not only to identify high-risk patients, but to optimise organ function. An anaesthetic is required which adequately suppresses the surgical stress response, the mainstay of ERAS, but also promotes rapid recovery with minimal side effects. Locoregional anaesthesia is the key. The use of a non-intubated, spontaneous breathing technique may confer some benefits. Effective analgesia is essential to allow early postoperative mobilisation and to reduce complications.

Keywords: Anaesthesia; enhanced recovery; lung resection; sub-xiphoid; video-assisted thoracoscopic surgical (VATS)

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Introduction

The importance of early ambulation after surgery to reduce complications was highlighted as far back as the 1940s (1,2). Enhanced recovery after surgery (ERAS) was developed in the 1990s to decrease postoperative morbidity by suppressing the stress response to surgery, consequently leading to improved patient outcome, reduced hospital length of stay and potential cost savings (3-5).

The main components of ERAS in thoracic surgery include preoperative optimisation, minimally invasive video-assisted thoracoscopic surgical (VATS) technique, standardised anaesthetic approach with multimodal analgesia, and early postoperative mobilisation with physiotherapy (6,7). An effective ERAS programme requires a multidisciplinary approach and the role of the anaesthetist is paramount throughout the perioperative period (8,9). The ultimate goal is to achieve day case surgery for lung resections (10).

Preoperative assessment

The main goal of the preoperative phase is the identification of high-risk patients, and optimisation of risk factors and organ function prior to surgery. In thoracic surgery, the preoperative efforts are specifically directed towards cessation of smoking, identifying and treating malnutrition, improving physical activity, and augmenting lung function. Physical inactivity, poor lung function and smoking are all important risk factors for complications after thoracic surgery (11).

Patient selection

Accurate risk prediction based operative mortality, perioperative adverse events and postoperative dyspnea, is recommended by the Society for Cardiothoracic Surgery in Great Britain & Ireland (12). Significant predictors of prolonged hospital length of stay after lung resection include advanced age, performance status, insulin-dependent diabetes mellitus, renal dysfunction, cigarette smoking and percentage predicted forced expiratory volume in one second (FEV_1) (11). Cardiovascular risk can be assessed using the American College of Cardiology/American Heart Association 2014 guidelines on perioperative cardiovascular evaluation for noncardiac surgery (13).

Optimisation

Smoking cessation prior to surgery is paramount, as continued smoking is associated with an increased risk of postoperative complications such as pneumonia, myocardial infarction and stroke, and a higher 30-day mortality (14).

The use of pulmonary rehabilitation, a core component of the management of individuals with chronic respiratory disease, can improve lung mechanics and exercise capacity prior to lung resection surgery (15). This may translate into favourable clinical outcomes, with increased six-minute walking test (6MWT) distance and force-generating capacity of skeletal muscle. Exercise training optimises functional state by increasing FEV_1, decreasing symptoms and improving quality of life, leading to a reduction in postoperative morbidity and mortality (15-17).

Malnutrition, common in oncologic patients, is associated with muscle weakness, impaired wound healing and immune dysfunction, resulting in delayed recovery and prolonged length of stay. Preoperative screening for malnutrition allows appropriate treatment for 14 days prior to surgery, if required (18,19). Preoperative fasting of liquids should be limited, and the administration of carbohydrate drink two hours before surgery is recommended (19,20).

Patient education and counseling is a vital component of the preoperative period. Management of patient expectation and addressing any issues prior to hospital admission can improve psychological wellbeing, reduce postoperative pain and assist in fast-tracking (21,22).

Intraoperative management

The intraoperative anaesthetic management is comprised of several key components, but is influenced by the surgical approach. The advent of uniportal VATS technique may confer some benefits in terms of reduced postoperative pain, and the subxiphoid approach allows bilateral procedures to be performed through the same surgical incision (23-25).

Anaesthetic agents

The choice of anaesthetic drugs remains contentious. During one-lung ventilation (OLV), inhalational anaesthetic agents (IAA) have been shown to stabilise the endothelial glycocalyx and hence reduce the local inflammatory response and the risk of acute lung injury (ALI) (26). However, IAA are not without side-effects: they can increase the incidence of postoperative nausea and vomiting (PONV), compared to propofol total intravenous anaesthesia (TIVA) (27), and their suppression of natural killer (NK) cells may increase the risk of metastasis or cancer recurrence (28,29). At present, with the conflicting evidence in thoracic anaesthesia (30), there does not appear to be any benefit of TIVA over IAA (31,32).

Neuromuscular blockade (NMB) is typically used to facilitate endotracheal intubation. Prevention of residual paralysis at the end of the procedure is essential to promote fast-tracking. Neuromuscular monitoring is recommended and NMB reversal is required when train-of-four (TOF) ratio is less than 0.9, with either an acetylcholinesterase inhibitor or sugammadex (33). Aggressive prevention of PONV, using a multimodal approach, is recommended (34).

Analgesia

Multimodal perioperative analgesia is the mainstay of ERAS. A combination of paracetamol, non-steroidal anti-inflammatory drugs (NSAIDs), opioids, local anaesthetic (LA) agents, NMDA antagonists and gabapentinoids should all be considered (7). However, intraoperative opioids should be used with caution. Expression of μ-opioid receptors is increased in human lung cancer, and in animal models' opioids have been shown to stimulate cancer progression and metastasis, leading to reduced survival (35-38). Opioid-sparing or even opioid-free anaesthesia is feasible and may also help to reduce early postoperative opiate-related side effects, such as nausea & vomiting, hyperalgesia and acute tolerance (39). Although ketamine has the advantage of attenuating opioid-related hyperalgesia (40), its deleterious effects include depression of NK cell function, potentially promoting cancer recurrence (41).

The use of locoregional techniques is to be encouraged. As well as attenuating the surgical stress response, a fundamental element of ERAS, they have been shown to reduce postoperative morbidity (42). In addition to their anti-inflammatory action, amide LA drugs also promote NK cell function, with the potential to inhibit the generation of metastases (43-45). Thoracic epidural analgesia (TEA) has traditionally been viewed as the gold standard, but paravertebral block (PVB) has been shown to provide equivalent analgesia, with fewer side effects (46). The development of newer plane blocks (serratus anterior plane block and erector spinae plane block) may prove to be equally efficacious alternatives (47,48). For the sub-xiphoid approach, a subcostal transversus abdominis plane block may provide adequate analgesia (49).

Ventilation

Lung protective strategies are important to reduce ALI and postoperative pulmonary complications. During OLV, best practice recommendations include a reduced tidal volume of 4–6 mL/kg; positive end-expiratory pressure (PEEP) titrated to individual lung compliance; intermittent recruitment manoeuvres; regular bronchial toilet; and adjustment of respiratory rate to achieve an adequate minute ventilation, with permissive hypercapnia tolerated (8,26,50). The use of pressure-controlled ventilation may confer some benefits over volume-controlled ventilation (51,52).

Alongside the evolution of minimally invasive surgery, anaesthesia has developed non-intubated techniques to reduce the adverse effects of tracheal intubation. Spontaneous breathing, with a surgically-induced pneumothorax, decreases lung inflammation caused by positive pressure ventilation, reduces postoperative pulmonary complications, avoids the risk of residual NMB, and expedites recovery (53-55). Such procedures can be carried out in awake patients under epidural anaesthesia (56).

Fluid balance

The goal of perioperative fluid management is to achieve euvolaemia, maintaining organ perfusion, but avoiding fluid excess and accumulation of extravascular lung water. Intraoperative crystalloid administration should be limited and intravenous colloid boluses used to replace significant blood loss. Goal-directed fluid therapy using minimally invasive monitors may be beneficial. Total fluid balance should not exceed 20 mL/kg in the initial postoperative 24 hours (8,57,58).

Temperature

Maintenance of normothermia is essential. Inadvertent perioperative hypothermia, defined as core temperature less than 36 ℃, is associated with increased intraoperative blood loss and transfusion requirements; reduced metabolism of anaesthetic drugs with subsequent delayed recovery; increased postoperative adverse myocardial events; poor wound healing with a higher incidence of surgical site infection; and depression of immune function, which may increase the risk of cancer recurrence (41,59-61). Monitoring core body temperature is now standard-of-care management, and the use of forced-air warming devices and warmed intravenous fluids is recommended to maintain normothermia (61).

Postoperative care

Rapid recovery is promoted by early mobilisation, effective analgesia, pulmonary rehabilitation and appropriate chest drain management. Patients should be mobilised as soon as possible following surgery and supervised ambulation is encouraged. Regular chest physiotherapy improves ventilation and aids clearance of secretions. Normal diet can be recommenced in a timely fashion (62-64).

Post-thoracotomy pain may contribute to atelectasis, leading to hypoxemia, pulmonary infection, and permanent alveolar damage. Continuation of the intraoperative multimodal analgesic approach to provide effective postoperative pain relief can reduce complications (65). With the introduction of liposomal bupivacaine, single-shot LA techniques can now provide analgesia for up to 96 hours (66,67).

In the postoperative period, the presence of chest drains is a significant source of pain and can impede patient mobilisation (68). Early chest drain removal is feasible and is associated with reduced pain, improved FEV_1, and shorter hospital length of stay (68-70).

Conclusions

The growth of ERAS in thoracic surgery has created new demands on the thoracic anaesthetist. Patient selection is key to identify those suitable for fast-tracking and preoperative optimisation is essential. The challenge is to provide an anaesthetic which both suppresses the stress response to surgery, the mainstay of ERAS, and utilises short-acting agents to enhance rapid recovery, whilst avoiding drugs which may promote cancer recurrence. Effective locoregional techniques appear to offer the optimal solution. Minimally invasive surgical methods in conjunction with less invasive anaesthetic approaches, such as the non-intubated spontaneous breathing technique, all facilitate an expeditious recovery for the patient (71).

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Footnote

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

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Opiate free anaesthesia and future of thoracic surgery anaesthesia

Chinmay Patvardhan, Mario Ferrante

Department of Anaesthesia, Royal Papworth Hospital, Cambridge, UK

Correspondence to: Chinmay Patvardhan. Royal Papworth Hospital, UK. Email: chinmay24@me.com.

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Introduction

History of development of anaesthesia as a specialty is intricately linked with the use of opiates. The word Anaesthesia derives from the Greek word "ΑΝΑΙΣΘΗΣΙΑ" anaisthēsia, its meaning is: an 'without', aisthēsis 'sensation', but if we look back, we find that anaesthesia has older origins. It is well known that Sumerian in 4000 BCE already used Opium for pain relief. However, it was only in 1805 that pharmacist Friedrich Sertürner was able to isolate a new substance from opium, which he later named "morphium" after Morpheus, the God of dreams. The history of synthetic opioids begins after 1950, with the development of the 'modern' anaesthetic techniques. In 1962 the use of Fentanyl, the first synthetic opioid for use in anaesthesia, was described in Belgium. Since then the use of synthetic opiates in modern anaesthetic practice has expanded greatly and opiates have become the mainstay of providing effective analgesia after surgical procedures. High doses of opiates have been traditionally been used in cardio-thoracic anaesthesia, which exploit the sedo-analgesic property of opiates combined with the relative cardio stability that follows from the high dosage of opiates.

However, opiates do not come without side effects. During the perioperative period, nausea and vomiting, dizziness, constipation, respiratory depression, puritus and delirium have a significant detrimental effect on recovery after surgery, especially among the elderly.

In the past decade, opiates have also been increasingly prescribed for management of chronic pain. Millions of these medicines are prescribed in western countries. This has resulted in an opiate prescription epidemic, which has resulted in over 200,000 people dying in the United States from Opiate Overdose between 1999–2016 (1).

There has been increasing awareness of problems associated with opiate overuse and misuse in the recent days. We know from medical literature that risk of opiate addiction is highest amongst people who have been on prescription opiate drugs. The risk of accidental overdose, death, addiction is higher among patients who have been prescribed opiates for a longer time. Perioperative prescription of opiates is often the first exposure of many of these patients to opiates which ultimately results in addiction (2).

As a result, there has been a re- emergence of multi-modal analgesic strategies using pharmacology and the knowledge gained from better understanding of neuropathic pain and pain pathways (2). Drugs like Gabapentin and pregabalin, or antidepressants like duloxetine are being increasingly prescribed for their opiate sparing and analgesic effect during and after surgery in combination with the traditional non opioid drugs like paracetamol/NSAIDS etc. Local anaesthetic medications like lignocaine is now being increasingly used as perioperative infusions with good effect. Clonidine and dexmedetomidine with their alpha agonistic effect on pain pathways have a relative opiate sparing effect. Anaesthetists are increasingly using these drugs in combination with nerve blocks, neuraxial blocks and wound infusion catheters in an attempt to reduce perioperative opiate use.

Problems with opiate analgesia

Opioid analgesia remains the corner stone of acute pain management in perioperative analgesic regimes. This is because of their high potency and efficacy. However as previously mentioned, they are not without their side effects. Opiate analgesia works through opioid receptors which are widely distributed through the body. Agonism at the μ receptors, which are widely distributed in the brain stem result in bradypnea, apnoea and reduction in minute ventilation. In perioperative setting, this effect is synergistic with benzodiazepines, and anaesthetic agents. This has a potential for causing serious respiratory depression leading to significant morbidity requiring prolonged mechanical ventilation and even mortality. This is particularly relevant in thoracic surgery, where an un intentional consequence of respiratory depression, from a well-intentioned prescription of perioperative opiates, can be disastrous.

This is because patients undergoing thoracic surgery/ lung resection, have a reduced functional residual capacity from the surgery and lung resection. They may have low FEV1, FVC or diffusion capacity and are prone to hypoxia. Any hypoventilation in perioperative period puts these patients at risk of developing hypercapnia, hypoxia and respiratory failure. This problem is also compounded by the narcotic and anti-tussive effect of opiates which depresses ciliary function causing sputum retention.

A more sinister effects of opiate analgesics which is not often appreciated is the immunosuppression and immunomodulation that occurs with administration of opiates (3). Natural killer (NK) cells are a subtype of innate Lymphocytes (also known as group I innate). These cells are responsible for eradication of tumour cells and virally infected cells in the body. They also secrete cytokines like interferon-gamma (IFNγ) and tumour necrosis factor (TNFα) which modulate functions of other immune cells and inflammation, which aids in eradication of tumour cells and viral infections. Commonly used opiates such as morphine, codeine, fentanyl have all shown immunosuppressive properties in both pre-clinical and clinical studies. They cause suppression of NK cell function resulting in reduced ability of the NK cell to eradicate malignant cells. They also suppress the cytotoxic ability of NK cells. Morphine administration in clinical studies has been shown to have accelerate progression of cancer and increased susceptibility to infections. Studies specifically looking at lung cancer have suggested a plausible hypothesis that opiate administration directly increases lung cancer progression through the Mu- opiate receptor up regulation (4). These studies noted that there is a 5–10-fold increase in Mu Opiate receptor expression on non-small cell lung cancer cell lines. they also noted that by knocking out the expression of the Mu receptor there was a significant decrease in invasiveness of the cancer and ability to metastasis (4).

Regional anaesthesia and thoracic surgery

Last decade has seen rapid increase in understanding how the neuro- inflammation and immune modulatory response of perioperative stress has an impact on oncological progression of cancers. We know that an effective inhibition of perioperative stress response has a beneficial effect on outcomes after major surgery. Regional anaesthesia i.e., neuraxial blocks (spinal, epidural or paravertebral) are effective in reducing the perioperative stress response. They also have beneficial effects in reducing blood loss, transfusion requirements, and provide superior analgesia. Therefore, it is not surprising that regional analgesia has been used extensively in thoracic surgery. As we begin to understand the effects of neuro-inflammation and immune modulation, evidence is beginning to emerge that the use of regional anaesthesia may have superior analgesic effects and may even have survival benefit in certain types of cancers (e.g., breast cancer). Local anaesthetic agents like lignocaine have also been shown to have anti-tumour activity. Regional anaesthetic techniques are popular in enhanced recovery programs as they allow for reduction in opiate requirement and general anaesthesia during surgery. Traditionally, thoracic epidural anaesthesia (TEA) has been the gold standard for provision of perioperative analgesia after thoracic surgery. This is because of its superior analgesia, which allows for the patient to cough, mobilise and rehabilitate effectively after a major thoracotomy. However, this is not without its problems. TEA can lead to incidents of significant hypotension, urinary retention and inadvertent administration of fluid, which can be detrimental to lung surgery patients. UK pneumonectomy outcome study (UKPOS) published in 2009 showed epidural analgesia to be an independent risk factor for development of major complication after pneumonectomy. They also paradoxically increase the length of stay by the fact that the patient remains connected to the epidural pump and therefore remain in the hospital. There is always the added serious risk of associated with insertion of an epidural catheter, namely, nerve damage and epidural hematoma. However, as epidurals have fallen out of favour in the U.K., paravertebral blocks combined with peripheral nerve blocks can provide equally effective analgesia. The newer truncal nerve blocks like PECS I &II, serratus plane block is increasingly being used in thoracic surgery with good effect. The popular appeal of these blocks is that it allows for the patient to be mobilised without being connected to a pump, and promotes faster rehabilitation, mobilisation and discharge from hospital.

The other factor that has promoted the popularity of nerve blocks in thoracic surgery is the increasing use of smaller incisions and newer techniques like sub xiphoid approach, uniporter video-assisted approach. These minimally invasive techniques described elsewhere in this book have revolutionised the perioperative conduct of thoracic anaesthesia. Smaller incisions mean lesser appetite among surgeons and anaesthetists for being 'heavy handed' with central neuraxial blocks.

This complex interplay of various push and pull factors, on top of increasing awareness of unintentional side effects of opiate analgesics in onco- surgery has led to a gradual evolution of anaesthetic techniques. In the forefront of this is Opioid Free Anaesthesia (OFA).

Opioid free anaesthesia and future of thoracic anaesthesia

Anaesthesia is a trial of hypnosis, analgesia and provision of muscle relaxation. Traditionally analgesia has always been used with strong synthetic opioid medications like fentanyl, alfentanil or remifentanil or natural opiates like morphine and its derivatives. Opioid free anaesthesia is a unique anaesthetic technique, which avoid all use of opioid medications during anaesthesia but instead utilises a combination alternative medication like α-1 agonists (i.e., clonidine or dexmedetomidine), local anaesthetic infusions (e.g., lignocaine), NMDA antagonists (e.g., ketamine, magnesium) to provide the analgesia and sympatholysis, while maintaining the quality of perioperative amnesia, hypnosis and muscle relaxation during surgery. The innovative idea behind this is that by avoiding opiates, this technique without compromising on the quality of anaesthesia, enhances the quality of recovery after anaesthesia by avoiding all the noxious side effects associated with opiates (5).

Another added benefit of using a combination of adjunctive medication is that it blocks the acute pain pathways at multiple levels, and in theory may beneficial in reducing chronic pain and hyperalgesia which is commonly associated with thoracic surgery.

Published evidence suggests OFA has been successfully used bariatric surgery, colorectal surgery, cholecystectomies, orthopaedic surgery and the experience of anaesthetists is rapidly increasing. However at present, there are currently no published papers trialling OFA in thoracic surgery.

Because of the unique anatomy of the lung and innervation of the chest wall, thoracic surgery pain lends itself well to nerve blockade with paravertebral or peripheral nerve plexus blocks (i.e., pectoral muscle plane block, serratus anterior plane block or intercostal nerve block). The nociceptive visceral aspect of the pain conducted through the Phrenic or Vagus nerve can be blocked during surgery with local anaesthetic without any detriment to respiratory function thereby reducing the 'referred' aspect of post thoracotomy pain.

Combining these 'nerve-blocks' along with an opioid free anaesthetic has the potential to significantly improve the quality of patient recovery and overall experience after minimally invasive thoracic surgery. Using an opioid free technique has the potential to virtually eliminate the noxious side effects of opioid medications, while continuing to provide high quality analgesia to patient. This allows for faster recovery from anaesthesia and shortening rehabilitation time. There is also a potential economic benefit—by reducing morbidity associated with opioid medication (i.e., respiratory depression, delirium, constipation, narcosis) OFA can reduce the length of stay in lung surgery patients. This technique can also virtually eliminate all the undesirable immunological and potential onco-proliferative side effects associate with perioperative opiate administration in lung cancer surgery.

However all this would have to be proven by a well conducted prospective randomised trial. But if the results from non-cardiac surgery are anything to go by, then we should be encouraged to trial OFA in thoracic surgery.

In our institution, we are currently trialling OFA for thoracic surgery in a safe and scientific fashion. Our initial results are encouraging, however we have not reached a critical mass to submit a peer review publication at the timing of writing this chapter. Our early informal experience at this stage suggests that the overall analgesia and patient experience is non-inferior to standard anaesthetic technique used in our institution. However, these initial results have not been scrutinised or published in a peer review journal yet.

Conclusions

The practice of opioid free anaesthesia shows the potential to innovate and transform the practice of thoracic anaesthesia and enhanced recovery programs after minimally invasive thoracic surgery. Although there are no proven clinical trials at this stage, our initial experience is promising. Future research would ultimately prove if the technique works and reveal the unknown—unknowns.

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Footnote

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Learning curve and subxiphoid lung resections most common technical issues

Luis Angel Hernandez-Arenas[1], William Guido[2], Lei Jiang[1]

[1]Department of Thoracic Surgery, Shanghai Pulmonary Hospital affiliated to Tongji University School of Medicine, Shanghai 200433, China; [2]Hospital Rafael Angel Calderon Guardia, San Jose, Costa Rica

Contributions: (I) Conception and design: LA Hernandez-Arenas; (II) Administrative support: W Guido; (III) Provision of study materials or patients: L Jiang; (IV) Collection and assembly of data: LA Hernandez-Arenas; (V) Data analysis and interpretation: L Jiang; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Lei Jiang. Department of Thoracic Surgery, Shanghai Pulmonary Hospital affiliated to Tongji University School of Medicine, Shanghai 200433, China. Email: leijiang2356@yahoo.com.

Background: Subxiphoid uniportal video-assisted thoracic surgery (SVATS) for major lung resections is a new approach. Clinical evidence is lacking. The aim of this article is to describe the learning curve of the 200 selected patients who underwent uniportal subxiphoid lobectomy or segmentectomy by subxiphoid midline incision, and with the lessons learned from this early experience in SVATS and from the experience with transthoracic uniportal VATS we sought to compile "tips and tricks" for managing the multiple intraoperative technical difficulties that can arise during the SVATS and help to set the recommendations for a SVATS program.

Methods: We describe the learning curve of the first 200 selected patients who underwent uniportal subxiphoid lobectomy or segmentectomy by subxiphoid midline incision From September 2014 with early-stage non-small cell lung carcinoma (NSCLC) and benign disease. We examine the rate of conversion and the operating time comparing group one (first 100 cases) with group two (subsequent 100 cases).

Results: Of the 200 consecutive selected cases (72 males, 128 females) with a mean age of 57.4±9 years, underwent either uniportal subxiphoid lobectomy or segmentectomy 136 were lobectomies and 64 were segmental resections The mean operating time was 170±45 mins; the average and after the case 86 the rate of the operating time appears to be similar. The conversion rate decrease from 13% in group one to 8% in group two.

Conclusions: There is a gradual reduction in the operating time and rate conversion with increasing experience. Lessons from our initial experience in the learning curve period in SVATS helps to create this trouble shooting guide that offers "tips and tricks" to both avoid and manage numerous intra-operative technical difficulties that commonly arise during the SVATS initial experience.

Keywords: VATS; subxiphoid; uniportal

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Introduction

The subxiphoid approach has been adopted during the last decades for thoracic and cardiovascular minor procedures such as thymectomies, pulmonary metastasectomies, pneumothorax or pericardial windows (1-3).

The first subxhipoid uniportal video-assisted thoracoscopic procedure for major lung resections was described in 2014 (4,5) and clinical evidence is lacking (6).

All data were collected prospectively from patient medical notes and computerized records. Consent forms were signed by all participating patients. This new procedure was approved by the hospital's Institutional

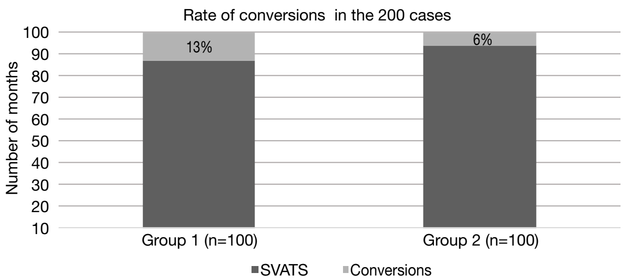
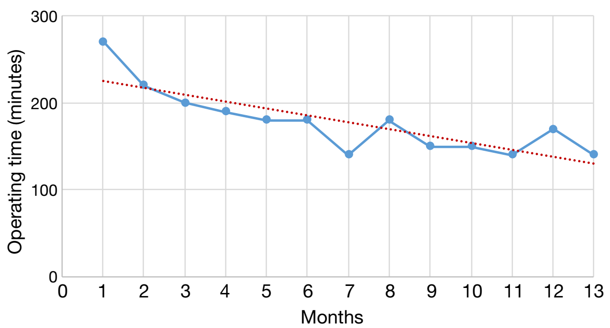


Figure 1 Conversion rate of the 200 SVATS cases. SVATS, subxiphoid uniportal video-assisted thoracic surgery.



Months	1	2	3	4	5	6	7	8	9	10	11	12	13
No. of cases	6	13	8	13	9	9	10	21	22	15	28	21	25
Operation time	270±60	220±36	200±42	190±36	180±42	180±23	140±48	180±54	150±24	150±42	140±32	170±60	140±31

Figure 2 Gradual reductions in the operating time with increasing experience.

Review Board. The subxiphoid uniportal video-assisted thoracic surgery (SVATS) program started in September 2014; approximately 450 patients underwent SVATS major lung resection in Shanghai Pulmonary Hospital, Shanghai, China. This included two different approaches: subcostal subxiphoid incision (7) and subxiphoid midline incision. We present the learning curve of the first 200 selected patients who underwent uniportal subxiphoid lobectomy or segmentectomy by subxiphoid midline incision.

With the lessons learned from this early experience in SVATS and from the experience with transthoracic uniportal VATS we sought to compile "tips and tricks" for managing the multiple intraoperative technical difficulties that can arise during the SVATS.

Length of the learning curve

The length of the learning curve has been suggested to consist of 50 VATS lobectomies for conventional and transthoracic uniportal VATS (8), but several factors influence the length of the learning curve; previous experience in VATS minor or major procedures and learning in a high volume training center.

The learning curve of the SVATS approach could be longer and more difficult in comparison with transthoracic uniportal VATS, because the view is caudal-cranial and anterior to posterior. From the subxiphoid incision to the hilum, it is in an oblique and longer distance so the instrument fighting problem during uniportal subxiphoid surgery will be challenging. For this reasons the surgeon who performs SVATS needs previous experience in uniportal VATS lobectomy and a skilled assistant.

Of the 200 consecutive selected cases (72 males, 128 females) with a mean age of 57.4±9 years, underwent either uniportal subxiphoid lobectomy or segmentectomy 136 were lobectomies and 64 were segmental resections. In *Figure 1*, the conversion rate of the group one (first 100 cases) and group two (subsequent 100 cases) are illustrated.

In *Figure 2* the gradual reduction in the operating time with increasing experience month by month is illustrated.

Recommendations for a SVATS lobectomy program

Before embarking in a SVATS program it is important to have previous experience in uniportal VATS lobectomy and a skilled assistant. Performing minor procedures like wedge resections and pneumothorax lung-repair is helpful as the surgeon will get familiar with the port placement, the anatomic variations and the caudal-cranial and anterior to posterior view. We recommend starting major lung resection on the right side and cases with complete fissure. The use of longer and sturdier VATS instruments makes easier to do lung grasping and sometimes curved-tip stapler technology to facilitate the passage around the structures.

Try to avoid obese patients, we consider a BMI >30 a contraindication for SVATS (*Table 1*).

Patient's selection

The inclusion criteria for operating on patients by SVATS in our Thoracic Unit includes patients with benign diseases and patients with lung cancer with T status of tumour <5 cm (T1, T2) N status for tumour N0, FEV1 and DLCO >40% postoperative predicted. The exclusion criteria for operating patients with subxiphoid approach includes: chest wall involvement, central masses, previous thoracic surgery,

Table 1 Initial recommendation for SVATS major lung resections

Previous experience in uniportal VATS
Skilled assistant
Perform minor procedures by SVATS
Right-sided cases
Complete fissures and upper lobes
Avoid obese patients and BMI >30
Use curve stapler technology or similar
Use longer and strider VATS instruments

SVATS, subxiphoid uniportal video-assisted thoracic surgery.

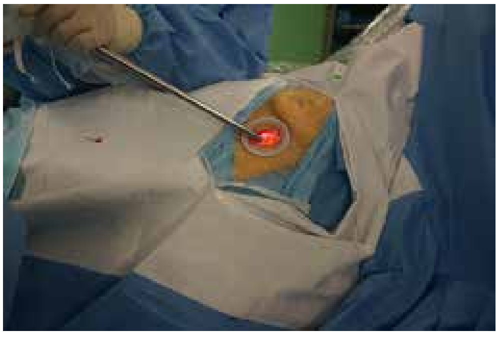


Figure 3 Patient positioned inclined at 60–70° allows better access and view of the anterior mediastinum, thus helping the assistant with optimal camera positioning.

adhesions, body mass index (BMI) >30, cardiomegaly and enlarged lymph nodes with N1 and N2 disease confirmed.

Troubleshooting guide

Patient position

The patient is put under general anesthesia with double lumen endotracheal intubation. The patient is positioned in a lateral position inclined at 60–70°. A surgeon and scrub nurse stand in front of the patient. The assistant stands at the back of the patient and the screen is placed at the head of the patient.

The lateral position of the patient inclined at 60–70° allows better access and view of the anterior mediastinum, thus helping the assistant with optimal camera positioning. Using a wound protector also enables effective camera and instrument insertion, without the need for a sternal lifter (*Figure 3*).

The operative field must be sterilized widely, to allow multiple port placements and conversion to thoracotomy in case of an emergency.

Figure 4 Pleura opened by finger dissection via the infra-sternal angle. The xiphoid process is exposed and detached from the rectus abdominis and resected (9).
Available online: http://www.asvide.com/articles/1035

Port placement

A 4 cm midline incision is made below the sterno-costal triangle, median subxiphoid incision is made if the infrasternal angle ≥70° or transverse incision is made if the infrasternal angle <70°. The rectus abdominis is divided. The xiphoid process is exposed and detached from the rectus abdominis and resected (*Figure 4*). The right or left pleura are opened by finger dissection via the infra-sternal angle above the level of the diaphragm and remove the pericardial fat tissue near and round the wound. One of the most common problems during dissection is the difficult passage of the staplers and longer instruments trough the incision. To avoid this is necessary to remove the surrounding pericardial adipose tissue at the beginning of the surgery (*Figures 5,6*).

Difficult body habitus

Obtaining Subxiphoid access can be difficult in patients with significant subcutaneous obesity or mediastinal adipose tissue. We consider a BMI >30 a contraindication to perform SVATS.

Surgeon-assistant

Is important the surgeon-assistant coordination for surgical movements to reach with the camera the desired areas. If

Figure 5 Wound protector enables effective camera and instrument insertion (10).
Available online: http://www.asvide.com/articles/1036

Figure 6 Removal of the surrounding pericardial adipose tissue at the beginning of the surgery (11).
Available online: http://www.asvide.com/articles/1037

Figure 7 Surgeon-assistant coordination for surgical movements. Median incision with camera placed on the caudal side of the incision with the assistant holding the camera at the back of the patient.

the incision is median the camera is placed in all cases on the caudal side of the incision. If the incision is transverse, the camera is placed on the inferior side of the incision, with the assistant holding the camera at the back of the patient. The longer and strider VATS instruments are placed from the cranial side of the incision if median and the superior side if transverse (*Figure 7*).

Laterality

This approach is more convenient and easier to perform right-sided procedures. The subxiphoid approach from the left side chest cavity is more challenging because the cardiac pulsation is transmitted to the VATS instruments and may cause intraoperative arrhythmia in some patients due to the compression of the heart by the insertion and manipulation of the instruments. In our experience 13% of the patients had intraoperative arrhythmia that lasted till the postoperative period. In some cases a self-limited hypotension event may occur during the operation secondary to heart compression, in these cases stop the procedure for some minutes. Try to avoid patients with cardiomegaly or previous arrhythmia.

Based in our initial experience with subxiphoid uniportal approach we founded that posterior segment (S3) and superior segment (S6) in the left side and basal-posterior segment (S10) in right and left side are not feasible by this approach.

Exposure and retraction

The access for the view of the posterior mediastinum is difficult, resulting in the need for the lung requiring more traction to assess the lesions in this area. The use of longer and sturdier VATS instruments makes it easier to carry out lung grasping, and sometimes the use of curved-tip stapler technology helps to facilitate passage around the structures. One limitation of the SVATS is the impossibility to palpate the lesions. The instruments we use to perform SVATS are self-made (*Figures 8,9*).

Bleedings

One of the limitations of the SVATS approach is the control of major bleeding. When an emergent conversion to open

Figure 8 Longer and sturdier VATS instruments. The instruments we use to perform SVATS are self-made. SVATS, subxiphoid uniportal video-assisted thoracic surgery.

Figure 9 Dissection of left anterior segmental bronchus, with longer and strider instruments and use of curve stapler technology (12). Available online: http://www.asvide.com/articles/1038

surgery is necessary, an extension of the subxiphoid incision is unlikely to be useful and an additional thoracotomy must be performed. In case of a major bleeding the most important attitude is keep calm compress with sponge and a stick and decide if you can repair it adding a second trans costal port or perform an additional thoracotomy

Lymph node dissection

We recommend performing the mediastinal lymph node sampling (MLNS) or mediastinal lymph node dissection (MLND) with energy devices.

In the right-sided procedures the lymph node dissection is easier to perform. To perform right paratracheal lymph node dissection or sampling, we recommend the retraction of the superior vena cava (SVC) and pulled up the azygos using suction creating a better exposure of the area, in some cases we recommend to loop the azygos vein for better traction and exposure

In left sided procedures station four, five and six are not very challenging to expose and dissect. The subcarinal lymph node dissection in the left and right side is challenging and traction manoeuvres are needed it to reach this area. In some cases it is possible to perform nodal sampling only. With increasing experience and the development of new instruments the dissection of the subcarinal lymph nodes will be routinely dissected like in conventional VATS.

Comments

The *Table 1* shows a set of recommendations for a surgeon embarking on SVATS program for major lung resections. The learning curve of the SVATS is longer and more difficult in comparison with transthoracic uniportal VATS. To our knowledge, there have been only case reports and a few recent of series of cases of the use of SVATS for major lung resections, describing benefits similar to those of transthoracic uniportal VATS in terms of duration of chest drain use, length of hospital stay, operating time, rate of conversion and complications (13-15).

There is a gradual reduction in the operating time with increasing experience. After the case number 85 the operating times becomes similar in almost all the procedures. In *Figure 1* the rate of conversion is illustrated showing improvement with increasing experience in group number two.

SVATS for major lung resections is an alternative approach with a new learning curve to pass same as occur when a surgeon decide to evolve from conventional VATS to Uniportal VATS (16-18). The different view cauda-cranial and anterior to posterior, the dissection of the hilar structures and lymph node dissection makes more challenging this approach.

Although conversion to multiport VATS or thoracotomy should be always performed if required for ensuring safety or complete resection. We recommend having a clear preoperative plan and case selection. Further studies are necessary to certificate the applicability and clinical outcomes of the SVATS in order to show clear benefits from this technique.

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None.

Footnote

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

Ethical Statement: The study was approved by the Shanghai Pulmonary Hospital Institutional Review Board and written informed consent was obtained from all patients.

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Tips and tricks for success in subxiphoid video-assisted thoracic surgery

Amr Abdellateef[1,2#], Jason M. Ali[3#], Gening Jiang[1], Giuseppe Aresu[3], Lei Jiang[1]

[1]Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University, Shanghai 200433, China; [2]Department of Cardiothoracic Surgery, Mansoura University Hospital, Mansoura School of Medicine, Mansoura University, Mansoura, Egypt; [3]Thoracic Surgery, Royal Papworth Hospital NHS Foundation Trust, Papworth Everard, Cambridge, UK

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[#]These authors contributed equally to the work.

Correspondence to: Lei Jiang, MD. Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University, Shanghai 200433, China. Email: jiangleiem@aliyun.com.

Abstract: The subxiphoid approach to video-assisted thoracic surgery (VATS) has been introduced as an alternative to intercostal VATS. There is some evidence that avoiding intercostal incision and instrumentation leads to reduced pain and facilitates early mobilisation and enhanced recovery. Access of the pleural cavities and anterior mediastinal space through a subxiphoid incision presents some challenges, particularly when accessing posterior pulmonary lesions. With increasing experience, a large range of thoracic surgical operations performed through the subxiphoid approach have been reported including anatomical segmentectomies, thymectomies. Another attraction is that bilateral procedures can be performed through a single incision. The experience of several surgeons passing through the learning curve of subxiphoid VATS surgery has resulted in overcoming many of the early challenges faced. In this paper, a series of tips and tricks are presented to enable surgeons considering adopting this technique into their practice to do so safely and with an appreciation of the difficulties that they may face.

Keywords: Subxiphoid; video-assisted thoracic surgery (VATS); learning curve; training

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Introduction

The uniportal subxiphoid video-assisted thoracoscopic surgery (SVATS) technique is becoming established as an alternative approach to performing thoracic surgery without making an incision in the intercostal spaces. There are now reports describing use of SVATS across a wide range of thoracic surgical procedures including thymectomy, metastasectomy, pneumothorax surgery and anatomical lung resections including lobectomy and segmentectomy (1-4). With experience and passing through the learning curve there have been modifications made to the technique through the experience of many surgeons and development of new instruments (1,4-7). This evolution has enabled SVATS to become faster, easier and more feasible even in some previously challenging conditions (6,7).

The aim of this paper is to present some tips and tricks starting from patient selection, going through surgical details and ending with postoperative care to provide a guide to thoracic surgeons interested in introducing the subxiphoid VATS approach into their practice in a safe and efficient manner.

General principles

Previous uniportal VATS experience and a good assistant

SVATS could be considered a modified version of the uniportal intercostal VATS technique as there are some similarities. However, there are important differences that introduce challenges that should be appreciated before embarking on SVATS techniques.

In particular, the subxiphoid access port restricts the range of motion that can be achieved with standard VATS instruments, and advanced bimanual dexterity is required of the operating surgeon. Furthermore, the different caudal-cranial and anterior to posterior views makes the view of the anatomical structures slightly different to that experienced in uniportal intercostal VATS requiring a very good knowledge of the three-dimensional anatomy of the hilar structures (3,8). Having said that, it is easy to appreciate that having previous experience with uniportal intercostal VATS will make the learning curve of SVATS much easier to climb.

It is advisable for surgeons to start working under the supervision of skilled surgeon in SVATS as a mentor, and to begin with minor surgeries like straightforward wedge pulmonary resections and thymectomies. After gaining more confidence and experience, moving to more complex procedures such as lobectomies then segmentectomies will be more straightforward (6).

It is also important to emphasise that presence of an experienced assistant is vital for success with SVATS. The assistant's movement should be fully coordinated with the surgeon to view difficult angles specially at apical arterial trunks and posterior mediastinal structures. Having a full understanding of using a 30° operating telescope is essential to achieve the visualization necessary for SVATS procedures. It is important for the assistant to withdraw the camera each time a new instrument is introduced into the surgical field to ensure this is performed under vision to avoid inadvertent injury—especially to the heart in left sided procedures (7).

Case selection

Despite increasing popularity of SVATS approach in various thoracic surgical procedures, case selection is still a crucial prerequisite for a successful operation specially at the start of learning curve (4,6). Preoperative discussion should be held by the surgical team to select patients most suitable for the SVATS approach. It is advisable to follow the following inclusion and exclusion criteria that could be loosened after gaining experience and with progression of learning curve (6,7,9).

Inclusion criteria:

- ❖ for major lung resection, it is advisable to include only cases with lesions of T1 or T2 status of tumour <7 cm for lobectomy and lesions <2 cm for segmentectomy;
- ❖ N0 status for tumour;
- ❖ localized infectious lung disease;

Exclusion criteria:

- ❖ central masses;
- ❖ enlarged lymph nodes with confirmed N1 or N2 disease;
- ❖ chest wall involvement;
- ❖ previous thoracic surgery (reoperation);
- ❖ cardiomyopathy or impaired cardiac function;
- ❖ obese patients with body mass index <30 kg/m^2 who may show difficulty in localization of xiphoid process in addition to the abundant pericardial and pleural fat which makes access to pleural space more difficult and time consuming (4,10).

One of the limitations of the SVATS approach, particularly during early experience, is difficult access to posterior lesions (8) which require traction and experience to accomplish. So, it is better in the early experience not to select cases with posterior lesions that require either unilateral or synchronous wedge resection or segmentectomy. Careful examination of preoperative chest imaging is mandatory to localize the lesion accurately.

The subxiphoid approach is more difficult on the left side due to the cardiac pulsation with risk of intraoperative arrhythmia (4). So, it is better to omit left-side operations for patients with cardiac diseases, such as cardiomegaly and arrhythmia (6). In addition to routine preoperative investigations, preoperative echocardiogram (ECHO) evaluation and cardiac assessment are advised to exclude cardiac problems that preclude safe subxiphoid approach.

Invasive thymoma is less likely to be operated through SVATS in the early experience (1).

Instruments

With increasing demand for the subxiphoid approach along with the strong desire to make it feasible and easier, special self-made instruments for SVATS (Shanghai Medical Instruments Group Ltd., Shanghai, China) were designed to overcome the relatively longer track and different axis of the subxiphoid approach compared with the intercostal one. Those instruments are with double joints, longer, harder with a more curved tip. They include lung graspers, dissectors, stapler guider, electrocautery blades and others (*Figure 1*) (4,6,11).

The instruments with their specific angles have helped

Figure 1 Instruments designed for SVATS (Shanghai Medical Instruments Group) (http://www. jzsf.com/en/index.aspx). SVATS, subxiphoid video-assisted thoracic surgery.

in reducing instrument interference, reducing cardiac compression, whilst providing easier and more comfortable exposure, dissection and cauterization of tissues. Also, use of curved tip staplers facilitates easier division of different structures during the procedure (4,6,7,9,11). A thoracoscope which can provide a variable range of view could also help to examine the posterior aspect of the lung for posterior mediastinal lesions and lymph node (3).

General operative set up

One monitor is placed cranially above the head of the patient. The surgeon and the scrub nurse stand on either sides in case of supine position of the patient and on the abdominal side of the patient in case of the patient lying in the lateral decubitus position with the assistant standing opposite. A 10-mm, 30-degree angled high-definition video thoracoscope (Karl Storz, Tuttlingen, Germany) is used. Usual VATS instruments plus the dedicated instruments specially designed for SVATS are used during the operations.

Anaesthesia

All cases are performed under general anaesthesia with double lumen tube. Alternating single lung ventilation is conducted in case of synchronous lesions. In case of subxiphoid thymectomy, injury and clamping of left brachiocephalic vein is a possible complication. So, it is advisable to initiate peripheral infusion in the right hand or foot to allow clamping of left brachiocephalic vein if it is injured (12).

Positioning of the patients

Positioning of the patients varies according to the site and laterality of the lesion. In the case of mediastinal, bilateral lesions or concomitant mediastinal and pulmonary lesions, it's preferred to put the patient in the supine position with both upper limbs adducted beside the patient (3). Alternative 30° up tilting of the operated side may help getting more space and improving ergonomics to provide the surgeon more comfort in case of synchronous lesions (3). Some surgeons prefer to put small soft roll between the two scapula or use a sternal elevator (*Figure 2*) (13) to elevate the sternum to get more space during the procedure (1,13).

In case of unilateral pulmonary lesion, the patient is placed in the lateral decubitus position with 30° backward inclination (*Figure 3*) (9) and the patient should be secured to the table to prevent a fall.

Although the supine position gives one access in case of bilateral or concomitant mediastinal and pulmonary lesions, some surgeons prefer to operate in the lateral decubitus position and change the patient's position intraoperatively according to the operated lesion with new sterile drapes, i.e., placing the patient in alternating decubitus positions with 30° backward tilting in case of bilateral lesions (11) or alternating supine and decubitus positions in case of concomitant mediastinal and pulmonary lesions respectively (6).

The 30° posterior inclination in case of lateral decubitus position helps to displace the lung posteriorly giving a clearer view of the hilum, more space for instruments with less interference between them and the heart particularly on the left side. Moreover, it gives the surgeon's hand

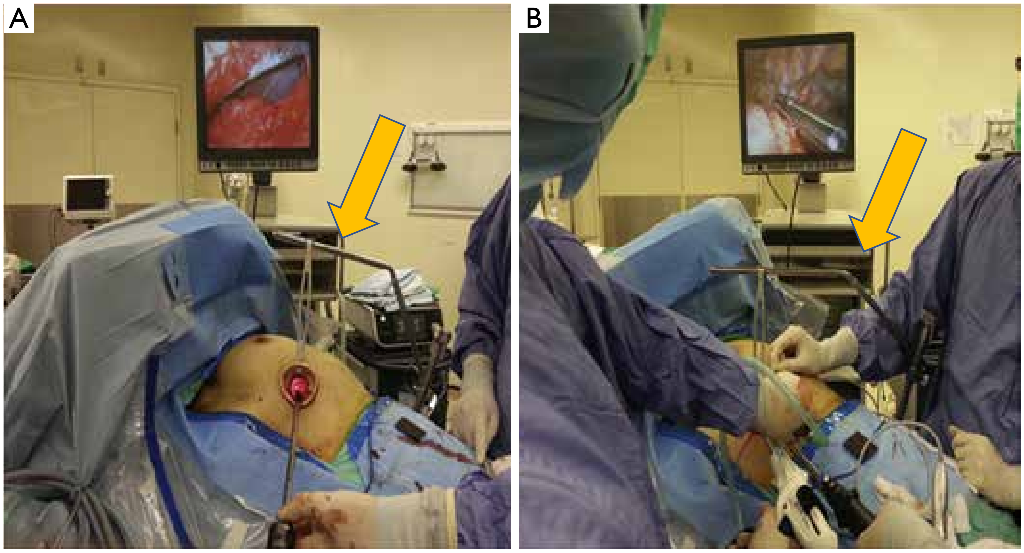

Figure 2 Patient positioned lateral decubitus position with use of a sternal elevator (yellow arrow).

Figure 3 Example of patient in lateral decubitus position with 30° backward inclination.

more space to move and handle the instruments freely. We have noticed also that 30° backward inclination provides better ergonomics for the surgeon's wrist as it makes hilar and fissural structures come at right angle when using the long curved tipped SVATS instruments which facilitates dissection with less effort (7).

Before deciding on the patients position to be used, the surgeon should review the preoperative imaging, particularly looking at the position of lesions requiring localised resections like small blebs or nodules. Posteriorly located lesions may be difficult to access in the supine position that may direct the surgeon to operate in the lateral decubitus position even if the patient has bilateral lesions for example.

The surgeon should also consider the possibility of unpredicted difficulty or complication like bleeding that require shifting the procedure to classic lateral approach or even conversion to thoracotomy. So, in case of operating upon bilateral pulmonary lesions and putting the patient in supine position, it is advisable to suspend both arms up in arm sling fixed to the operating table to keep arms away from lateral chest wall and to allow fast turning of the table

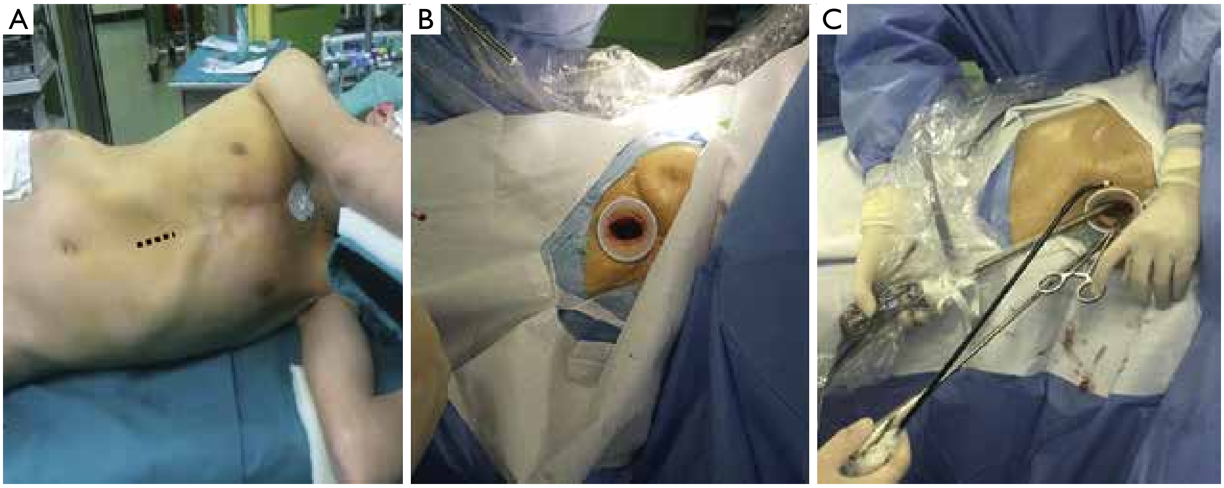

Figure 4 Intraoperative photos demonstrating (A) the patient positioned in lateral decubitus position with black dashes indicate position of incision (B) subxiphoid port with wound protector; (C) arrangement of instruments through wound protector.

into decubitus position to make the set immediately ready for lateral approach or thoracotomy without need to take off the sterile drape to reposition the arm. Also, the operative field should be sterilized widely to allow conversion to uniportal, multiple port approaches or thoracotomy once needed. In case of bleeding during thymectomy, extension of the subxiphoid incision into sternotomy is fast without need to change patient's position.

General surgical technique

Incision

A 3–4 cm longitudinal incision is made extending from the xiphisternal junction to 1 cm below the xiphoid process (*Figure 4A*) (6). The subcutaneous tissue is dissected then the rectus abdominis muscle is exposed and its fibers dissected longitudinally to expose the xiphoid process that is completely resected to provide a widened operative access and to facilitate the instrumentation during the surgery. By index finger dissection, a retrosternal tunnel is created above the diaphragm with moving the index finger more toward the operated side in a trial to make a retrosternal space or to open the required pleura bluntly. A wound protector (Chinese Manufacture wound protector, Changzhou, China) (*Figure 4B*) (6) is inserted giving more space for the camera and instruments and even lessen the need for sternal lifter (8).

Some surgeons prefer to perform a transverse incision, particularly in the case of operating in supine position for bilateral lesions or concomitant mediastinal and pulmonary lesions (14). The transverse incision is made at the level of xiphoid process between the two costal margins.

In our early experience we operated via a transverse incision if the infrasternal angle was ≥70° or via a vertical incision if the infrasternal angle was <70° (6,9). Now, a vertical subxiphoid incision is currently made routinely in almost all cases regardless the degree of infrasternal angle or bilaterality of the lesion. With time, it has been thought that a vertical incision with its upper end at the xiphi-sternal junction make the working port nearer to the hilum. In addition, the vertical incision goes with the same underlying dissected longitudinal planes of subcutaneous tissue, rectus muscle fibers and xiphoid process minimizing the degree of tissue trauma and giving an even and wider retraction by the wound retractor. As the incision is totally above the diaphragm, abdominal herniation is unlikely (7).

After the incision has been made, a 10-mm, 30° video thoracoscope is placed on the caudal side of the incision with the assistant holding the camera and pressing the camera slightly against the lower costal margin using it as a fulcrum. VATS instruments are placed from the cranial side of the incision (*Figure 4C*) (6). In case of transverse incision, the camera is placed in the angle toward the assistant's side.

The pericardio-phrenic fat is removed which facilitates passage of instruments and staplers into the correct space. In case of pulmonary lesion, the pleura of the operated side is opened under thoracoscopic visualization. The pleural cavity is evaluated for unexpected pathology and the site of the lesion is confirmed. Working on mediastinal disease requires creation of a retrosternal space followed by introduction of the video scope and instruments to accomplish the job. This may be facilitated with the use of a sternal elevator as discussed above.

Individual surgical techniques

Lung resection: lobectomy and segmentectomy

The subxiphoid approach is considered convenient for performing lobectomy and segmentectomy particularly in the upper and middle lobes. It has the advantage of more convenient angles during introduction of staplers than the intercostal approach to these lobes. On the other hand, limited vision for lower lobes near the diaphragm, compression of the heart during left-sided operations and difficult access to posteriorly located lesions make the subxiphoid technique more challenging for those conditions (6,10).

Surgical steps

After entering the pleural cavity, the interlobar fissural status is assessed, upon which the approach towards the lobectomy is determined. The lung is retracted using specially designed long curved lung grasper held by the assistant and dissection is carried out by the surgeon using a suction instrument in their left hand and a long curved laparoscopic hook, electrocautery or 5 mm blunt tip LigaSure of 37 mm length (Covidien Ltd., Dublin, Ireland) in the right hand (7). Use of a long sucker with distal curvature can be beneficial to slightly retract the pericardium medially in order to optimize visualization, being careful not to disturb the cardiac function or venous return (6).

As usual, the order of stapling the artery first, vein then bronchus is followed. If the fissure is well developed, the surgeon should try to open it early to delineate the vascular anatomy, but if not well developed, the fissure could be left as the last step or follow the fissureless technique by stapling the interlobar arteries and fissure last.

The vessels, bronchus and fissures are exposed and divided with appropriate straight or articulated endostaplers. In some cases, a curved-tip stapler technology is used to facilitate the passage around the structures. To transect minor pulmonary arteries, usage of proximal and distal silk ligature or polymer clips (Click'a V® Endoscopic Polymer Clip Appliers 45°, Grena Ltd., Brentford, UK) then resection in between with LigaSure is a satisfactory alternative. A specimen pouch Endo Catch bag 10 mm (Covidien Ltd.) is used to remove the specimen, with prior removal of the wound protector.

The order of dissection and division of pulmonary vessels and bronchi had been followed classically by starting with the artery, vein then the bronchus particularly at the start of learning curve associated with precise selection of straightforward cases with classic anatomy and minimal or no adhesions. With experience, there has been acceptance of operating more challenging cases with more advanced adhesions or anatomical variations requiring the surgeon to follow the role of "whatever easy comes first", making the surgeon no longer stick to a specific order in all cases including sometimes the fissureless technique the same as in intercostal approach (7,15).

Regarding segmentectomy, it was previously thought that posterior segments (S2, S6, S9, and S10) would not be accessible by SVATS (16). But, with increasing experience and familiarity to the approach in addition to development of specific SVATS instruments, surgeons started to perform all those previously challenging segmentectomies safely by subxiphoid approach. However, to reach to that point of proficiency, surgeons should first develop their learning curve in standard uniportal lung resection then move to performing SVATS segmentectomies of the more accessible and easy segments before attempting those challenging posteriorly located segmentectomies (6).

Anatomical thoracoscopic segmentectomy needs accurate demarcation of the inflation-deflation line in order to perform precise segmentectomy. In addition to the classic manoeuvre of differential inflation of the preserved segments around the desired segment to be resected after clamping the potential feeding bronchus to the resected segment, we use another innovative open insufflation technique during lung collapse. The technique includes accurate localization of the feeding bronchiole to the segment to be resected, proximal ligation by silk suture just after it's take off from the lobar bronchus, creation of minute hole in the distal part of its membranous wall and insertion of small pore central venous catheter and insufflation of 30–40 mL of air slowly that allows inflation of the segment and delineation of intersegmental plan. Before air pushing, the surgeon should aspirate first to be sure that the tip of the catheter is outside a blood vessel not to cause air embolism.

In all indicated cases, systemic lymph node dissection of at least three N2 lymph nodes stations can be performed according to the IASLC/mountain classification. With early experience, surgeons can experience some difficulty in accessing particularly the posteriorly located subcarinal lymph nodes. Dissection of the posteriorly located subcarinal lymph nodes requires maintained anterior traction of the lung by a lung gasper held by the assistant along with simultaneous dissection by the surgeon. Tilting the patient more toward the lateral position while working posteriorly may facilitate more access to the posterior lesions and lymph nodes. With more experience and adjustment to using the special long curved instrument set, surgeons started to get more comfortable with lymph nodes dissection, including the subcarinal lymph nodes. Usage of energy sealing devices in lymph node dissection is preferred as it helps with extracapsular dissection along with ensuring optimum haemostasis (7,9).

After completion of the procedure, the bronchial stump is checked under water for air leak. In the subxiphoid approach, it is difficult to flood the surgical field with water to test air leak by the usual manner as the wound through which you pour the water is lower than the surgical field and not as high as that of lateral approach leading to getting the water back out of the incision or inability to fill the surgical field adequately. That is why a special metal pot with long nozzle was designed to deliver the water from outside the wound to deep inside the surgical field making that mission easy and feasible (*Figure 5*) (6,9).

Figure 5 Specially designed metal pot with long nozzle to deliver the water inside the surgical field to check air leak (Shanghai Medical Instruments Group) (http://www. jzsf.com/en/index.aspx).

Wound closure and drainage

At the end of the procedure, a 28Fr pleural drainage tube is inserted at the inferior end of the incision passing laterally to the thoracic apex, and then connected to a drainage bottle (*Figure 6A*). A deep venous puncture catheter is inserted at the 8th intercostal space on the lateral chest wall then connected to a drainage bag as a basal drain. An additional drainage tube is inserted in the other end of the incision in patients with concomitant mediastinal lesion, bilateral lesions or associated opening of the pleura during thymectomy (*Figure 6B*). Only one drain is inserted on one side of the incision in case of isolated mediastinal lesion. The incision is closed in layers. All patients are extubated on table.

Thymectomy

As usual, selection of cases is an important step for a successful procedure especially in the early experience.

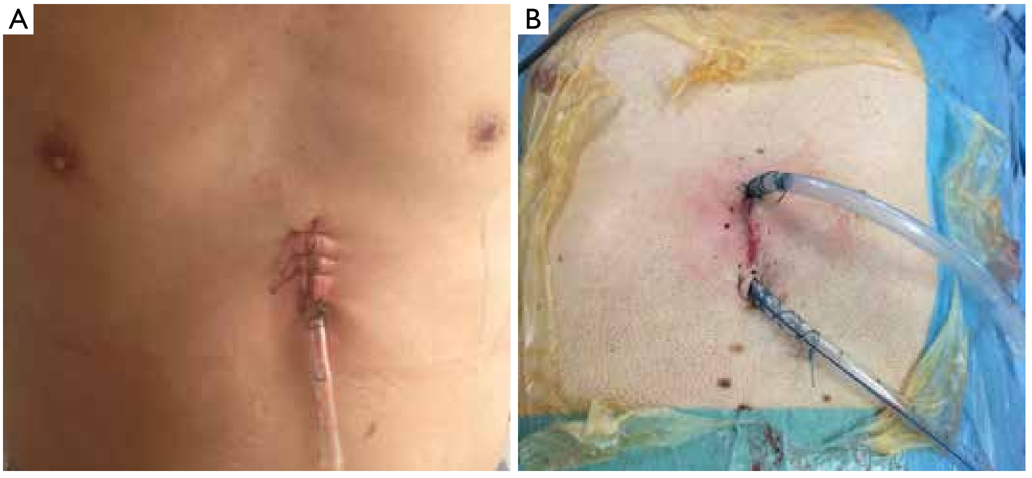

Figure 6 Position of drains postoperatively (A) drain is positioned at the inferior end of the incision in case of unilateral or isolated mediastinal lesion, and (B) 2 drains are positioned at both sides of the incision in case of concomitant mediastinal lesions, bilateral lesions or associated opening of the pleura during thymectomy.

It is better to avoid cases with large or invasive tumours. Also, cardiomegaly, poor cardiac function or preoperative arrhythmia are high risk factors for poor intraoperative access, arrhythmia or cardiovascular instability as a result of instrumentation over the heart or the left hemithorax (1).

Some authors advise surgeons adopting SVATS thymectomy for the first time to start with performing subxiphoid dual-port thymectomy through insertion of a subxiphoid port initially and then adding a 5-mm port into the left, right, or bilateral fifth intercostal space(s) after dissection of mediastinal pleura and opening of the thoracic cavity. The additional intercostal port reduces interference between surgical instruments and improves surgical operability. Then, by getting more familiar with the view and technique, the additional lateral port can be omitted (17).

Surgical steps

After following the same previous general surgical technique and creating a retrosternal tunnel by blunt finger dissection, a wound protector is placed to allow suitable primary positioning of telescope and instruments. The surgeon holds a bent-tip grasping forceps specially designed for the subxiphoid approach in the left hand for tissue grasping and elevation and 5 mm LigaSure Maryland type (Covidien, Mansfield, MA, USA) vessel sealing device or bent-tip endoscopic electrocautery in the right hand for dissection (1).

The subxiphoid approach gives the advantage of good visualization of both phrenic nerves (18). It's advisable to start the procedure with bilateral opening of both mediastinal pleurae that makes the mediastinum drop dorsally giving more space for the surgical field and wide panoramic view between the two phrenic nerves (19). Then, all mediastinal fat is dissected up from the pericardium guiding the surgeon to underneath the thymus. Dissection of the thymus off the pericardium should go from the caudal to cranial direction and from right to left phrenic nerves till reaching the left brachiocephalic vein superiorly. Complete freeing of the thymus gland till the left brachiocephalic vein helps traction of the right lobe to the left and the left lobe to the right to help dissection of the thymus off the right and left halves of the left brachiocephalic vein respectively as well as dissection and downward traction of thymic horns (20). It is important to ensure complete haemostasis of the most cranial tip of thymic horns by ligaSure during separation of thyro-thymic connection while pulling down of thymic horns.

Lateral traction of the thymus gland makes the thymic tributaries more clearly visualised from the caudal view of the subxiphoid approach. They are mostly 2–4 in number, but anatomical variations are frequent and should be considered. Good circumferential dissection around thymic tributaries with subsequent distal clipping (towards left brachiocephalic vein) and proximal cutting by ligaSure (towards thymus gland) ensures good haemostasis and avoids accidental bleeding.

Use of the curved tip of LigaSure is very helpful in dissection of the thymic tissue off the pericardium and left brachiocephalic vein. Holding the convex surface of the ligaSure jaws during dissection facing towards vital structures like left brachiocephalic vein, phrenic nerve and pericardium helps to get cleaner dissection and to prevent injury to these structures. It is crucial not to hold, coagulate or cut any structure without clear vision.

How to deal with bleeding during thymectomy

Bleeding from left brachiocephalic vein is a common complication during thoracoscopic thymectomy. The first step to deal with bleeding is to apply pressure with a gauze piece for 10 minutes which can be changed again by another one for a further 10 minutes if the first one doesn't stop the bleeding (21). Most bleeding cases are managed by compression in such way, but if it does not work, application of a ligaclip or placing a suture at the bleeding point may be required.

The main problem with the subxiphoid access is that the axis of the working instrument is perpendicular to the axis of left brachiocephalic vein making it difficult to deal with the bleeding. Sometimes, insertion of an extra right or left intercostal 10 mm port may help introduction of a clip applier or needle holder in an axis semi parallel to left brachiocephalic vein making it easier to deal with the bleeding. Of course, extension of the subxiphoid incision into sternotomy should be considered urgently in case of massive bleeding or failure of surgical control of the problem.

Bilateral lesions

Bilateral wedge resection may be performed in patients with bilateral lung tumours or bilateral pneumothorax. Most common pitfalls in bilateral procedures are accessing posteriorly located lesions and lesions in the lower lobes and cardiac compression especially upon operating on the left side. So, careful examination of the preoperative imaging is crucial to localize the lesion precisely. Try to avoid cases with posteriorly located lesions in early experience. Also, selection of thin, young patients with no cardiac morbidity will ease the technique and lessen the incidence of cardiac complications.

Fortunately, most blebs or bullae are found in the apex of the upper lobes or superior segment of lower lobes. These locations can be easily seen and approached via the subxiphoid technique taking into consideration that back of the superior segment of upper lobes should be visualized carefully for any blebs. Additionally, patients with primary spontaneous pneumothorax (PSP) are mostly slim and young with normal size of the heart. The heart can be less compressed, and intraoperative arrhythmia, even if it occurs, it might be better tolerated by those young and otherwise healthy patients (3).

Tilting the surgical table towards dead lateral position along with anterior traction of the lung facilitates the access and resection of posteriorly located lesions. Because intraoperative palpation is not possible as in the lateral thoracic VATS approach, hook wire marking will be helpful when resecting pulmonary nodules unless the mass is not directly beneath the pleura and near to the subxiphoid incision (22).

An important tip in order to shorten the operative time in case of bilateral lesions, is to operate while the patient in supine position with alternative upward 30° tilting of the operated side without need to change patient's position in alternate decubitus positions (23). Also, SVATS can apply the same role in case of concomitant resection of anterior mediastinal masses and lung pathologies (19).

Bleeding, adhesions, conversion to uniportal lateral VATS approach

Sometimes in case of bleeding, extensive adhesions or technical difficulty, the surgeon may need to convert to intercostal approach through adding an intercostal incision at the 5th intercostal space between anterior and mid axillary lines which is then converted to anterior thoracotomy if needed. It is not helpful to extend the subxiphoid wound for major bleeding control except in thymectomy (5,8).

Management of bleeding generally starts as usual by compression, then attempt to control by placing a stitch or by clipping then conversion to thoracotomy if failure to control. With better instrumentation and experience, incidence of accidental intraoperative bleeding should decrease with more ability to control through SVATS if it occurs (7). Anyway, previously mentioned precautions during positioning in case of bleeding should be considered.

Left sided lesions

Cardiac compression and arrhythmia are challenges in left sided operations. Improved handling skills, backward tilting of the patient, longer and specially curved instruments making the concave edge of the instruments toward the heart during the operation have enabled surgeons to make better retraction and dissection of pulmonary structures with lesser compression on the heart. Some surgeons prefer usage of sternal elevators to increase the working space with subsequent reduction in instruments-heart interference (24).

Postoperative care

Postoperatively, all patients are requested to mobilize early and perform aggressive physiotherapy. It is recognised that the SVATS approach can lead to reduced postoperative pain than with intercostal VATS procedures (24,25) which helps with early mobilization, effective physiotherapy and better ability to get clear chest secretion and therefore reduced length of hospital stay (5).

Postoperative pain is managed using a patient-controlled analgesia pump, as required, with sufentanil citrate 1 mL: 50 µg, and regular medication with flurbiprofen 50 mg every 6 hours, alternating with paracetamol 1 g every 6 hours. Drains are removed when there is no air-leakage and fluid drainage less than 300 cc in 24 hours. Patients are usually discharged 1 day after tube removal and followed up at outpatient clinic as per scheduled.

Summary

The use of the subxiphoid VATS approach has been increasing over the past few years. Case selection should be taken seriously into consideration especially at the start of learning curve. Growing adoption of SVATS by many surgeons has contributed to evolution of the surgical technique with many tips and tricks that make the procedure easier and more feasible. With growing experience and following those tips and tricks, many previously addressed challenges have been overcome.

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Footnote

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

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The Zakopane Pulmonary Hospital experience on subxiphoid thymectomy

Marcin Zieliński[1], Mariusz Rybak[1], Katarzyna Solarczyk-Bombik[1], Michal Wilkojc[1], Wojciech Czajkowski[1], Sylweriusz Kosinski[2], Edward Fryzlewicz[2], Tomasz Nabialek[2], Malgorzata Szolkowska[3], Juliusz Pankowski[4]

[1]Department of Thoracic Surgery, [2]Department of Anaesthesiology and Intensive Care, Pulmonary Hospital, Zakopane, Poland; [3]Department of Pathology of the Tuberculosis Institute, Warsaw, Poland; [4]Department of Pathology, Pulmonary Hospital, Zakopane, Poland

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Correspondence to: Marcin Zieliński, MD, PhD. Department of Thoracic Surgery, Pulmonary Hospital, Ul. Gładkie 1, 34 500 Zakopane, Poland. Email: marcinz@mp.pl.

Background: To present the technique of minimally invasive extended thymectomy performed through the subxiphoid-bilateral subcostal video-assisted thoracoscopic surgery (VATS) approach, with double elevation of the sternum for nonthymomatous myasthenia gravis (MG).

Methods: The whole dissection was performed through the 4–7 cm transverse subxiphoid incision with single 10 mm extra-long bariatric laparoscopy ports inserted subcostally to the right and left chest cavities for videothoracoscope and subsequently for chest tubes. The sternum was elevated with two hooks connected to the sternal frame (Rochard bar, Aesculap-Chifa, Nowy Tomysl, Poland). The lower hook was inserted through the subxiphoid incision and the superior hook was inserted percutaneously, after the mediastinal tissue including the major mediastinal vessels were dissected from the inner surface of the sternum. The fatty tissue of the anterior mediastinum and the aorta-pulmonary window was completely removed.

Results: There were 147 patients (62 patients operated on for thymomas, 75 patients for nonthymomatous MG and 10 for rethymectomies) in the period 1.1.2009–30.3.2016. There was no mortality and morbidity. The mean operative time was 109.1 min (range, 75–150 min).

Conclusions: The subxiphoid approach combined with bilateral single port subcostal VATS and double elevation of the sternum enables very extensive thymectomy in case of nonthymomayous MG.

Keywords: Thymoma; thymectomy; myasthenia gravis (MG); mediastinum

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Introduction

We started to use the subxiphoid incision for thymectomy in 2000. By that time we had been using the extended transternal approach similar to that described by Bulkley *et al.* (1). We proved that this extensive technique resulted in the improved complete-remission rate in comparison to our previous basic thymectomy approach consisting of the removal of the sole thymus gland, without the surrounding adipose tissue performed through the upper sternal split (2). Considering the expectations of the patients for less invasive approach avoiding sternotomy, we changed our policy and started to perform the transcervical-bilateral video-assisted thoracoscopic surgery (VATS) technique, with elevation of the sternal manubrium and introduction of three ports on each side of the chest as described by Novellino *et al.* (3). Soon, we found that this technique was not comfortable for us, in part due to our small experience in VATS surgery, at that time. We decided to change our approach by adding

Table 1 Patients operated with transcervical-subxiphoid-VATS, subxiphoid-VATS and subxiphoid-subcostal-VATS approaches

Indication for surgery	Transcervical-subxiphoid VATS "maximal" thymectomy	Subxiphoid-VATS extended thymectomy	Subxiphoid-subcostal VATS extended thymectomy	Overall
Nonthymomatous MG	390	62	13	465
Thymoma	7	62	0	69
Rethymectomy	4	10	0	14
Overall	401	134	13	548

VATS, video-assisted thoracoscopic surgery; MG, myasthenia gravis.

the subxiphoid approach with double elevation of the sternum from the side of the manubrium and the lower angle of the sternum. Initially, we tried the subxiphoid longitudinal midline incision, but very soon it was replaced with the transverse incision, which provided much better access to the mediastinum. Finally, our approach consisted of the collar incision in the neck combined with bilateral one-port thoracoscopy and the subxiphoid incision with double elevation of the sternum provided with the modified Rochard frame (Aesculap-Chifa) (4). We called this procedure the transcervical-subxiphoid-videothoracoscopic "maximal" thymectomy. Our aim was to remove maximally the whole thymus with the surrounding fatty tissue of the lower neck and the anterior and middle mediastinum. We tried to perform thymectomy in the same radical way as was described by Jaretzki *et al.* (5). Initially, for several years most of the procedure was performed mainly through the transcervical incision, with dissection of both laryngeal recurrent nerves, the vagus nerves, the upper poles of the thymus, the lower thyroid and the thymic veins, removal of the fatty tissue from the right paratracheal space (called by us "the aorta-caval groove") and the fatty tissue of the aorta-pulmonary window. The upper part of the thymus was dissected from the pericardium. The subxiphoid approach was used for dissection of the lower part of the thymus from the pericardium and for removal of the epiphrenic fat pads bilaterally. Both pleural cavities were widely opened and the sheets of pleura were removed with the whole specimen en-block. Subsequently, our technique of thymectomy was modified with introduction of the "two team approach", with two surgical teams working simultaneously—one from the transcervical and theother from the subxiphoid side (6). This policy helped us to reduce the operating time from 2.5–3 hours to 1.5–2 hours. We operated on 401 patients with use of this technique (390 patients operated for nonthymomatous myasthenia gravis (MG), 7 patients for thymomas and 4 for rethymectomies (in the period 1.9.2000–31.12.2015).

The next modification of our technique of thymectomy was the omission of the transcervical incision to reduce the invasiveness and for better cosmesis. This technique was called the subxiphoid-right VATS extended thymectomy and initially, was used for resection of thymomas (7). Subsequently, this technique was modified by adding a single left VATS port and was used for thymectomy for nonthymomatous MG and for rethymectomies, besides that of thymomas. This technique was described as the subxiphoid VATS extended thymectomy (8). In our last modification the intercostal VATS ports were replaced with bilateral single ultra-long bariatric laparoscopy ports introduced subcostally to the pleural cavities, through the insertions of the diaphragm to the chest wall, without violation of the peritoneal cavity. This new approach, called the subxiphoid-subcostal-VATS extended thymectomy will be described for the first time in this article. We started to use it from 16.8.2013. The *Table 1* presents the numbers of patients operated on with use of and the subxiphoid-bilateral VATS extended thymectomy.

Patient selection and workup and pre-operative preparation

All patients with nonthymomatous MG are the candidates for this kind of procedure. In case of the advanced stage III thymomas the transsternal approach is preferred (9-11). In case of nonthymomatous MG the operation is proposed primarily to patients in the MGFA class I–IIIb (mild to moderate ocular, bulbar and extremities' muscles affected) (12). In case of severe MG the operation is postponed until the patient's clinical improvement after preoperative preparation with steroids, immunosuppressive drugs, plasmapheresis or immunoglobulins.

Figure 1 Subxiphoid incision, elevation of the sternum, opening of the right mediastinal pleura (13).
Available online: http://www.asvide.com/articles/1277

Figure 2 Introduction of the video-assisted thoracoscopic surgery (VATS) port through the subcostal incision to the right pleural cavity (14). Available online: http://www.asvide.com/articles/1278

Equipment preference card

- The modified Rochard frame with two hooks;
- Bi-clamp, Harmonic knife or LigaSure;
- The Yankauer suction tube;
- The Cameleon videothoracoscope (Carl Storz);
- Standard VATS instruments;
- The extra-long bariatric laparoscopy ports.

Surgical technique

Preparation

The patient was positioned supine on the operating table with a roll placed beneath the thoracic spine to elevate the chest and to hyperextend the patient's neck. Under general anaesthesia an endobronchial tube was inserted to conduct selective lung ventilation during the latter part of the procedure.

A transverse 5 cm subxiphoid incision was made above the xiphoid process. The subcutaneous tissue and the medial parts of the rectus muscles were cut near the insertions to the costal arches. The xiphoid process was removed. Selective left lung ventilation was started resulting in the collapse of the right lung. The anterior mediastinum was opened from below the sternum. A sternal retractor connected to the traction frame (Rochard bar, Aesculap-Chifa, Nowy Tomysl, Poland) was placed under the sternum, which was elevated to facilitate access to the anterior mediastinum from below (*Figure 1*). The single 10 mm extra-long bariatric laparoscopy ports were inserted to the right chest cavity for videothoracoscope (VATS) and subsequently for chest tube. To avoid injury of the peritoneum and entrance to the abdominal cavity a special technique of the port insertion was used (*Figure 2*). The first step was to introduce the Cameleon thoracoscope supplied with a very wide range of view enabling to view the insertion of the diaphragm in the area the port is going to be introduced. Subsequently the Yankauer suction tube is used to stretch the diaphragm by pressure in the direction of the spine. Therefore, the introduction of the port is made under control of VATS. The whole dissection was performed through the subxiphoid incision under control of a videothoracoscope inserted alternatively to the right and left pleural cavities.

The right mediastinal pleura was cut near the sternal surface up to the level of the right internal thoracic vein, which was left intact with bipolar cautery (Bi-Clamp, ERBE). Alternatively, such devices as a harmonic knife, LigaSure or vascular clips can be used to secure the vessels throughout the procedure (*Figure 3*). After dissection of the mediastinal tissue from the inner surface of the sternum a 2–3 mm puncture was performed over the sternal notch and a single-tooth hook was inserted percutaneously under the sternal manubrium (*Figure 4*). The second hook improved exposure of the superior mediastinal and the lower neck regions facilitating considerably performance of the procedure and enabling visualization of the whole upper poles of the thymus and the lower part of the thyroid. The prepericardial fat and the right epiphrenic fat pads were dissected from the pericardium and diaphragm (*Figure 5*). Dissection of the prepericardial fat containing the thymus gland proceeded upwards under control of thoracoscope in en bloc fashion, without any attempt to dissect the thymus gland with thymoma separately. The right phrenic nerve was a margin of dissection. The dissection of the thymus

Figure 3 Dissection of the mediastinal tissue from the sternum (15).
Available online: http://www.asvide.com/articles/1279

Figure 4 Introduction of the upper sternal hook (16).
Available online: http://www.asvide.com/articles/1280

Figure 5 Dissection of the right epiphrenic fat pad from the diaphragm and the pericardium (17).
Available online: http://www.asvide.com/articles/1281

Figure 6 Opening of the left mediastinal pleura, transfer of the specimen to the left pleural cavity (18).
Available online: http://www.asvide.com/articles/1282

Figure 7 Dissection of the right and left lobes of the thyroid gland, the lower thyroid vein, the trachea and the thymic vein (19).
Available online: http://www.asvide.com/articles/1283

proceeded along the left innominate vein with closure with vascular clips and division of the thymic veins, until the left internal thoracic vein (left mammary vein) was visualized. The left mediastinal pleura was opened at the relatively early stage of dissection, enabling the manoeuvre of transferring of the dissected specimen obscuring plane of dissection from the right to the left pleural cavity (*Figure 6*). This manoeuvre facilitated dissection substantially due to improved exposure of the rest of the thymus. Dissection proceeded cranially with closure and division of the lower thyroid veins, performed in the same way as in the case of the thymic veins. Further dissection proceeded along the thymic poles until the lower part of the thyroid was clearly visualized (*Figure 7*). The specimen is dissected from the right and the left sides until the thyro-thymic ligaments are the sole attachments from the cranial side. At this point

Figure 8 Dissection of the specimen from the left phrenic nerve and removal of the specimen in the bag (20).
Available online: http://www.asvide.com/articles/1284

Figure 9 Dissection of the aorta-pulmonary window (21).
Available online: http://www.asvide.com/articles/1285

the upper poles were divided close to the thyroid. After dissection such structures as the innominate, the right carotid arteries and the trachea were clearly visualized. The liberated upper poles of the thymus were grabbed and pulled caudally enabling dissection of the thymus from the pericardium. A single ultra-long bariatric laparoscopic port was inserted subcostally to the left pleural cavity, in the same way as it was done on the right side. Dissection of the specimen along the left phrenic nerve was performed, the same as was done on the right side. The specimen containing the thymus and the adipose tissue was placed in a plastic bag and removed through the subxiphoid incision (*Figure 8*). Dissection of the aorta-pulmonary window was completed, finally (*Figure 9*). Haemostasis was checked and single chest tubes were inserted into both pleural cavities through the incisions made for insertion of the ports. Ventilation of both lungs was resumed. The subxiphoid incision was closed in the standard manner, a puncture incision was closed with a single 5/0 suture, which was replaced with a peristrip on the next day. The patient was extubated immediately after the operation.

Generally, the dissection of the neck area performed during the subxiphoid VATS extended thymectomy and the subxiphoid subcostal VATS extended thymectomy is less extensive than in the transcervical-subxiphoid-VATS approach. Therefore, we describe the techniques without a cervical incision as the extended, contrary to the previous technique called as "the maximal". Nevertheless, the differences of extensiveness between the techniques with and without the transcervical incisions are probably slight. The reason to replace a intercostal incision for the subcostal one for insertion of the ports is due to a possible reduction of the postoperative pain. Our initial unpublished experience with the subcostal approach for thymectomy and VATS pulmonary lobectomy suggested that the subcostal incision was probably less painfull than the intercostal one. Currently, we are conducting a prospective randomized trial comparing the subxiphoid-bilateral VATS thymectomy with the subxiphoid-subcostal bilateral VATS thymectomy, in regard to the amount of the postoperative pain and reduction of the spirometric parameters. The closure of accrual of all patients for the completion of the study and the presentation of the results are expected in the next year.

The subxiphoid-bilateral VATS approach with elevation of the sternum with two hooks was used in 147 patients (62 patients operated on for thymomas, 75 patients for nonthymomatous MG and 10 for rethymectomies) in the period 1.1.2009–30.3.2016. There was no mortality and 3.4% morbidity. The mean operative time was 109.1 min (range, 75–150 min). The dimensions of the largest thymoma removed completely with this technique were 13 cm × 10 cm ×5 cm. The subxiphoid-subcostal-VATS thymectomy was performed in 13 patients with nonthymomatous MG in the period 16.8.2013–30.3.2016.

Post-operative management

Generally, a patient is extubated immediately after the operation. Steroids and/or immunosuppressive drugs are started soon after the operation. The anticholinesterase drugs given in the preoperative doses are resumed when the clinical symptoms of MF recur, which may happen after a variable period of time. Generally, the chest tubes are removed on the first or second postoperative day and the patients are discharged on the 4–7th postoperative day.

Tips, tricks and pitfalls

- ❖ The subxiphoid incision should be performed just below the junction of the lower angle of the sternum. The length of the incision depends on the patients' body habitus—in case of slim patients 3 cm could provide an adequate approach instead of the length of 5 cm, which is usually performed in the medium body habitus patients;
- ❖ Generally, we start dissection from the right pleural cavity with completion of dissection in left one;
- ❖ After dissection of the mediastinum from the posterior surface of the sternum the mediastinal structures are pressed posteriorly towards the spine, with the Yankauer suction tube to protect these structures from injury during percutaneous insertion of the second sternal hook elevating the sternal manubrium;
- ❖ To avoid injury of the peritoneum and entrance to the abdominal cavity a special technique of the port insertion was used. The first step was to introduce the Cameleon thoracoscope supplied with a very wide range of view enabling to view the insertion of the diaphragm in the area the port is going to be introduced. Subsequently the Yankauer suction tube is used to stretch the diaphragm by pressure in the direction of the spine. Therefore, the introduction of the port is made under control of VATS;
- ❖ The next step is dissection of the right epiphrenic fat pad from the right dome of the diaphragm and the pericardium. Dissection of the specimen containing the whole thymus gland is proceeded in the cephalad direction. In case of obese patients and especially in thymomas it is useful to open the mediastinal pleura to transfer the specimen to the contralateral left pleural cavity. This maneuver gives the clear view of the plane of dissection facilitates dissection of the specimen from the pericardium;
- ❖ During dissection on the right it is useful to rotate an operating table to the right and to rotate it in the opposite direction during dissection on the left side;
- ❖ Dissection of the area cranial to the left innominate vein is the most difficult part of the procedure. The aim is to reach and visualize of lower poles of the thyroid gland to remove completely the upper poles of the thymus and the surrounding fatty tissue. The innominate artery, right and left carotid arteries and the trachea should be clearly dissected. This can be achieved with the simultaneous use of the bipolar cautery (or harmonic knife or LigaSure) and the Yankauer suction tube, which is used to dissect and retract tissue. Avoidance of injury of the left recurrent nerve might occur during dissection in the area located on the left side of the trachea;
- ❖ Dissection and removal of the fatty tissue from the aorta-pulmonary window is done separately after extraction of specimen from the chest.

Possible future modifications

- ❖ Uniportal subxiphoid technique with avoidance of the additional incision for ports;
- ❖ The use of CO_2 insufflation. It would be possible if the single incision laparoscopic port (SILS port) is used as was described by Suda *et al.* (22).

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Footnote

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

Ethical Statement: The study was approved by the institutional ethical committee (No. KB/430-37/14) and written informed consent was obtained from all patients.

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Robotic subxiphoid thymectomy

Takashi Suda

Division of Thoracic Surgery, Fujita Health University School of Medicine, Toyoake, Aichi, Japan

Correspondence to: Takashi Suda, MD. Division of Thoracic Surgery, Fujita Health University School of Medicine, Toyoake, Aichi, Japan. Email: suda@fujita-hu.ac.jp.

Abstract: When endoscopic surgery is indicated for myasthenia gravis and thymomas, most institutions use a lateral thoracic approach that includes robot-assisted surgery. However, with the unilateral thoracic approach, it can be difficult to ensure the operative field in the neck and difficult to identify the location of the contralateral phrenic nerve. In 2015, we reported on a robotic subxiphoid thymectomy (RST) in which the camera is inserted from the subxiphoid incision and robotic forceps are inserted from the bilateral intercostal spaces. With this approach, a camera is inserted into a subxiphoid incision which is the midline of the body and a surgical field comparable to that in a median sternotomy can be achieved. This makes it easier to identify the location of the bilateral phrenic nerves and offer the good visualization in the neck area. Here we report on our RST techniques. For a thymectomy without suturing, a subxiphoid, single-port thymectomy is performed because it is minimally invasive. In patients who require suturing, such as with a pericardial patch closure, RST is selected. The RST has excellent operability when performed with a robot, making it suitable for more difficult procedures. In the future, we believe that a robot-assisted thymectomy might become the standard method.

Keywords: Thymectomy; subxiphoid; thoracoscopy/VATS; robot

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Introduction

When endoscopic surgery is indicated for myasthenia gravis and thymomas, most institutions use a lateral thoracic approach that includes robot-assisted surgery (1-3). However, with the unilateral thoracic approach, it can be difficult to ensure the operative field in the neck and difficult to identify the location of the contralateral phrenic nerve. Previously, we reported on a single-port thymectomy using a subxiphoid approach to extract the thymus from a single subxiphoid incision (4). The operative field from the camera inserted through the midline of the body made it easy to verify the neck area and identify the location of the bilateral phrenic nerves. However, a shortcoming of this approach is operability. With surgery through a single incision, there is interference between the camera scope and the forceps in the surgeon's hands, making it difficult to perform more complex procedures such as suturing operations.

In 2003, a robot-assisted surgery for myasthenia gravis and anterior mediastinal tumors was reported (5), and in recent years good outcomes with such surgery have been reported (6). However, these robot-assisted surgical techniques use a lateral thoracic approach (7). Even with the use of a robot, the lateral thoracic approach makes it difficult to gain a good operative field of the neck and to identify the location of the contralateral phrenic nerve. Furthermore, to adequately exert the performance of the robot system, the target, i.e., the thymus, should be between the left and right arms of the robot; however, with the lateral thoracic approach, the neck portion of the thymus is not between the left and right arms. In 2015, we reported on a robotic subxiphoid thymectomy (RST) (*Figure 1*) (8). With this approach, a camera is inserted into a subxiphoid incision which is the midline of the body and a surgical field comparable to that in a median sternotomy can be achieved. This makes it easier to identify the location of the

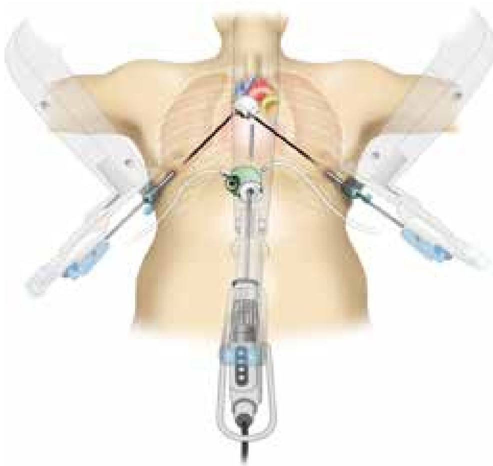

Figure 1 Robotic subxiphoid thymectomy (RST). A pericardial resection and substitution with an artificial pericardial sheet are very easy with an articulated robotic system.

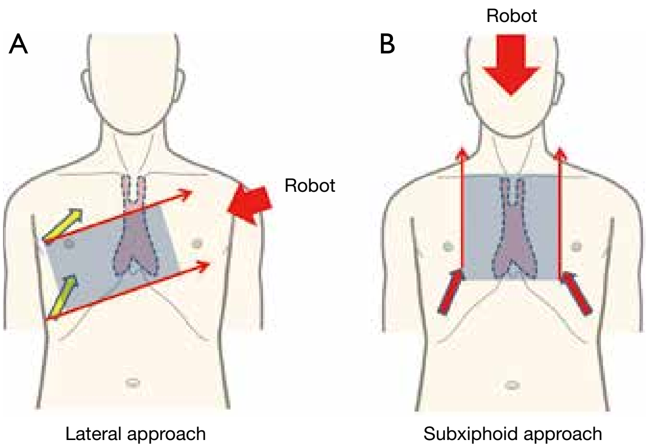

Figure 2 With the approach from the lateral thoracic side, the neck portion of the thymus is not between the left and right arms (A). In contrast, with the subxiphoid approach, the entire thymus is between the left and right arms, thereby enabling good robotic operability (B) (9).

bilateral phrenic nerves and offer the good visualization in the neck area. Furthermore, with this approach, the left and right robot arms are inserted in the 6th intercostal space of the bilateral precordium and the entire target/thymus lies between the left and right arms, thereby enabling maximum robot performance (*Figure 2*) (9). In the event of suspected invasion into the left brachiocephalic vein, to perform the surgery safely, taping of the left brachiocephalic vein

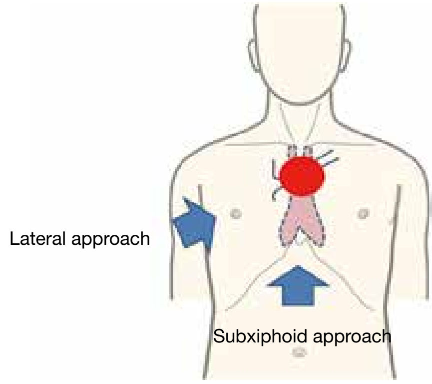

Figure 3 When the tumor is close to the brachiocephalic vein, the approach from the lateral chest cannot identify the contralateral brachiocephalic vein beyond the tumor (Lateral approach). In contrast, with the subxiphoid approach, the left brachiocephalic vein may be identified at proximal and distal ends to the tumor (Subxiphoid approach).

distal and proximal to the tumor is needed. However, with robot-assisted surgery using a lateral thoracic approach, the presence of a tumor makes it difficult to identify the contralateral left brachiocephalic vein. In contrast, with RST, the entire left brachiocephalic vein can be observed through a midline incision, and the left brachiocephalic vein may be taped distally and proximally to the tumor (*Figure 3*). Furthermore, in the event of tumor invasion into the pericardium, an endoscopic pericardial incision and patch closure with a pericardial sheet is a highly difficult procedure when performed endoscopically with human hands; however, if the robot-assisted system with articulated forceps is used, it is very easy (9). In cases where the left brachiocephalic vein is taped distally and proximally to the tumor, or a concurrent pericardial resection and reconstruction is required, it is generally highly likely that endoscopic surgery will not be indicated; however, if a robot is used they can become minimally invasive procedures. As robot-assisted surgery is expensive, the benefits to the patient should balance the high cost. In general, we indicate robot-assisted surgery for highly complicated procedures that are difficult for human hands to perform endoscopically. RST helps secure the operative field of the neck and facilitates the identification of the location of the bilateral phrenic nerves. Furthermore, it has excellent operability when performed with a robot, making it suitable for more difficult procedures. In the future, we believe that a robot-assisted thymectomy might become the standard

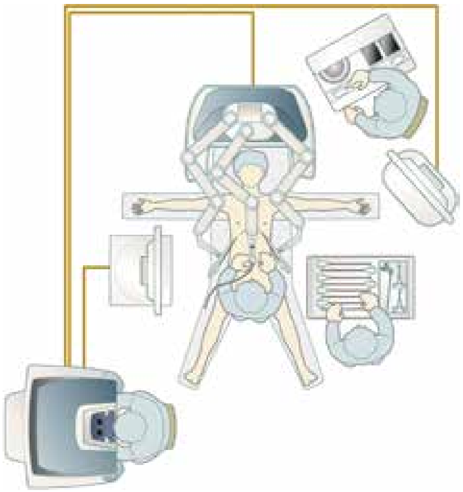

Figure 4 Equipment configuration with the da Vinci SI surgical system.

method. Here we report on our RST technique.

Patient selection

For a thymectomy without suturing, a subxiphoid, single-port thymectomy is performed because it is minimally invasive. In patients who require suturing, such as with a pericardial patch closure, dual-port thymectomy with an additional port placed in the right 5th intercostal space along with a subxiphoid single-port thymectomy (10) or RST is selected.

Pre-operative preparation

The patient is placed in the supine position. The arms are open so as not to be hit by the robot arms. The configuration of the equipment when using the da Vinci SI surgical system (Intuitive Surgical, Sunnyvale, CA, USA) is shown in *Figure 4*.

Equipment preference card

We use the da Vinci SI surgical systems, which are capable of using vessel sealers as the vessel-sealing system. We use the GelPOINT Mini (Applied Medical, Rancho Santa Margarita, CA, USA) as the port for a single-port surgery. The GelPOINT Mini has a gel seal on the port platform, which prevents over-fixation of the mini-ports and decreases interference of the instruments once inserted. It also enables of CO_2 insufflation. The surgeon performs a pre-docking procedure using the vessel-sealing device. There are various types of vessel-sealing devices; however the LigaSure™ Maryland Jaw 37 cm (Covidien, Mansfield, MA, USA) device with a dissecting shaped tip is suitable for this surgery.

Forceps mounted on the robotic arms include Cadiere forceps or fenestrated grasping forceps attached to the bipolar vessel-sealing device on the left hand arm, and Maryland forceps attached to the bipolar vessel-sealing device or spatula attached to a monopolar vessel-sealing device on the right hand arm. A needle holder is used when suturing. The da Vinci surgical system can use four arms; however, to decrease the number of incisions, we do not use the 4th arm.

Procedure

Pre-docking procedure

Under general anesthesia, artificial ventilation is performed using a double-lumen endotracheal intubation tube. The surgeon performs the surgery standing between the legs of the patient, while the scopist stands to the right of the patient to operate the thoracoscope. To begin with, a 3-cm transverse incision is made 1 cm below the xiphoid process, and the rectus abdominis is dissected at its attachment to the xiphoid process. The posterior aspect of the sternum is blindly detached using the finger. A 5-mm vertical incision is made on the fascia of the rectus abdominis, the GelPOINT Mini-port for a single-port surgery is inserted into the subxiphoid incision and CO_2 insufflation is performed at 8 mmHg. Using a rigid scope of 5 mm in diameter with 30° oblique view and using a LigaSure™ Maryland type device, the thymus is detached from the posterior aspect of the sternum. An incision is made into the bilateral mediastinal pleura and the thoracic cavity is exposed bilaterally. Next, 1-cm skin incisions are made on either side in the 6th intercostal space along the anterior axillary line of the precordium, and a port used for the da Vinci robotic surgery is inserted (*Figure 5*).

RST

When using the da Vinci SI surgical system, the system is docked from the cranial side (*Figure 4*). A port used for a 12-mm camera is inserted into the subxiphoid port for a single-port surgery and attached to the da Vinci camera

Figure 5 Pre-docking procedure (11).
Available online: http://www.asvide.com/articles/1039

Figure 6 Robotic subxiphoid thymectomy (RST) (12).
Available online: http://www.asvide.com/articles/1040

Figure 7 Robotic pericardial patch closure by the subxiphoid approach (13).
Available online: http://www.asvide.com/articles/1041

scope. The da Vinci arms are then attached to the bilateral ports in the 6^{th} intercostal space along the anterior axillary line of the precordium. The camera scope is used changing opportunely from direct-forward viewing to a 30° oblique viewing. At times, the assistant will expand the surgical field by pulling the thymus using an Autonomy Grasper 45 cm (Cambridge Endo, Framingham, MA, USA), which are forceps for single-port surgery, or a SILS™ Hand Instrument SILS Clinch 36 cm (Covidien, Mansfield, MA, USA). The thymic vein is dissected using an EndoWrist Vessel Sealer (Intuitive Surgical, Sunnyvale, CA, USA). The thymus and thymoma are placed in a pouch inside the mediastinum and extracted via the subxiphoid incision. A 20-Fr drain is inserted through the subxiphoid incision into the mediastinum (*Figure 6*).

In the event of a suspected tumor infiltration of the lungs, a stapler is inserted through the subxiphoid port or the bilateral lateral thoracic ports, and a partial lung resection is performed. In recent years, it has become possible to attach a stapler to the da Vinci surgical system. An articulated stapler will facilitate surgery in a narrow mediastinum and thoracic cavity. In the event that pericardial invasion is suspected and a pericardial patch closure is performed, the incision is performed after the pericardium has been adequately detached from the tumor, and the pericardium is dissected using the EndoWrist Vessel Sealer. The defective portion of the pericardium is closed by a patch using a Gor-tex pericardial sheet with 3–0 Vicryl interrupted sutures (*Figure 1*). The interrupted sutures can be easily performed using the articulated robotic forceps (*Figure 7*).

Role of team members

For a safe robotic surgery, procedures must be performed by a surgical team consisting of a surgeon, anesthesiologist, engineer, and nurse, all of whom must be well-skilled in robotic surgery. When performing a new surgery, the entire team must meet in advance to perform a simulation.

Tips, tricks, and pitfalls

When using the da Vinci SI surgical system, the robot is docked from the cranial side. At this point in time, the authors have no experience in this approach using the daVinci Xi system. However, with the da Vinci Xi system the robotic arms are mounted on the ceiling and therefore docking can be performed from the lateral side of the patient. If docking from the lateral side of the patient can be performed, the robot does not lie over the patient's head, ensuring that a space is available near the head of the patient for the anesthesiologist.

For the endotracheal intubation tube, if there is no lung invasion, a single-lumen tube can be used. However, if there is suspected tumor invasion of the lungs, a double-lumen tube is chosen to enable differential lung ventilation. When establishing artificial ventilation, pressure control ventilation delivered at the minimal intratracheal pressure is used to ensure sufficient ventilation. PEEP is not used as it inflates the lungs and disturbs the operative field. CO_2 insufflation in the mediastinum at 8 mmHg provides a good operative field by maintaining lung ventilation and eliminating pressure moderately on the bilateral lungs.

In CO_2 insufflation, when using suction, the supplied CO_2 is aspired, which inflates the lungs and worsens the surgical operative field. As an alternative to suction, a gauze roll should be placed in the mediastinum to wipe up blood as required. The AirSeal system (SurgiQuest, Milford, CT, USA) is a CO_2 insufflation system with which suction can be used, and thus might be useful for robotic surgery.

In the event that pulling the thymus is desired to enlarge the operative field, the assistant does so by inserting forceps with an articulated tip through the subxiphoid port; however, if this is difficult to do, then an additional port can be placed on the lateral chest. Although we do not use this practice, if necessary, a 4th robotic arm may be used.

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Footnote

Conflicts of Interest: The author has no conflicts of interest to declare.

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Uniportal subxiphoid video-assisted thoracoscopic thymectomy

Takashi Suda

Division of Thoracic Surgery, Fujita Health University School of Medicine, Toyoake, Aichi, Japan

Correspondence to: Takashi Suda, MD. Division of Thoracic Surgery, Fujita Health University School of Medicine, Toyoake, Aichi, Japan. Email: suda@fujita-hu.ac.jp.

Abstract: With a uniportal subxiphoid video-assisted thoracoscopic surgery (VATS) thymectomy, the thymus is not accessed through the ribs, which avoids intercostal nerve damage. Furthermore, compared to a VATS thymectomy via the lateral chest, decreased use of postoperative analgesics (lower doses and shorter duration), decreased blood loss, and shorter surgical duration and hospital stay have been reported. Here we report our surgical method and solutions for a uniportal subxiphoid VATS thymectomy. A uniportal subxiphoid VATS thymectomy is indicated for patients with myasthenia gravis and anterior mediastinal tumors who do not require surgical suturing. The operator stands between the patient's legs and the scopist stands to the right of the patient to operate the camera scope. To begin with, a 3-cm transverse incision was made along Langer's lines 1 cm caudal below the xiphoid process. The CO_2 insufflation is performed in the mediastinum at 8 mmHg. The pericardial adipose tissue and thymus are detached from the pericardium in an anterior manner from the bilateral phrenic nerves. The resected thymus is placed in a pouch in the mediastinum and removed from the body through the subxiphoid incision. The subxiphoid approach is highly beneficial for the patient in that it results in superior esthetic outcomes considering that there is no sternotomy and no intercostal nerve damage; thus, it is a surgical procedure that surgeons should learn.

Keywords: Thymectomy; subxiphoid; thoracoscopy/video-assisted thoracoscopic surgery (VATS)

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Introduction

Recent studies have reported thymectomy for myasthenia gravis and anterior mediastinal tumors using a minimally invasive approach rather than the conventional median sternotomy. Minimally invasive approaches without a median sternotomy include cervical, lateral thoracic and subxiphoid approaches. The cervical approach was reported by Cooper *et al*. (1) in 1988 as transcervical thymectomy. Because the cervical approach does not pass through the ribs, there is no damage to the intercostal nerves, which is considered to minimize postoperative pain. However, the operation is limited by the size of the neck wound, which is small; therefore, the cervical approach has not become very common. The lateral thoracic approach was first performed by Landreneau *et al*. (2) in 1992, with the thoracoscopic excision of anterior mediastinal tumors. At present, the use of a lateral thoracic approach, including robot-assisted surgery is the most common approach (3). A technical shortcoming of surgery associated with this approach is that the operative field is poor for a cervical resection of the upper pole of the thymus. This complicates the resection procedure, making it difficult to confirm the location of the contralateral phrenic nerve and to resect the thymic adipose tissue anterior to the contralateral phrenic nerve. Furthermore, the placement of the intercostal port will inevitably cause intercostal nerve damage, which can persist as lifelong post-thoracotomy pain syndrome, which is disadvantageous to patients (4). The subxiphoid approach was first performed by Kido *et al*. (5) in 1999. In recent years, advancements in CO_2 insufflation and new surgical instruments have resulted in improved operability and enabled a single-port thymectomy (6) (*Figure 1*). With this approach, the thymus is not accessed through the ribs, which avoids intercostal nerve damage. Furthermore, compared to a video-assisted thoracoscopic surgery (VATS) thymectomy via the lateral chest, decreased use of

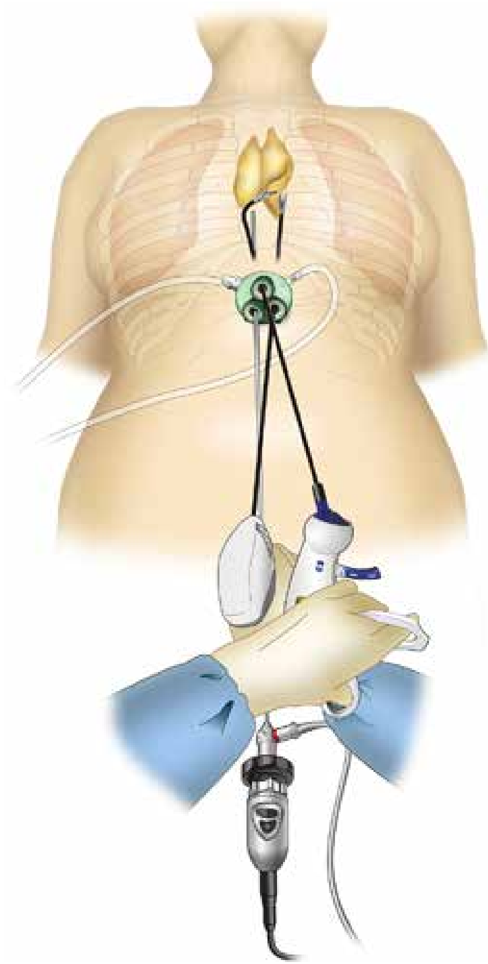

Figure 1 Uniportal subxiphoid VATS thymectomy. For the left lobe of the thymus, the forceps in the left hand are bent to the right and the thymus is pulled to the right of the patient. At this point, the surgeon's hands are crossed, and detachment is performed using LigaSure™. For the right lobe of the thymus, the forceps are bent to the left and the thymus is pulled to the left of the patient. In this instance the surgeon does not need to cross the hands. VATS, video-assisted thoracoscopic surgery.

postoperative analgesics (lower doses and shorter duration), decreased blood loss, and shorter surgical duration and hospital stay have been reported (7). A shortcoming of this approach is operability. A scope and forceps for the left and right hands, respectively, are inserted via a single port; therefore, a means to decrease instrument interference needs to be devised. The subxiphoid approach is highly beneficial for the patient in that it results in superior esthetic outcomes considering that there is no sternotomy and no intercostal nerve damage; thus, it is a surgical procedure that surgeons should learn. Here we report our surgical method and solutions for a uniportal subxiphoid VATS thymectomy.

Patient selection

A uniportal subxiphoid VATS thymectomy is indicated for patients with myasthenia gravis and anterior mediastinal tumors who do not require surgical suturing. In the event that suturing is required, similar to the case of pericardial patch closure for a thymoma invading the pericardium, (I) a dual-port subxiphoid VATS thymectomy (8) with an additional port placed in the right 5^{th} intercostal space along with a uniportal subxiphoid VATS thymectomy or (II) a subxiphoid robotic thymectomy using the DaVinci robot (9) is indicated. In the event that vascular anastomosis is required, similar to the case of prosthetic vascular grafting of the left brachiocephalic vein, a median sternotomy is usually indicated. Procedures such as partial resection of the lung, for which a stapler needs to be used, are only possible via the subxiphoid port.

Pre-operative preparation

The patient is placed in the supine position. The operator stands between the patient's legs and the scopist stands to the right of the patient to operate the camera scope. A monitor is positioned at the patient's head (*Figure 2*). When the operator stands between the patient's legs, it may seem that the distance from their standing position to the surgical port seems far; however, the distance does not actually inhibit the surgical performance.

Equipment preference card

Various types of ports are commercially available for a single-port surgery. Personally, I prefer to use the GelPOINT Mini (Applied Medical, Rancho Santa Margarita, CA, USA) because the gel seal cap on the port platform prevents over-fixation of the forceps port. This decreases the potential for the forceps to interfere with each other. The practitioner performs the surgery with the vessel-sealing device held in his/her right hand and the gripping forceps in the left hand. There are various types of vessel-sealing devices; however, the LigaSure™ Maryland jaw 37 cm (Covidien, Mansfield, MA, USA) device with a tip shaped for dissecting is user-friendly. We use SILS™ Hand Instruments; SILS clinch 36 cm (Covidien, Mansfield, MA,

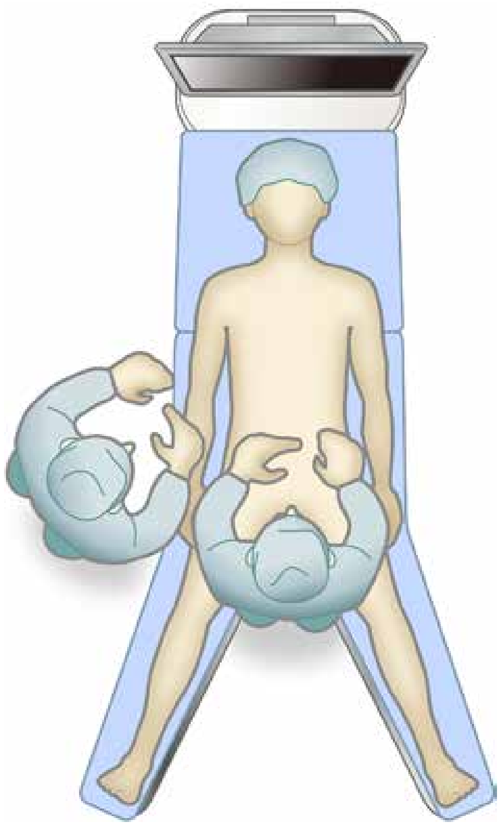

Figure 2 The surgeon stands between the legs of the patient and the assistant stands to the right of the patient to operate the camera scope.

Figure 3 For the GelPOINT Mini, a mini-port can be inserted regardless of the location of the platform. We inserted a port for the camera on the right side of the patient (C), a port for the surgeon's left hand on the left cranial side of the patient (L), and a port for the right hand primarily used by the surgeon for the vessel-sealing device on the left caudal side of the patient (R).

USA) as a gripping forceps, which has an articulating tip for single-port surgery. Prior to performing this surgery, it is important to thoroughly master the skills of bending the forcep tip with the left hand. We use a rigid camera scope 5 mm in diameter with a 30° viewing angle. A camera head that obtains clear images must be used even when using a 5-mm scope.

Procedure

Surgery was performed under general anesthesia. Bilateral lung ventilation was performed through a single-lumen endotracheal intubation tube. To begin with, a 3-cm transverse incision was made along Langer's lines 1 cm caudal below the xiphoid process. The incision can also be made in a vertical manner, and when taking out large tumors, this type of wound tends to expand. Caution should be exercised as if the skin incision is made too close to the xiphoid process, it can be difficult for the forceps to reach the posterior aspect of the sternum. The rectus abdominis is dissected where it attaches to the xiphoid process to reach the posterior aspect of the xiphoid process, the thymus is then blindly detached from the posterior aspect of the sternum using a finger. Thereafter, a 0.5–1 cm vertical incision is made on the fascia of the rectus abdominis, without opening the peritoneum, and a space is created to insert the port for single-incision surgery. There is no need to dissect the xiphoid process. The GelPOINT Mini, a port for single-incision surgery with three mini-ports, is inserted into the subxiphoid incision (*Figure 3*). The CO_2 insufflation tube is connected to the GelPOINT Mini and CO_2 insufflation is performed in the mediastinum at 8 mmHg. The surgeon detaches the thymus from the posterior aspect of the sternum to the neck using the LigaSure™ Maryland device. The positive pressure of CO_2 insufflation eliminates pressure on the pericardium and bilateral lungs and, along with the detachment of the thymus, broadens the space at the posterior aspect of the sternum. Bilateral incisions are made into the mediastinal pleura and the thoracic cavity is exposed bilaterally.

Next, the locations of the bilateral phrenic nerves are identified. The location of the left phrenic nerve on the caudal side in the thoracic cavity can be verified by either pulling the pericardial adipose tissue to the right, or by displacing the heart with cotton swabs for thoracoscopic

Figure 4 Uniportal subxiphoid video-assisted thoracoscopic thymectomy (10).
Available online: http://www.asvide.com/articles/1049

surgery. The pericardial adipose tissue and thymus are detached from the pericardium in an anterior manner from the bilateral phrenic nerves. To prevent collateral damage to the adjacent organs when using a vessel-sealing device, the device should only be used once the dissected thymus is at a safe distance and is sufficiently detached from vital structures, such as the pericardium and brachiocephalic vein. The left lobe of the thymus is pulled toward the right of the patient by bending the forceps of the left hand to the right. At this point in time, the surgeon crosses hands to detach the left lobe with LigaSure™. The right lobe of the thymus is pulled towards the left of the patient by bending the forceps to the left. This time the surgeon does not need to cross hands. The lower pole of the thymus is detached from the pericardium.

A trick to perform this surgery well is to firmly grasp the thymus near the detachment site with the forceps in the left hand and pull. To safely expose the distal side of the left brachiocephalic vein, the superficial adipose tissue is slowly and gradually detached at the area thought to be near the left brachiocephalic vein. The proximal side of the left brachiocephalic vein is close to where it joins the right internal thoracic vein. Similar to the distal side, the proximal side is exposed by slowly and gradually detaching superficial adipose tissue at the area thought to be near the left brachiocephalic vein. Once the proximal side of the left brachiocephalic vein is exposed, the area of the confluence of the brachiocephalic veins is exposed. Thereafter, the neck portion is detached and the thin membrane above the thymus is dissected. Although the right internal thoracic vein is not usually dissected, it can be done if it hinders the operation. While exercising caution to not injure the left brachiocephalic vein, the superior pole of the thymus is grasped using grasper forceps and pulled caudally to push the left brachiocephalic vein and expose a good field of vision of the neck. The superior pole of the thymus and the cervical adipose tissue are dissected from the right brachiocephalic vein on the right side, the thyroid at the upper end, the brachiocephalic artery and trachea on the posterior aspect, and the left brachiocephalic vein on the left side. Due care should be exercised to not damage the inferior thyroid vein. Lastly, the thymus is pulled to either the right or left and dissected from the innominate vein. In the sequential order of the procedure, the thymic vein is dissected using a LigaSure™ device and thymectomy is completed. The resected thymus is placed in a pouch in the mediastinum and removed from the body through the subxiphoid incision. A 20-Fr drain is inserted through the subxiphoid incision and the surgical incision is closed (*Figure 4*).

Tips, tricks, and pitfalls

When establishing artificial ventilation, use pressure control ventilation delivered at the minimal intratracheal pressure to ensure sufficient ventilation. PEEP is not used as it inflates the lungs and disturbs the operative field. CO_2 insufflation in the mediastinum at 8 mmHg provides a good operative field by maintaining lung ventilation and moderately eliminating pressure on the lungs bilaterally.

The use of a long-rigid camera scope prevents interference with the surgeon's hands.

When a LigaSure™ device with an unarticulated tip is difficult to reach the posterior aspect of the sternum, scissors with a flexible tip should be used that can connect with a monopolar or bipolar sealer.

The LigaSure™ tip operated by the right hand of the surgeon can interfere with the camera scope and forceps of the left hand, restricting where the surgeon intends to go. In a single-port surgery, the camera scope and forceps can crossover within the port. The pathway by which the surgeon inserts the LigaSure™ device with his/her right hand can pass either above or below the camera scope and forceps of the left hand; thus, the placement of the LigaSure™ tip held with the right hand will vary greatly. If it seems that the LigaSure™ is not advancing in the intended direction, the pathway should be changed.

In the event that the tumor has invaded into one side of the thoracic cavity, the contralateral thoracic cavity will not be opened to prevent contralateral tumor dissemination from occurring in some cases; this makes it difficult to identify the location of the phrenic nerves. To prevent injury to the phrenic nerves, it is generally important to identify their location.

Following thymectomy, the thymus/thymoma is placed in a pouch in the mediastinum and removed through the subxiphoid incision. With a shaft-type pouch, the pouch insertion opening will be in the direction of the forceps insertion and tangential direction, which makes it difficult to place the resected thymus into the pouch (*Figure 4*). In such cases, once a non-shaft-type pouch is inserted into the mediastinum, the surgeon should expand the pouch in the mediastinum using forceps so that the thymus can be inserted into the pouch.

For surgeons who are unfamiliar with single-port surgery and the subxiphoid approach, the authors recommend first commencing with a subxiphoid incision and a 5-mm port in the right 5th intercostal space (8). The use of this method greatly decreases the interference between the forceps held by both hands of the surgeon. It also facilitates suturing operations such as the pericardial patch closure.

It is also important achieve hemostasis in case of bleeding. If bleeding occurs from the brachiocephalic vein, pressure is first applied with cotton swabs for thoracoscopic surgery. If pressure hemostasis is achieved, hemostasis is performed with the use of TachoSil® (Takeda Austria GmbH, Linz, Austria) or other hemostatic drugs. Regardless of the whether single-port surgery is being performed, at the time of bleeding an additional port can be inserted in the midclavicular line of the 5th or 6th intercostal space of the right anterior chest to obtain better maneuverability. If pressure hemostasis is not achieved, immediately switch to a median sternotomy. Some institutions perform a thymectomy using an approach from the lateral thoracic side with the patient in the decubitus position. However, there is the risk that in the decubitus position, the distal end of the left brachiocephalic vein cannot be taped. As the subxiphoid approach is performed in the supine position, the surgery can be quickly switched to a median sternotomy if necessary.

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Footnote

Conflicts of Interest: The author has no conflicts of interest to declare.

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Subxiphoid SILS thymectomy

Jay Karunanantham, Matthew Fok, Jason M. Ali, Adam Peryt, Aman Coonar, Giuseppe Aresu

Department of Thoracic Surgery, Papworth Hospital NHS Foundation Trust, Cambridge, UK

Correspondence to: Mr Giuseppe Aresu, MD, PhD. Department of Thoracic Surgery, Papworth Hospital NHS Foundation Trust, Papworth Everard, Cambridge, CB23 3RE, UK. Email: giuseppe.aresu@nhs.net.

Abstract: Thoracic surgery is rapidly evolving with minimally invasive strategies now dominating. Thymectomy has traditionally been performed through a sternotomy, but more recently video-assisted thoracoscopic surgery (VATS) approaches have become increasingly popular. To further minimise surgical impact, the uniportal subxiphoid VATS technique has recently been described, using a muscle sparing incision that avoids intercostal nerve injury. A potential advantage that makes this approach particularly suited to thymectomy includes the ability to access both sides of the chest with a single incision. There is also the potential for reduced post-operative pain and chronic thoracostomy neuralgia. Here we describe the management of a patient with thymoma, reporting our procedure and technique for performing uniportal subxiphoid VATS thymectomy.

Keywords: Thymectomy; single incision laparoscopic surgery (SILS); subxiphoid; video-assisted thoracoscopic surgery (VATS); single incision thoracoscopic surgery; uniportal

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Introduction

Although rare, thymoma constitutes the most common malignancy of the anterior mediastinum (1). Surgical thymectomy with complete resection of thymoma remains the gold standard in the management of these patients, which has good long term survival and recurrence rates when complete en-bloc resection is achieved (1,2).

Traditionally, thymectomy is approached through a median sternotomy which provides full exposure and access to surrounding mediastinal structures and pericardial fat which may potentially be involved with the tumour. However, over recent years development of video-assisted thoracoscopic surgery (VATS) has provided an attractive alternative minimally invasive operative strategy. Now median sternotomy is reserved for patients in whom complete resection is not thought possible via the VATS approach or due to intra-operative complications. VATS surgery has evolved over time from multiport to uniportal access with the aim of reducing the pain associated with multiple trans-thoracic incisions. Uniportal VATS has become widely adopted as the approach of choice for managing a variety of thoracic diseases including thymectomy (3).

More recently, to further minimise the surgical impact, the uniportal subxiphoid VATS (SVATS) technique has been described. This approach may offer several advantages when performing a thymectomy, including: the ability to access both sides of the chest with a single incision, reduced post-operative pain and chronic thoracostomy neuralgia due to being a muscle sparing incision and to avoiding damage to the intercostal nerves (4).

This case report describes our procedure and technique for performing uniportal subxiphoid VATS thymectomy.

Case presentation

A 51-year-old female myasthenic patient was referred for surgical management of a 2.5 cm anterior mediastinal mass likely to be a thymoma. The computed tomography (CT) scan did not reveal any obvious invasion of surrounding mediastinal structures (*Figure 1*). The decision was made to proceed with an extended thymectomy. She was otherwise fit and well with no co-morbidities. She had

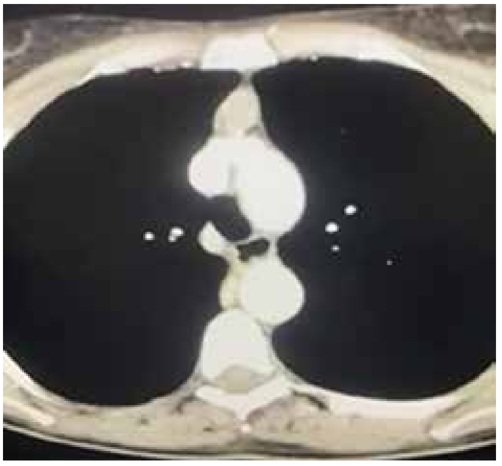

Figure 1 Pre-operative computed tomography scan.

Figure 2 Subxiphoid incision for thymectomy.

bilateral breast implants.

Surgical procedure

A single staged bilateral surgical intervention was planned. With the patient under general anesthesia and double lumen endotracheal tube intubation we positioned the patient supine with both arms adducted. Inflatable air bags were positioned under the right and left hemithorax. These were later inflated, to tilt the patient and achieve better visualisation of the medial mediastinum as required.

A 3 cm midline vertical incision was made below the sternocostal triangle to expose the xiphoid process. Dissection of the linea alba was performed and the pleural cavity was entered by blunt finger dissection above the level of the diaphragm (*Figure 2*). A SILS port (Covidien, Mansfield, MA, USA) was then inserted (*Figure 3A*), and CO_2 insufflated at a maximal pressure of 8 mmHg. CO_2 insufflation within the mediastinum generates a very useful amount of extra working space within the anterior-superior mediastinum allowing for easier dissection and better visualization of the mediastinal structures especially toward the cranial part of the mediastinum cephalad to the left innominate vein including the upper poles of the thymus.

Under visual guidance provided through a 10-mm EndoCAMeleon® Telescope (Karl Storz, Tuttlingen, Germany) the operator utilized grasping forceps designed for single-incision surgery (SILS Hand Instruments Endo Clinch™ II, Covidien, Mansfield, MA, USA—*Figure 3B*) and performed dissection, coagulation, and division of tissue mainly using the Sonicision™ cordless ultrasonic dissection

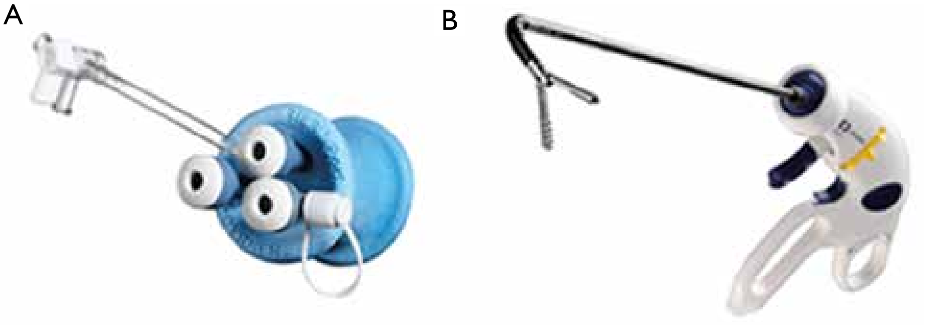

Figure 3 Instruments used for subxiphoid VATS thymectomy include the (A) single incision laparoscopic surgery (SILS) port and (B) SILS Endo Clinch™ (Covidien, Mansfield, MA, USA. Reproduced from www.medtronic.com).

Figure 4 SILS port inserted into subxiphoid incision (Covidien, Mansfield, MA, USA). SILS, single incision laparoscopic surgery.

Figure 5 Immediate post-operative appearance with a single drain.

device (Covidien, Mansfield, MA, USA) and occasionally using a normal straight hook cautery (*Figure 4*).

The phrenic nerves and mammary arteries and veins bilaterally were visualized throughout the procedure minimizing the risk of injury as was the cranial part of the mediastinum, permitting a safe dissection en-bloc of the thymus, thymic mass, and surrounding fatty tissue anterior to the phrenic nerves. The specimen was removed using an endoscopic retrieval bag (EndoBag, Covidien, Mansfield, MA, USA).

One 28 Fr drain was placed via the subxiphoid incision (*Figure 5*) and placed on −2 KPa suction using a Thopaz system (Medela, Switzerland).

Post-operative management

The patient was mobilized and received intensive physiotherapy from day 0 with minimal pain. The drain was removed on the first post-operative day and the patient was discharged home on the second post-operative day. Adequate post-operative analgesia was achieved with paracetamol alone. Final histology confirmed a Masaoka stage I thymoma with an R0 resection.

Discussion

Although surgical resection through a median sternotomy remains the gold-standard approach for thymectomy it is associated with significant morbidity. Division of the sternum requires a large incision and is associated with greater pain, length of hospital stay and slower return to pre-morbid function when compared to VATS thymectomy. VATS thymectomy has been demonstrated to have several advantages including reduced intraoperative blood loss, earlier removal of chest drains, reduced requirement for blood products, reduced inflammatory cytokine response, shorter hospital stay and superior cosmesis (5). VATS thymectomy can be performed through left, right or bilateral approaches, which is dependent on pre-operative planning, intra-operative findings but often surgeon preference. There are several studies which suggest the superiority of a VATS approach to thymectomy compared to median sternotomy without compromising the oncological outcome (6).

As the minimally invasive era has evolved, the recent development of uniportal thoracoscopic access has become increasingly popular. This approach was first described by Rocco *et al.* for minor thoracic and pulmonary procedures and is now used for a variety of major thoracic procedures including pulmonary lobectomies (3).

A further development has been the use of the subxiphoid VATS approach which has been described for a number of cardiothoracic procedures including subxiphoid pericardial window creation, coronary artery surgery, ablative sympathectomy, pulmonary wedge resection and even lobectomy (7-10). The potential benefits of the subxiphoid VATS approach includes reduced postoperative pain and the absence of chest wall paraesthesia due to preservation of the intercostal innervation and the absence of chest drains impinging on the intercostal neurovascular bundles.

Uniportal subxiphoid VATS access provides excellent views of the anterior mediastinum as well as of the two pleural spaces including the phrenic nerves making it an ideal alternative approach to performing a thymectomy. This access and view provides the surgeon the opportunity to perform an oncologically radical and safe resection of the thymus and peri-thymic fatty tissues with low risk of incurring phrenic nerve injury.

The subxiphoid VATS technique can be learnt by surgeons experienced in uniportal VATS. The camera views and instrument positioning can be more challenging than for conventional VATS but the necessary skills can be acquired over a short learning curve, particularly for minor procedures. The approach has been demonstrated to be safe with good short-term outcomes and superior cosmetic results (7-11).

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Footnote

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The future of minimally invasive thymectomy: the uniportal subxiphoid video-assisted thoracic surgery technique—a case series

Jason M. Ali[1#], Sara Volpi[1#], Lei Jiang[2], Chenlu Yang[2], Liang Wu[2], Gening Jiang[2], Giuseppe Aresu[1]

[1]Thoracic Surgery, Royal Papworth Hospital NHS Foundation Trust, Papworth Everard, Cambridge, UK; [2]Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University, Shanghai 200433, China

Contributions: (I) Conception and design: L Jiang, C Yang, L Wu, G Jiang, G Aresu; (II) Administrative support: None; (III) Provision of study materials or patients: L Jiang, C Yang, L Wu, G Jiang, G Aresu; (IV) Collection and assembly of data: L Jiang, C Yang, L Wu, G Jiang, G Aresu; (V) Data analysis and interpretation: JM Ali, S Volpi; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

[#]These authors contributed equally to the work.

Correspondence to: Jiang Lei, MD. Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University, Shanghai 200433, China. Email: jiangleiem@aliyun.com.

Background: Thymectomy for early thymic tumours is rarely performed by sternotomy in the current era of minimally invasive thoracic surgery. With standard video-assisted thoracic surgery (VATS) it can be difficult to visualise the entire thymus. Subxiphoid VATS (SVATS) has been developed as an alternative surgical approach which is particularly suited to performing thymectomy due to providing visualisation of both pleural cavities. This study reports a large case series of uniportal SVATS extended thymectomy.

Methods: Over the period of study, 39 patients underwent uniportal SVATS extended thymectomy for a thymic nodule at the Shanghai Pulmonary Centre. Seventeen patients were female, and the mean age of the cohort was 60 years. The mean size of nodule was 30.27 mm.

Results: The mean operative duration was 2.1 hours, with one conversion to thoracotomy for bleeding. The mean operative blood loss was 93 mL. The median length of hospital stay was 4 days. There were no episodes of phrenic nerve palsy and the 30-day survival was 100%. Comparing the first and second cohorts, there was reduced operative time (P=0.005), reflecting the learning curve.

Conclusions: The uniportal SVATS technique is safe and feasible for performing extended thymectomy. It allows the surgeon to perform a radical oncological thymectomy with lower risk of damaging adjacent nerves and vessels. The procedure can be performed safely during the learning curve period.

Keywords: Thymectomy; single incision laparoscopic surgery; subxiphoid; video-assisted thoracic surgery (VATS); subxiphoid VATS (SVATS)

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Introduction

Thoracic surgical techniques have evolved significantly over the last two decades. For anterior mediastinal masses, of which thymoma is the most frequent, very often surgical treatment is recommended as the principal management. The gold standard surgical approach to anterior mediastinal masses like thymomas, has been median sternotomy. Nowadays, alternative less invasive surgical techniques are possible thanks to video-assisted thoracoscopic surgery (VATS). Thoracoscopy offers the benefit of reduced postoperative pain allowing for earlier mobilisation which facilitates shorter hospital lengths of stay. It is reported that recovery to normal function is faster and patients experience fewer post-operative complications (1-3).

Figure 1 Uniportal subxiphoid incision and position of instruments intraoperatively.

For thymectomy, cervical and standard lateral thoracic VATS has been described. The cervical approach has not become popular because of the small size of the neck wound (4).

At present, the lateral approach through a thoracoscopic incision is the most common surgical approach; however, it can be challenging to achieve a satisfactory visualisation of the whole thymus from 'phrenic to phrenic' and passing through the intercostal space could lead to postoperative acute and chronic pain due to intercostal nerve injuries (4).

Uniportal subxiphoid VATS (SVATS) approach has been proposed to potentially reduce the invasiveness and the surgical stress providing exposure of entire thymus and a bilateral vision of the phrenic nerves. In this technique, a single vertical incision is made in the subxiphoid region, allowing muscle-sparing and avoiding intercostal incisions and intercostal nerve damage (5).

The SVATS technique is becoming established as an alternative thoracoscopic approach increasingly utilised for a range of thoracic surgical procedures including lobectomies, segmentectomies, pneumonectomy (6-12). Here we present our case series of SVATS thymectomy demonstrating that this technique should be considered as an alternative approach to anterior mediastinal masses.

Methods

The reported surgeries were performed in Shanghai Pulmonary Hospital, Shanghai, China, between October 2014 and January 2018.

Patient demographics, intraoperative and postoperative data were collected from patients notes and electronic records. The following are considered contraindications to SVATS:

(I) stage 3–4 thymic tumours;
(II) body mass index >30 kg/m$^{2;}$
(III) impaired ventricular function and/or cardiomegaly;
(IV) severe arrhythmia.

Surgical technique

Our technique for SVATS thymectomy has been previously described (8). In summary: the operation is performed with the patient positioned supine on the operating table ventilated through a double lumen tube to permit selective ventilation to facilitate the procedure. Access is through a 4 cm subxiphoid vertical incision and a wound retractor positioned upon entry into the pleural spaces. The xiphoid process can be resected to provide an optimal view if required. The sternum is elevated using a table mounted retractor to maximise the anterior mediastinal operating space (*Figure 1*). A 10 mm 30° angle thoracoscope (Karl Storz, Tutlingen, Germany) was used. Subxiphoid VATS instruments are used to perform the procedure (Shanghai Medical Instruments Group Ltd, Shanghai, China).

The right pleural cavity is opened initially, with the left lung being selectively ventilated. Electrocautery dissection is used to mobilise the right lobe of the thymus and any pericardial and epiphrenic fat pads, with clear visualisation of the phrenic nerve provided by SVATS. The large neck veins are well visualised using this approach and guide the superior dissection. Subsequently, the left pleural cavity is opened and the thymus dissected from the pericardium in a similar manner. The resected specimen can then be retrieved through the subxiphoid incision (*Figure 2*).

At the end of the procedure, one or two chest drains are placed through the subxiphoid incision (*Figure 3*). The patients are usually extubated on the operating table.

Data collection

Data was retrieved from a prospectively maintained database with additional data retrieved retrospectively from patient notes and electronic patient records. Data concerning patient demographics, intraoperative details and post-operative course were collected.

Figure 2 Example thymic specimen resected by SVATS. SVATS, subxiphoid video-assisted thoracic surgery.

Figure 3 Position of drains following closure of uniportal subxiphoid incision.

Table 1 Preoperative entire cohort characteristics

Characteristic	Values
Sex	
Male	22
Female	17
Age, mean [range]	60 [26–80]
Smoking	
Yes	13
No	26
BMI	24.3 [14.37–32.46]
FEV_1, L	
Actual	2.33±0.73
% predicted	88.72±18.68
Albumin, mg/L	38.79±3.90
Haemoglobin, g/dL	133.0±13.63
Lesion size, mm	30 [12–77]

BMI, body mass index.

Results

Patient characteristics

Over a period of study, 39 SVATS thymectomies were performed for thymic lesions. Patient characteristics are summarised in *Table 1*. The mean age of patients was 60 years.

Intraoperative details

Intraoperative details are summarised in *Table 2*. The mean length of surgery was 2 hours with a range of 1–4 hours. Injury to the innominate vein resulted in one patient requiring conversion to thoracotomy in the series. There was a low intra-operative blood loss with a mean loss of 93 mL. Comparing the first 20 cases to the more recent 19 cases, it is evident that there was a significant improvement in terms of reduced operative duration (2.55 *vs.* 1.68 hours, P=0.005).

Postoperative course

One patient's postoperative course was complicated by a myasthenic crisis. The patient required intubation and respiratory support for 1 week. The patient was discharged on day 9. The median length of hospital stay was 4 days. There were no instances of phrenic nerve palsy. There was no 30-day mortality in this patient series.

Post-operative pathological examination of the resected thymic lesions is summarised in *Table 3*. Thymic cysts were the commonest pathology observed.

Discussion

This report demonstrates that the uniportal subxiphoid VATS approach can be considered as an alternative approach to performing thoracoscopic resection of anterior mediastinal masses. The approach provides excellent visualisation of the entire thymus from phrenic-to-phrenic allowing for radical resection under direct vision, whilst performing a minimally invasive surgery.

In recent years, VATS has been increasingly used as a surgical approach for thymectomy using a lateral approach. While the lateral approach is ideal for lobectomy and tumour resections, performing a total thymectomy via the lateral approach can be challenging. In particular, the lateral approach does not allow a complete vision of the

Table 2 Operative characteristics

Characteristic	Entire cohort	First 20 cases	Last 19 cases	P value
Surgical duration (hours)	2.13±0.98	2.55±1.01	1.68±0.74	0.005
Conversion to thoracotomy	1	1	0	0.99
Operative blood loss (mL)	93.33±74.31	111.0±92.90	74.73±42.86	0.21
Drainage in first 24 hours (mL)	244.21±179.82	271.0±183.73	214.44±175.70	0.39
Postoperative length of stay (days)	4.33±2.84	4.20±1.79	4.47±3.68	0.64

Statistical analysis comparing first 20 and last 19 cases—Mann-Whitney U test.

Table 3 Postoperative histopathology

Type	Frequency
Thymic cyst	21
Thymic bronchial cyst	6
Thymic hyperplasia	2
Ectopic thyroid tissue	2
B2 thymoma	3
AB thymoma	5

contralateral phrenic nerve (4). However, in comparison to sternotomy there are many advantages reported including reduced intraoperative blood loss, earlier removal of chest drains, reduced requirement for blood products, reduced inflammatory cytokine response, shorter hospital stay and superior cosmetic result (13), without compromising the oncological outcome.

In an attempt to further refine the thoracoscopic technique and improve post-operative outcomes, the SVATS approach has been developed with the advantage of avoiding intercostal incision and manipulation (6-11,14). Since the postoperative chest drains do not enter the thoracic cavity through intercostal spaces postoperatively, they do not impinge on the intercostal neurovascular bundle. This has the potential benefit of allowing early aggressive mobilization which is recognised to be associated with reduced risk of venous thromboembolism and may facilitate a reduction in pulmonary atelectasis and development of lower respiratory tract infections. Together this offers the potential for reduced hospital length of stay (15). To date, there is only one randomised controlled trial comparing SVATS to standard VATS—in patients undergoing bullectomy and pleurectomy. They observed a significant reduction on postoperative pain in the SVATs group which was associated with earlier mobilisation and reduced risk of complication (16).

The SVATS approach is particularly suited to thymectomy as it provides excellent views of the anterior mediastinum as well as of the two pleural spaces including the phrenic nerves. This access and view provide the surgeon the opportunity to perform an oncologically radical and safe resection of the thymus with low risk of injuring the phrenic nerves or other intrathoracic structures. To date there have been a small number of reports of SVATS thymectomy, but our study represents the largest case series to date (7,17-19). One recent series has reported performing robotic SVATS thymectomy (20), highlighting the versatility of the subxiphoid incision. In all of the published series there have been no mortality to date, and the incidence of intraoperative and postoperative complication is very small.

Our case series adds further to the evidence that the uniportal SVATS approach is a safe and appropriate method for thymic resection particularly in non-obese patients with Masaoka stage I tumours and without significant underlying cardiorespiratory disease. In our practice, comparing this case series with our early experience, the surgical duration, operative blood loss, 24-hour drainage and hospital stay have all decreased. This observation supports the concept that there is a learning curve and that over time with increased skill, outcomes can continue to improve. We would predict that this approach is associated with reduced pain and earlier postoperative mobility and discharge and intend to examine this further in a randomised controlled trial.

Conclusions

The uniportal SVATS technique should be considered as an alternative approach to thoracoscopic resection of an anterior mediastinal mass. The uniportal SVATS technique is particularly suitable for thymectomy since it allows an extended view of the anterior mediastinum as well as the right and left pleural spaces from phrenic-to-phrenic. It allows the surgeon to perform a radical oncological thymectomy with lower risk of damaging adjacent nerves and vessels.

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None.

Footnote

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

Ethical Statement: The study was approved by the Shanghai Pulmonary Hospital Ethical committee (No. 010029) and informed consent was obtained from all patients.

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Subxiphoid single-port video-assisted thoracoscopic surgery

Chia-Chuan Liu[1], Chih-Shiun Shih[1], Yun-Hen Liu[2], Chih-Tao Cheng[3], Enrico Melis[4], Zhen-Ying Liu[3]

[1]Division of Thoracic Surgery, Department of Surgery, Koo Foundation Sun Yat-Sen Cancer Center, Taipei, Taiwan, China; [2]Division of Thoracic Surgery, Chang Gung Memorial Hospital, College of Medicine, Chang Gung University, Keelung, Taiwan, China; [3]Department of Medical Research, Koo Foundation Sun Yat-Sen Cancer Center, Taipei, Taiwan, China; [4]Division of Thoracic Surgery, Department of Surgical Oncology, Regina Elena National Cancer Institute, Rome, Italy

Contributions: (I) Conception and design: CC Liu, YH Liu; (II) Administrative support: CC Liu, CS Shih, E Melis; (III) Provision of study materials or patients: CC Liu, CS Shih; (IV) Collection and assembly of data: CC Liu, CS Shih, E Melis; (V) Data analysis and interpretation: CC Liu, ZY Liu; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Chia-Chuan Liu, MD. Division of Thoracic Surgery, Department of Surgery, Koo Foundation Sun Yat-Sen Cancer Center, 125 Lih-Der Road, Peitou District, Taipei, Taiwan, China. Email: gcliu@kfsyscc.org.

Background: We report the feasibility and safety of chest surgery through the subxiphoid single port approach based on our preliminary experience.

Methods: From December 2013 till January 2016, 39 patients underwent 40 thoracoscopic surgeries via a 3- to 4-cm subxiphoid single incision. A sternal lifter was applied for better entrance and working angle. A zero-degree deflectable scope was preferred. The technique for anatomic resection was similar to that in the traditional single-port approach. Patient characteristics and demographic data were analyzed.

Results: There were 29 females and 10 males, with a median age of 56 years. Indication for surgery included 24 patients with primary lung cancer, eight with lung metastases, two with benign lung lesions, one with bilateral pneumothorax, and five with mediastinal tumors. Surgeries included lobectomy in 21, segmentectomy in five, wedge resection in nine, and mediastinal surgery in five patients. There was no surgical mortality. Complications (10%, 4 in 40) included postoperative bleeding in one patient, chylothorax in one patient, and transient arrhythmia in the early learning curve in two patients.

Conclusions: Our results indicated that subxiphoid single-incision thoracoscopic pulmonary resection could be performed safely but under careful patient selection with modification of instruments. Moreover, having a previous single-port incision experience was crucial. Major limitations of this approach included more frequently encountered instrument fighting; interference of left-side procedure related to heartbeat and radical mediastinal lymph node (LN) dissection; and the ability to handle complex conditions, such as anthracotic LNs, diffuse adhesion, and major bleeding.

Keywords: Subxiphoid; single-port; thoracoscopic; lobectomy; segmentectomy

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Introduction

Thoracoscopic surgery is increasingly performed because of improvements in endoscopic instruments and surgical techniques. Growing evidence indicates that thoracoscopic surgery is associated with decreased postoperative pain, reduced length of hospital stay, and fewer postoperative complications (1-6). However, traditional transthoracic video-assisted thoracic surgery (VATS) always involve the creation of a small incision on the chest wall and may result in intercostal neuralgia and chronic thoracotomy pain (7-9). We believe that the approach or incision in thoracic surgery still has the potential for continuous improvements. Therefore, we investigated an alternative approach for thoracic intervention.

Subxiphoid incision is employed in many transthoracic procedures for both thoracic and cardiovascular surgeries.

These procedures include subxiphoid pericardial window creation, coronary surgery, thymectomy, and pulmonary metastasectomy (10-14). We have used animal models to determine alternative approaches such as natural orifice transluminal surgery through transoral, transtracheal (15-18), and transumbilical routes (19). However, most of these procedures are currently not feasible to be performed in humans.

With previous experience on transthoracic single-port VATS surgery since 2010 (20,21), despite trauma outside on the chest has been minimized to only one. However, we observed that the single-port approach did not significantly reduce postoperative pain as compared with a two-port approach (22). Moreover, this surgery still leaves a wound in the chest near the breast, which is not idealistic especially for young females with cosmetic concern. Therefore, we switched to a subxiphoid single-port technique for lung resection and described the first case report of subxiphoid single-incision thoracoscopic left upper lobe (LUL) lobectomy (23). However, this novel technique is quite challenging and has some limitations. Appropriate patient selection and modification of instruments are necessary to perform a safe and sound surgery. Here, we report our preliminary experience with the subxiphoid single-incision approach for thoracoscopic chest surgery.

Materials and methods

This study retrospectively analyzed 39 consecutive patients who underwent subxiphoid single-incision thoracoscopic surgery at the Koo Foundation Sun Yat-Sen Cancer Center between December 2013 and January 2016. Inclusion criteria for patients were (I) confirmed early lung cancer without obvious mediastinal lymph node (LN) metastasis according to preoperative image staging, (II) metastatic lung cancer, (III) mediastinal disease, (IV) and unconfirmed lung nodule or benign lung lesion that deserved surgery. Exclusion criteria were similar to those for the traditional transthoracic approach. Moreover, patients with clinical stage I disease that is suitable for technique-demanding atypical segmentectomy, e.g., lower lobe posterior basal segmentectomy, were suggested to undergo transthoracic sublobar resection instead of subxiphoid lobectomy to preserve more lung parenchyma. All the patients were carefully explained about the benefits and drawbacks of the subxiphoid approach versus the transthoracic approach and were asked to sign an informed consent for subxiphoid surgery. Preoperative workup included complete blood counts, serum biochemistry tests, chest computed tomography (CT) scans, and positron emission tomography computed tomography (PET-CT) scans. Information on demographic characteristics of patients, operating time, number of dissected LNs, length of hospital stay, postoperative complications, and pathological characteristics of tumors according to the American Joint Committee on Cancer staging system (7th edition) was collected. This study was approved by the institutional ethical committee in Sun Yat-Sen Cancer Center Hospital, and we obtained the informed consent from every patient before surgery was performed.

Operative setting and surgical technique

The patients were orotracheally intubated with a double-lumen endotracheal tube to provide adequate one lung ventilation. Positioning of the patients was based on the location of the lesion and the procedure to be performed. Supine position was the standard position for mediastinal surgery, such as thymomectomy, or bilateral surgery for bilateral pneumothorax or pulmonary metastases. Semi-decubitus position was adopted in the early few cases; however, we now prefer true lateral-decubitus position as the standard position for anatomic lung resection. Artificial CO_2 pneumothorax was applied to none of the patients in the whole series.

Creation of the subxiphoid single port

A 3- to 4-cm vertical skin incision was made above the xiphoid process, after cutting the skin and the linea alba, and the muscle was detached to reach the xiphoid process. A blunt dissection was performed using a finger to create a subxiphoid route similar to a retrosternal route used for gastric tube pull-up after esophagectomy. A deep thyroid retractor was then applied to lift the sternum. By holding a sucker in the left hand, and an endoscopic hook cautery in the right hand of the operator, a thoracoscope was inserted into the substernal tunnel created previously by finger dissection. Under thoracoscopic guidance, pericardial fat was detached from the pleura and pericardium and the thoracoscope was inserted into the pleural cavity after hook cauterization on the pleura under direct observation (*Figure 1A,B*). A homemade trauma-less wound protector (trocar set) was designed for the subxiphoid port. By partially inserting an extra small size Alexis Wound Retractor (Applied Medical, USA) into a 12-mm laparoscopic trocar (Endopath Xcel Bladeless Trocars;

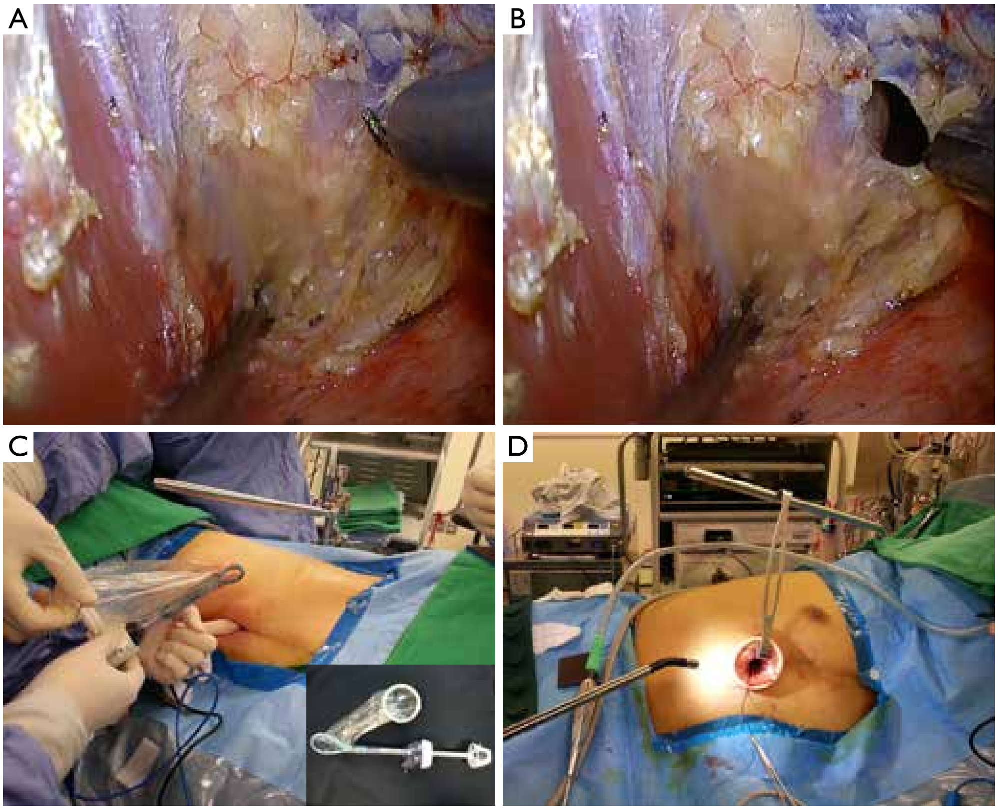

Figure 1 Novel method for creation of subxiphoid single port. (A,B) Under thoracoscopic guidance, pleura cavity was entered with laparoscopic hook cautery; (C) an Alexis Wound Retractor (Applied Medical, USA) was partially inserted into a 12 mm laparoscopic trocar (Endopath Xcel Bladeless Trocars, Ethicon, USA) to facilitate the application of wound protector, and lifted the sternum with a retractor; (D) completion view of subxiphoid single port.

Ethicon Inc., Blue Ash, OH, USA; *Figure 1C*), the wound protector was deployed into the pleural cavity. This was confirmed later by using the thoracoscope. Finally, a sternal lifter was used to lift the tunnel above the mediastinum and the pericardium to create more working space as well as avoid the interference of the heartbeat. A 10-mm, zero-degree articulating thoracoscope (EndoEye Flex; Olympus, Tokyo, Japan) was inserted into the subxiphoid incision to explore the pleural cavity for anatomic lung resection (*Figure 1D*).

Anatomic consideration and surgical technique

When the traditional 30-degree scope was inserted through the subxiphoid port into the chest cavity, it ran parallel to the mediastinum and directly faced the oblique fissure. It is even clear if we apply 3D-reconstructed CT images for better anatomic understanding; the subxiphoid incision itself is located at the horizontal level of the fifth costal junction to the sternum, and the distance might be 2–3 cm longer compared with a transintercostal approach. With the oblique fissure in the front, it was easy to visualize the interlobar bronchovascular structure from the oblique fissure. The anterior and apical pulmonary arteries and the superior/inferior pulmonary vein (*Figure 2*) could also be easily approached anteriorly/inferiorly (*Figure 2D*); however, it was quite difficult to reach the deeply seated left-side subcarinal area. The instrument-fighting problem during the subxiphoid single-port surgery would be even more challenging than that encountered during the transthoracic approach since the mediastinum occupied the lower part of the working tunnel, which reduced the working space. Moreover, there was interference related to instrument transmission from the heartbeat during left-side procedures. Therefore, we employed the following methods to minimize these problems: (I) we released the fibrous and adipose tissue around the subxiphoid tunnel away from

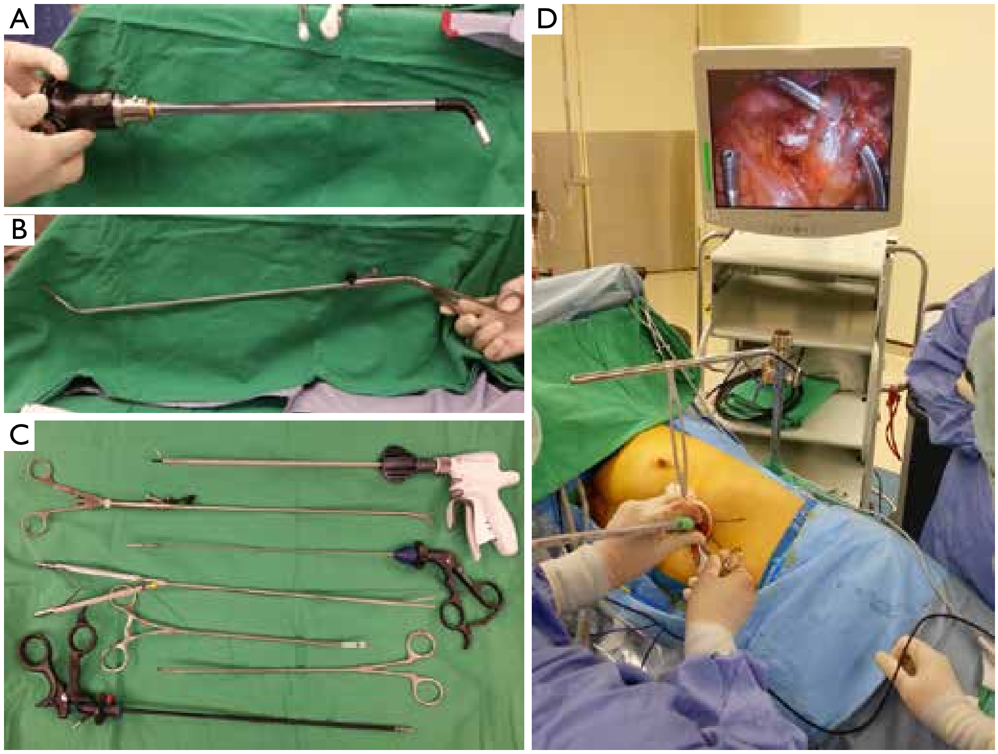

Figure 2 Modification of instruments used during subxiphoid single port lung resection. (A) An 10 mm articulating thoracoscope (EndoEye Flex, Olympus, Tokyo, Japan); (B) a novel laparoscopic instruments with adjustable and rotatable wrist (LYD RealAngle Articulating Instrument, Ningbo LYD Med Tech, China); (C) double joint thoracoscopic instruments (Scanlan international, USA), Harmonic scalpel (Ethicon, USA) and other laparoscopic instruments; (D) dissection of left upper superior pulmonary vein during trisegmentectomy via subxiphoid single port approach.

the pericardium and diaphragm. This enlarged the space of the port and provided more room for manipulation; (II) we applied a sternal retractor to lift the port away from the mediastinum, including the pericardium; (III) we used a small tidal volume whenever possible to let the mediastinum drop into the dependent non-operative side; (IV) we used long and curved or articulated instruments (*Figure 2A-C*) to avoid contact with the heart and to minimize both internal and external instrument fighting; (V) we used an articulate scope to obtain a better view from above, which was similar to the view with the traditional 30-degree lens in the transthoracic approach, and also minimized the instrument fighting.

Technically, the subxiphoid approach for anatomic lung resection follows the same principle as the transthoracic approach (*Figure 3A*), i.e., it uses a combination of traditional laparoscopic instruments or double-joint thoracoscopic instruments (Scanlan International, Inc., USA) for exposure and dissection, Endostapler (Ethicon Inc.), or Endo GIA Curved Tip Reload (Covidien and Medtronic, USA) for transecting the bronchovascular structure (*Figure 3B*) and lung parenchyma (20,21). Traditional open chest instruments are no longer used. However, stapling of vessels might be more challenge than transthoracic procedures related to instrument fighting and different angles needed to apply to the envil to pass through the hilar vessel safely.

For LN dissection, the intrapulmonary, hilar, and/or mediastinal LNs were retrieved using a combination of laparoendoscopic instruments and Harmonic scalpel (Ethicon Inc.) and the representative hilar/segmental LNs were checked intraoperatively by frozen to exclude the possibility of nodal metastasis. Complete lymphadenectomy in en-bloc style for the deeply seated right-side upper mediastinum and the left-side subcarinal nodes was sometimes difficult not only because most of the energy-

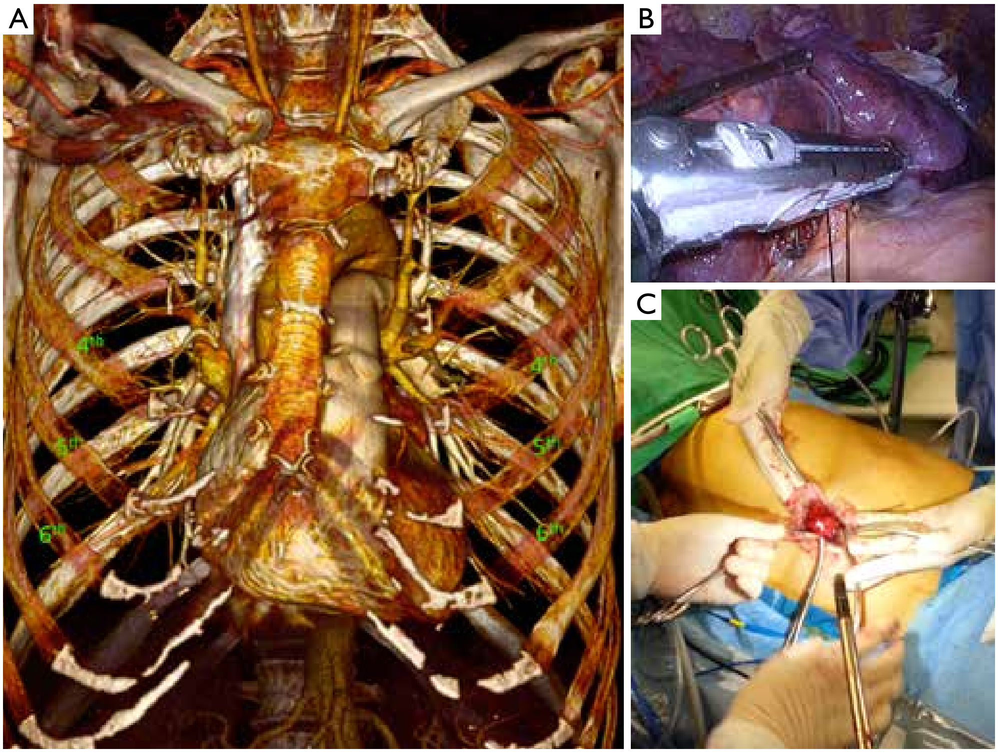

Figure 3 3D reconstructed CT images and intra-operative photos during subxiphoid approach. (A) 3D-CT reconstruction image from computer tomography scan showing the anatomic relationship between hilar structures to the subxiphoid area; (B) endostpaler inserted through subxiphoid incision for transection of the right middle lobe (RML) vein; (C) specimen retrieval through the subxiphoid incision is easier than through the narrow intercostal space. CT, computed tomography.

delivering instruments, such as hook and Harmonic scalpel, are straight and parallel to the mediastinum, but also due to the potential bleeding risks if injured the nearby great vessels. In some patients, right subcarinal lymphadenectomy is possible, but only when performed by experienced surgeons. Therefore, it is extremely important to carefully select patients suitable for this approach, which is probably reserved for nodal-negative patients after preoperative staging workup. The present study used both systematic LN sampling according to ACOSOG Z0030 protocol (24) and/or lobe-specific dissection method (25-27) based on the lobar location of the lesion. For patients with lung cancers having pure, ground-glass opacity (GGO), and only regional LN sampling was performed.

The specimen was secured in a plastic bag and delivered through the subxiphoid incision (*Figure 3C*). Specimen retrieval from the subxiphoid port was much easier than that through the transthoracic port without the limitation of the rib cage, thus indicating an advantage of the subxiphoid approach over the transthoracic approach. A chest tube was placed in the pleural cavity through the same subxiphoid wound (28,29). No epidural pain control or intercostal blockade was used in this study.

Results

From December 2013 to January 2016, 39 patients underwent 40 chest surgeries via a single incision 3- of 4-cm in length on the subxiphoid area (*Table 1*). In one patient, the surgery had to be repeated because of single pulmonary metastasis 1 year and 10 months after the previous bilateral pulmonary metastasectomies. There were 29 females and 10 males, with a median age of 55 years (range, 33–69 years). Indication for surgery included 24 patients with primary lung cancers, eight with lung metastases, two with benign lung lesions, one with bilateral pneumothorax, and five with mediastinal tumors. Operative procedures included lobectomy in 21, segmentectomy in five, wedge resection in nine, and mediastinal surgery in five patients. There were two patients requiring an additional 3-cm

Table 1 Indications and procedures for 39 patients underwent 40 chest operations via subxiphoid single port VATS approach

Location	Indication	Surgical type				Total
		Wedge	Segmentectomy	Lobectomy	Mediastinal surgery	
RUL	Lung cancer	2	0	6	0	8
	Benign lung	0	0	1	0	1
RML	Lung cancer	0	0	2	0	2
	Lung mets	1	0	2	0	3
	Benign lung	0	0	1	0	1
RLL	Lung cancer	0	1	2	0	3
	Lung mets	2	0	0	0	2
LUL	Lung cancer	0	3	4	0	7
	Lung mets	0	1	0	0	1
LLL	Lung cancer	1	0	3	0	4
RLL + LLL	Lung mets	1	0	0	0	1
RUL + LUL	Pneumothorax	1	0	0	0	1
RLL + LUL + LLL	Lung mets	1	0	0	0	1
Mediastinum	Mediastinum	0	0	0	5	5
Total		9	5	21	5	40

Mediastinal surgery, resection of thymic tumor and bronchogenic cyst. LUL, left upper lobe; LLL, left lower lobe; RUL, right upper lobe; RML, right middle lobe; RLL, right lower lobe; lung mets, lung metastasis; VATS, video-assisted thoracic surgery.

single chest incision to complete the procedure due to inadequate length of instruments and anthracotic LNs for anatomic lung resection. Bilateral surgery was adopted for four patients (three bilateral multiple wedge resections and another one patient underwent right-side upper mediastinal LN sampling to rule out N3 metastasis, followed by a left lower lobectomy and LN sampling). For 24 patients with primary lung cancers, the median tumor size was 2.0 cm (range, 0.8–5.5 cm), the median operation time was 3 hours (range, 1.0–4.5 hours), the median blood loss was 30 cc (range, 10–150 cc), and the median LN dissection number was 16.0 only (range, 4–37), which was inferior to our historical control group in the transthoracic procedure (20-22). Furthermore, fragmentation of dissected LNs was observed more frequently in the subxiphoid group. Tumor stages based on AJCC 7th were stage I in 18, stage IIa in 4, stage IIIa in 1, and stage M1a (two tiny pleural seedlings) in 1. For five patients with mediastinal surgery, radical thymothymecotmy was performed in one, resection of diaphragmatic bronchogenic cyst in one, and three patients received thymomectomy, with one of them undergoing partial pericardial resection and mesh-repair through the single subxiphoid incision. Among these 39 patients, 26 underwent anatomic lung resections [seven right upper lobe (RUL)/five right middle lobe (RML)/two right lower lobe (RLL)/four LUL/three left lower lobe (LLL) lobectomies, two tri-segmentectomies, two S3-segmentectomies, and one common basal segmentectomy], with a median operation time of 3 h (range, 2.0–4.5 h), median blood loss of 30 cc (range, 10–170 cc), and a median hospital stay of 5 days (range, 4–10 days).

No surgical mortality was observed in the entire series. Complications (4/40, 10.0%) included transient arrhythmia in the early learning curve period in two patients. Postoperative chylothorax was observed in one patient, which was managed with thoracic duct ligation. The procedure for this particular patient was right-side lymphadenectomy (station 4R) and wedge resection under the indication for second primary GGO lung cancer 2.5 years after the previous surgery for left upper lung cancer. One patient developed postoperative bleeding on postoperative day 2 because of delayed bleeding from a small vessel in the pericardial fat. This patient was reoperated using the transthoracic single-port approach to check the bleeding. After this painful experience, we innovated the current method for the safe creation of a subxiphoid port under direct vision. None of the patients experienced herniation in the subxiphoid area, nor phrenic nerve palsy, in this study.

Discussion

Based on our previous experience with the transthoracic single-port approach (20-22) and review of current animal and human studies (15-19), we employed the subxiphoid single-port approach for anatomic lung resection and learned a lot from this novel procedure. Although both the transthoracic and subxiphoid single-port techniques focus on hilar dissection, port design, instrument setting, and limitations of both the techniques vary considerably. We encountered some difficulties while using the subxiphoid single-port approach. First, creation of a safe subxiphoid single port is crucial. In contrast to the use of a laparoscopic trocar or SILS™ Port (Covidien) in other studies (13,14), we used a wound protector for creating the subxiphoid incision, which was easier and similar to that created in the transthoracic approach. Second, the visual field is restricted by the standard 30-degree thoracoscope inserted through the subxiphoid single incision because the visual field is parallel to the mediastinum and is disrupted by the instruments. An articulating endoscope (*Figure 2A*) is more useful in regaining the visual field similar to that in the traditional transthoracic approach and provides more space for other surgical instruments. Third, instrumental transmission of the heartbeat is troublesome, especially during dissection or stapling of the hilar structures while performing procedures on the left side. Moreover, instruments compressing the heart might induce arrhythmia and even transient hypotension. We used a sternal lifter and applied low tidal volume setting on the ventilator to overcome this problem. Fourth, traditional endoscopic instruments might be too short and interference between the instruments might be problematic during surgery, especially in tall patients, as experienced in this study. Therefore, long and articulating endoscopic instruments might be helpful. Fifth, structures in the posterior aspect of the chest, e.g., the subcarinal area, are difficult to approach with a patient in the supine position without the availability of proper instruments for retraction. Thus, proper positioning of the patient is important. In our experience, the supine position was suitable for bilateral pulmonary metastasectomy of tumors located in the anterior chest. The true decubitus position was suitable for anatomic lung resection with or without mediastinal LN dissection. Finally, mastering this technique requires a learning curve. This technique is easier to perform for surgeons having a previous experience with single-port transthoracic techniques.

We considered other approaches such as subcostal approach; however, this approach still requires cutting the external oblique muscle. Moreover, intercostal nerve branches attached to the subcostal area still remain, which may induce neuralgia and pain. Furthermore, the distance to the target hilar structure is farther than subxiphoid. With respect to patient recovery after surgery, subjective wound pain after surgery was considerably reduced after the subxiphoid approach compared with that after the transthoracic approach. Mediastinum pain was minor and was easily controlled with a short-term use of painkillers. No limitations were observed in shoulder movements immediately after the surgery, and 90% (36/40) of the patients did not require any painkillers at their first return to the clinic compared with the vast majority who still asked for painkiller refill in the transthoracic group.

This study suggests that anatomic resection of every lobe and traditional segmentectomy, including trisegmentectomy and basilar segmentectomy, could be performed using the subxiphoid single-incision approach, and modification of the technique and instrument settings is crucial to the success of this approach. Radicalism for mediastinal LN dissection for lung cancer was inferior to transthoracic procedures in our historical control group (20-22).

The main limitation of our study is the limited number of patients. We explained in detail the benefits and potential risks of the subxiphoid single-incision approach to each patient included in the study and offered single-incision transthoracic thoracoscopic surgery at the same time. About half of the patients hesitated and declined to undergo the subxiphoid approach because they felt that it is still new and may be associated with inferior lymphadenectomy results. Another consideration was for segmentectomy, which is much easier through the transthoracic approach than through the subxiphoid approach. We think that subxiphoid segmentectomy is technically more challenging than transthoracic procedures, particularly when handling atypical segmentectomy. During the study period, most patients were recommended to undergo the transthoracic sublobar resection if lobectomy via the subxiphoid approach could be avoided. At present, we intend to enroll patients with cT2N0M0 or centrally located cT1N0M0 cancers for subxiphoid lobectomy; subxiphoid segmentectomy was reserved for traditional segmentectomy, as lingular or trisegmentectomy, superior segmentectomy of the lower lobe.

Conclusions

In conclusion, we observed that anatomic lung resection through lobectomy or segmentectomy is feasible through the subxiphoid single-incision approach. This approach is associated with advantages of decreased postoperative pain, better cosmetic outcome, and easy specimen retrieval as compared with the traditional transthoracic approach. However, this novel approach has limitations for mediastinal LN dissection and handling unexpected intraoperative complications such as major bleeding or anthracotic LNs. The future looks promising with the possibility of designing novel single-port or robotic single-port instruments for this approach. However, large-scale studies are needed to document the application and to compare clinical outcomes associated with the subxiphoid single-incision approach with those associated with the transthoracic approach to provide evidence of the benefits of the former approach.

Acknowledgements

None.

Footnote

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

Ethical Statement: The study was approved by the institutional ethical committee in Sun Yat-Sen Cancer Center Hospital and written informed consent was obtained from all patients.

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The Shanghai Pulmonary Hospital subxiphoid approach for lobectomies

Giuseppe Aresu[1,2,3], Liang Wu[2], Lei Lin[2], Gening Jiang[2], Lei Jiang[2]

[1]Department of Cardiothoracic Surgery, Santa Maria della Misericordia University Hospital, Udine 33100, Italy; [2]Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University, Shanghai 200433, China; [3]Department of Cardiothoracic Surgery, Papworth Hospital, Cambridgeshire, UK

Contributions: (I) Conception and design: G Aresu, L Jiang; (II) Administrative support: None; (III) Provision of study materials or patients: G Jiang, L Jiang; (IV) Collection and assembly of data: L Wu, L Lin, L Jiang; (V) Data analysis and interpretation: G Aresu, L Jiang; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Lei Jiang, MD. Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University, No. 507 Zhengming Road, Shanghai 200433, China. Email: Jiangleiem@aliyun.com.

Abstract: Video-assisted thoracoscopic surgery (VATS) has recognized benefits. However, patients undergoing VATS also complain acute and sometime chronic postoperative pain due to the damage of the intercostal bundles. Subxiphoid uniportal VATS has been presented as alternative approach that can completely avoid the intercostal nerve injury and further reduce the surgical outcome. The aim of this manuscript is to illustrate the Shanghai Pulmonary Hospital uniportal subxiphoid lobectomy surgical techniques.

Keywords: Subxiphoid; video-assisted thoracoscopic surgery (VATS); minimally invasive thoracic surgery; lobectomy

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Background

Video-assisted thoracoscopic surgery (VATS), compared with open thoracotomy, has recognized benefits including lesser postoperative pain and the possibility of earlier mobilization (1-3).

However, patients undergoing VATS also complain of a moderate degree of acute postoperative pain and the incidence of chronic postoperative pain has been reported to be similar to that with open thoracotomy (4-6).

Uniportal VATS through intercostal space has been introduced as a less invasive alternative to the traditional multiport VATS; even so working through a single intercostal space can reduce but not completely avoid the damage of the intercostal bundle (7).

In this context the uniportal subxiphoid video-assisted thoracic surgery (SVATS) has been proposed as alternative option for a variety of thoracic procedures that could completely avoid the intercostal nerve injuries (8,9).

In Shanghai Pulmonary Hospital, after a very important experience with multiport and uniportal vats resections, we started the uniportal SVATS program for lung resection in September 2014 with very good short terms results in terms of safety, post-operative pain and morbidity (10).

The aim of this study is to describe the surgical technique used by our team for uniportal SVATS lobectomy.

Indications for SVATS lobectomy

The surgical indications were early-stage lung cancer and selected cases of localized infectious lung disease or benign lung tumor discussed within our multidisciplinary team prior to surgery.

Exclusion criteria included:

- Diffuse dense adhesion;
- Lymph nodes enlargement;
- Body mass index, BMI >30;
- Cardiomegaly patients with left-side diseases;
- Reoperation.

Operating room set up and surgical instruments

The standard set-up of the operatory room includes one monitor placed cranially above the head of the patient, the first surgeon and the scrub nurse positioned on the abdominal side of the patient with the assistant positioned on the opposite side (*Figure 1*).

All VATS lobectomies are performed with a 10 mm, 30 degree angled HD video-thoracoscope. The 30-degree angulation allows a good vision within the chest cavity but the use of a variable angle camera could be useful during certain part of the operation in particular the lymph node dissection.

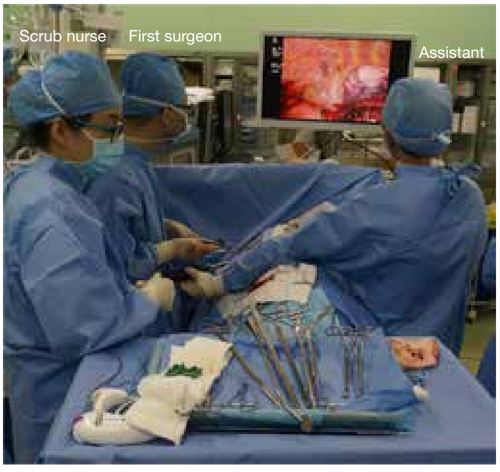

Figure 1 Operating room set up.

Normal VATS instruments plus dedicated instruments specially designed for SVATS [Shanghai Medical Instruments (Group) Ltd.] are used during the operations (*Figure 2*).

Operative technique

Positioning of the patients and anesthetic technique (Figure 3)

After the positioning of the double lumen tube the patients are placed in the lateral decubitus position with a backward inclination of 30° to reduce the interference deriving from the beating heart during the surgical procedure.

For left-sided operations we always put a central venous catheter line as in certain circumstances working through the subxiphoid port and pushing the pericardium can lead to circulatory instability and cardiac arrhythmias.

Creation of the port (Figures 4,5)

A 4-cm-long horizontal subxiphoid incision is made if the infrasternal angle is within normal limits (≥70°), otherwise a longitudinal incision is used in patients with infrasternal angle less than 70°.

At first, the subxiphoid incision is made and after dissection of the subcutaneous tissue the rectus abdominis muscle is exposed and its fibers dissected longitudinally to expose the xiphoid process that is completely resected to provide a widened operative access without lifting the

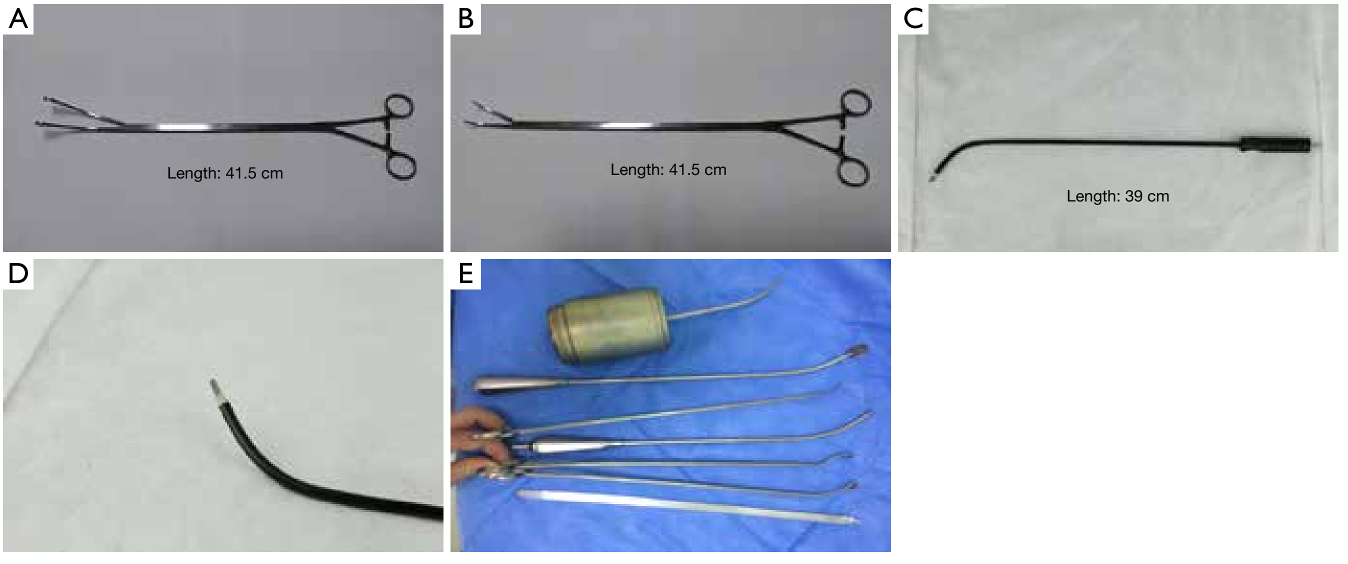

Figure 2 Subxiphoid dedicated instruments [Shanghai Medical Instruments (Group) Ltd.].

Figure 3 Positioning of the patients.

Figure 4 Subxiphoid ports with wound protector.

Figure 5 Creation of the subxiphoid port (11).
Available online: http://www.asvide.com/articles/1076

sternum upward.

By index finger dissection, a retrosternal tunnel is created between the thoracic cavity, a wound protector is inserted and under thoracoscopic visualization the pleura is opened and the pericardial fat tissue is removed.

Basic surgical principles (Figure 6)

The camera is inserted through the port at the level of the caudal portion of the wound leaving the cephalic part utilizable for the insertion and the maneuver of the other surgical instruments.

In this setting is very important have confidence with the uniportal intercostal technique in order to reduce the fighting between the instruments.

The chest cavity is evaluated looking for unexpected pathology, and adhesions, and the lung is retracted using long thoracoscopic lung graspers designed to optimize the hilum exposure and reduce the interferences between the other instruments.

To reduce the interference of the heart beats is very useful the utilization of a long sucker with a distal curvature to push the pericardium medially being careful to not disturb the heart function or distort the mediastinal structure causing a reduction of the venous return.

A particularly designed long electrocautery blade is used to lift, dissect and cauterize the tissue.

The vessels, the fissures and the bronchus are exposed and divided sequentially, with appropriate endostaplers.

To transect minor pulmonary arteries, lymph adenectomy and division of thin portions of fissure we also use energy-based devices and surgical endoclips.

In case of conversion to multiport VATS an extra port

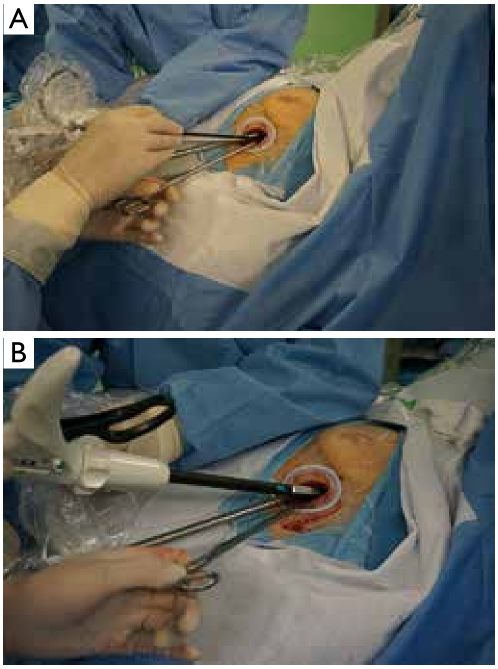

Figure 6 Insertion of the instruments and bimanual instrumentation through the subxiphoid port.

Figure 7 Uniportal subxiphoid right upper lobectomy (12). Available online: http://www.asvide.com/articles/1077

is usually made at the level of the 5th intercostal space at the level of between the anterior and the middle ascellary lines while the conversion to open procedure is obtained doing a sparring muscle anterolateral thoracotomy at the 5th intercostal space level.

At the beginning of our experience we started doing a lymph node sampling but with the experience we are optimizing the technique and increasing the number of lymph nodes dissected gradually arriving to a systematic lymph node dissection with removal of lymph nodes from at least 3 N2

Figure 8 Uniportal subxiphoid right middle lobectomy (13). Available online: http://www.asvide.com/articles/1078

Figure 9 Uniportal subxiphoid right lower lobectomy (14). Available online: http://www.asvide.com/articles/1079

stations according to the IASLC/Mountain classification.

At the end of the procedure, one drain is placed in through subxiphoid incision and a thin percutaneous drain is placed at the level of the 8th intercostal space.

After surgery, the patient is transferred to an intensive postoperative care ward and, if no complications occur, the next day we proceed to the transfer to the normal ward.

We use early mobilization policy and lung physiotherapy.

The tube is removed when there is no air-leakage and less than 300 cc of fluid in 24 hours.

Patients are usually discharged one day after tube removal and seen 10 days later in the outpatient clinic.

Video atlas of uniportal subxiphoid VATS lobectomy (*Figures 7-12*)

Early results and comments

From November 2014 to January 2016 we performed

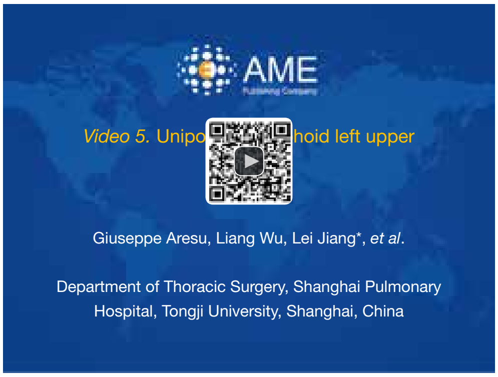

Figure 10 Uniportal subxiphoid left upper lobectomy (15).
Available online: http://www.asvide.com/articles/1080

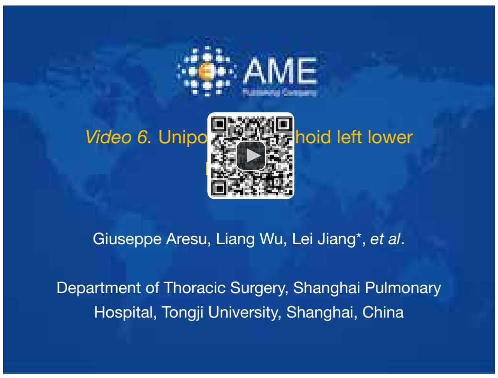

Figure 11 Uniportal subxiphoid left lower lobectomy (16).
Available online: http://www.asvide.com/articles/1081

Figure 12 Uniportal subxiphoid right lower bilobectomy and lymphadenectomy (17).
Available online: http://www.asvide.com/articles/1082

Table 1 Conversions and post-operative complications

Variables	Left-side group (n=46)	Right-side group (n=126)
Conversion of the surgical approach	4	8
Conversion to intercostal VATS	1	4
Lymph node involvement	0	3
Technical difficulties	1	1
Conversion to thoracotomy	3	4
Bleeding	1	2
Technical difficulties	2	1
Surgical mistakes	0	1
Postoperative complications	7	11
Intrathoracic hematoma	1	1
Prolonged airleak	3	4
Arrhythmia	3	6
Mortality	0	0

VATS, video-assisted thoracoscopic surgery.

172 uniportal SVATS lobectomies, 126 right lobectomies and 46 left lobectomies.

We had to convert surgical approach in 12 patients (7.0%), including 5 patients (2.9%) in whom we switched to multiport VATS approach and 7 patients (4.1%) that needed thoracotomy.

The causes of conversion are indicated in *Table 1*.

A total of 18 patients (10.5%) had postoperative complications (see *Table 1*), and no 30-day mortality occurred.

Even if we recognize that a more detailed analysis of the results is required to draft any statement, in our experience uniportal SVATS lobectomy for a selected category of patients showed to be a reproducible and safe alternative to the conventional multiport and uniportal lung resection techniques.

Acknowledgements

None.

Footnote

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

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Subxiphoid uniportal video-assisted thoracoscopic anatomical segmentectomy: technique and results

Jason Ali[1,2#], Haiyang Fan[3#], Giuseppe Aresu[1,2#], Chenlu Yang[1], Gening Jiang[1], Diego Gonzalez-Rivas[1,4], Lei Jiang[1]

[1]Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University, Shanghai 200433, China; [2]Thoracic Surgery, Papworth Hospital NHS Foundation Trust, Papworth Everard, Cambridge CB23 3RE, UK; [3]Department of Thoracic Surgery, The Seventh Hospital, Sun Yat-sen University, Shenzhen City, Guangdong Province 518107, China; [4]Coruña University hospital, Coruña, Spain

[#]These authors contributed equally to this work.

Correspondence to: Mr. Lei Jiang. Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University, Shanghai 200433, China. Email: jiangleiem@aliyun.com.

Background: Performing sub-lobar resection for early stage non-small cell lung carcinoma is becoming increasingly popular with studies suggesting equivalent outcomes to lobectomy when sufficient lymph node sampling is performed. Furthermore, there has been a move to minimally invasive thoracic surgery facilitating enhanced recovery and reduced postoperative morbidity. The subxiphoid video-assisted thoracic surgery approach (SVATS) is a novel technique that is becoming increasingly popular, with evidence of reduced postoperative pain. Here we report experience and the technique of performing segmentectomy by the uniportal SVATS approach

Methods: The uniportal SVATS approach was used to perform all possible segmentectomies. Specific instruments were designed to facilitate performing surgery through this approach, and the operative technique is described and demonstrated with videos.

Results: Between September 2014 to April 2017, 242 segmentectomies were performed by uniportal SVATS. Twenty-nine of the patients underwent bilateral procedures. The mean duration of surgery was 2.14±0.78 hours. Lymph node stations were accessible and a mean of 4.00±1.00 lymph node stations and 10.64±3.38 lymph node were sampled. The mean postoperative hospital length of stay was 4.67±9.54 days. Only 4 cases required conversion to thoracotomy and 3 to full lobectomy. There were no perioperative deaths, with 30-day survival of 100%.

Conclusions: This report demonstrates that the uniportal SVATS approach can be safely and effectively utilised to perform pulmonary segmentectomies. Our series demonstrates that it is possible to access and resect all segments by this novel approach to VATS surgery.

Keywords: Subxiphoid; video-assisted thoracic surgery (VATS); segmentectomy; advanced pulmonary resection

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Introduction

Over the last decade there has been a significant drive towards minimally invasive thoracic surgery. With increased experience, more advanced procedures are now reportedly performed by video-assisted thoracic surgery (VATS) in high volume centres, including sleeve and carinal resections and anatomical segmental resection (1-3).The reported benefits of VATS over open surgery include reduced postoperative pain, reduced postoperative complications, reduced length of hospital stay and period of recovery to normal function (4-7). Even so, patients undergoing thoracoscopic surgery still have moderate postoperative pain, and the incidence of chronic pain after surgery is similar to that of thoracotomy (8-10).

Single port (uniportal) thoracoscopic surgery through an intercostal space can reduce the surgical trauma when compared with multiport thoracoscopic surgery, but cannot completely avoid injury to the intercostal nerve and therefore the potential for acute and chronic thoracic pain (11).

More recently, the subxiphoid uniportal VATS (SVATS) approach has been described and is increasingly utilised for a range of thoracic operations including thymectomy, lobectomy and resection of giant solitary fibrous tumours of the pleura (12-19). In this technique, a single vertical muscle-sparing incision is made in the subxiphoid space permitting thoracic surgery to be performed without requiring intercostal incisions. This offers the potential for reduced pain – both acute and chronic, in comparison to intercostal VATS surgery, and the ability to retrieve the specimen from the pleural cavity without needing to spread ribs or run the risk of intercostal nerve injury (20,21).

Here we describe our technique for performing SVATS anatomical segmentectomy and present the results from our series.

Methods

All procedures were performed at the Shanghai Pulmonary Hospital, Shanghai, China. All procedures were either performed or supervised by JL. Operating surgeons were: GA, YC, DGR and JL.

This study was approved by the Shanghai Pulmonary Hospital Ethical committee and informed consent was obtained from all patients.

Indications and contraindications for subxiphoid VATS segmentectomy

Indications:

- Early-stage lung cancer IA, without evidence of lymph node involvement;
- Benign lung tumours, such as hamartoma;
- Undetermined central lesions.

Contraindications:

- Diffuse dense adhesion;
- Body mass index >30 kg/m^2;
- Left-side operations for patients with cardiac diseases, such as cardiomegaly and arrhythmia;
- Reoperation.

Operating room set up

The standard set-up of the operation room includes one monitor placed cranially above the head of the patient. The first surgeon and the scrub nurse positioned in front of the patient with the assistant positioned on the opposite side to provide the optimal endoscopic view.

Instruments for subxiphoid VATS surgery

All SVATS segmentectomy are performed with a 10 mm 30-degree angled HD video-thoracoscope (Karl Storz, Tuttlingen, Germany). The 30-degree angulation allows for good visualisation within the pleural cavity and requires a competent assistant to make optimal use of the angulation.

As the distance between the subxiphoid incision and the operative field is greater than for standard VATS, most of the instruments used in SVATS are extended and double-articular. At the same time, in order to easily pass the diaphragm or heart and normal lung tissue, the instruments used are curve-tipped (*Figure 1*). Instruments used in this institution are purchased from Shanghai Medical Instruments Group Ltd., Shanghai, China

Operative technique

Positioning of the patient

The operation is performed with the patient under general anaesthesia and double lumen endotracheal tube intubation to allow for selective lung ventilation. The patient is placed in a lateral decubitus position with a backward inclination of 30° in order to optimize exposure of the subxiphoid region and reduce the interference deriving from the beating heart during the surgical procedure (*Figure 2A*). Some patients underwent bilateral procedures through the same incision at the same setting. These patients were repositioned once the first sided procedure has been completed.

Creation of the port

A 4-cm-long horizontal subxiphoid incision is made if the infrasternal angle is within normal limits (≥70°), otherwise a longitudinal incision is used in patients with infrasternal angle less than 70°. In the process of creating the port, we cut the skin, and then divide the subcutaneous fascia and muscle layers to expose the xiphoid cartilage and then remove the cartilage so as to establish a tunnel from xiphoid

Figure 1 Instruments used to perform uniportal subxiphoid video-assisted thoracic surgery are extended and doublearticular and curve-tipped (designed by Shanghai Medical Instruments [Group] Ltd., Shanghai, China).

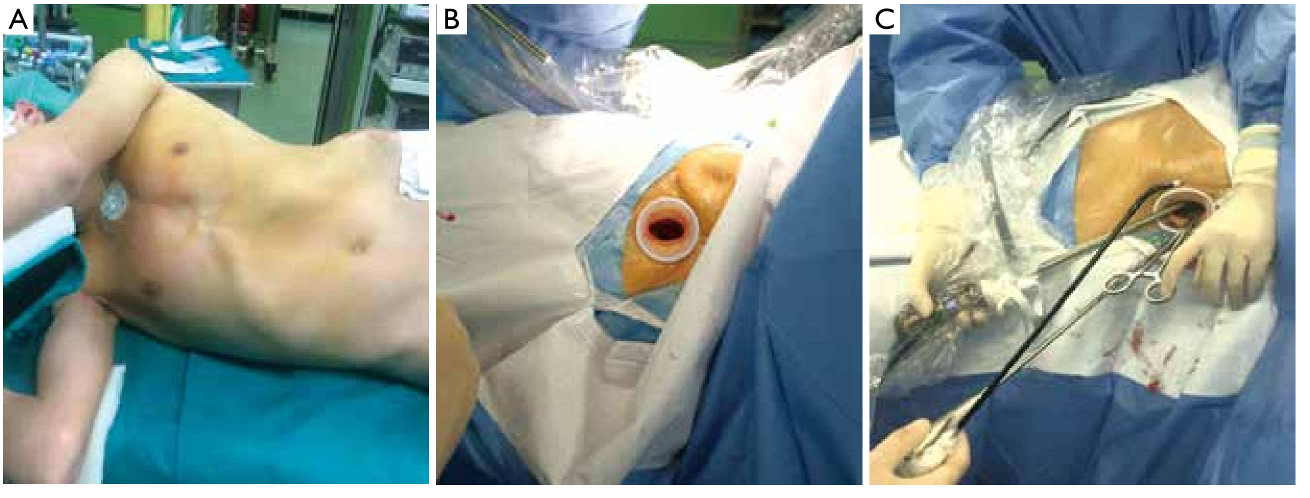

Figure 2 Intraoperative photo demonstrating (A) the patient position required for subxiphoid video-assisted thoracic surgery segmentectomy (black dashes indicate position of incision) and (B) subxiphoid ports with wound protector. (C) The assistant inserts the camera follow the lower edge of the incision, and with a lung retractor in the other hand, which helps to expose the surgical field.

to pleural. Then a wound protector is inserted and under thoracoscopic guidance the pericardial fat tissue is removed (*Figure 2B*).

Basic technique

Due to the narrow nature of the subxiphoid access into the pleural cavity, the camera should be positioned inferiorly and the lower edge of the incision enabling instruments to be positioned superiorly (*Figure 2C*). The assistant must make full use of the 30-degree camera angles to ensure optimal visualization of the operative field due to the limited movement available at the level of the subxiphoid port. This requires an experienced and competent assistant.

Once the pleural cavity is entered the first step is to examine the pleural cavity for any unexpected pathology and divide any adhesions that there may be. The lung should be retracted in order to visualize the entire pleural cavity and lung surface. Particularly in left sided procedures, a long sucker with distal curvature can be used to displace the pericardium medially to optimise visualisation, being careful to not disturb the cardiac function or distort the mediastinum, causing a reduction of venous return.

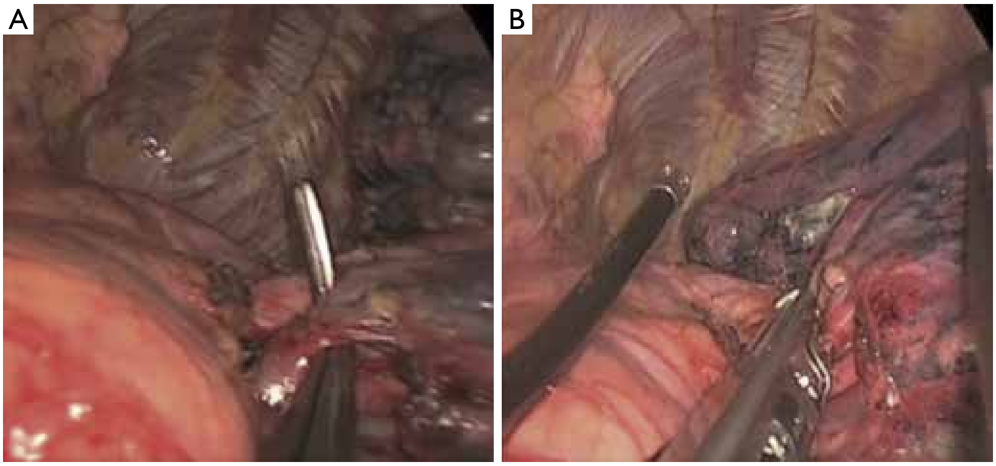

Figure 3 Intraoperative photos demonstrating the visualisation achieved during SVATS. (A) Dissection of the left upper lobe vein and (B) positioning of the stapler for division; during a left upper lobe tri-segmentectomy.

Table 1 Preoperative characteristics

Variables	Values
Age (years)	56.77±10.42
Male gender	76 (31.40%)
Smoking history	30 (12.55%)
BMI (kg/m^2)	23.78±3.38
Lesion diameter (mm)	12.14 (5–50 mm)
FEV1 (L)	2.47±0.64
FEV1 (% predicted)	93.78±14.84

For age and smoking history, the value represents number of patients (percentage of cohort). For lesion diameter the value represents mean (range). For remaining variables, the value represents: mean (standard deviation).

Next, the segmentectomy is performed. The vessels, the fissures and the bronchus are dissected, mobilised and divided sequentially, with appropriate endoscopic staplers (Medtronic EndoGIA, MA, USA, *Figure 3*). For the dissection, a long electrocautery blade designed for SVATS surgery is used to lift, dissect and cauterize the tissue (Shanghai Medical Instruments Group Ltd, Shanghai, China). To divide minor pulmonary arteries, thin portions of the fissure and during the lymphadenectomy energy-based devices and surgical endoclips are used.

The specimen is removed using an endoscopic retrieval bag (EndoBag, Covidien, Mansfield, MA, USA). A full lymphadenectomy is performed. The bronchial stump is checked under water for air leak and a drain positioned through the subxiphoid incision. The subxiphoid incision site is then closed.

After surgery, the patient is usually transferred to an intensive postoperative care ward. If no complications occur, the next day the patient will be transferred to the post-operative ward and encouraged to mobilise. The drain is removed when there is no air-leakage and less than 300 mL fluid drainage in 24 hours. Patients are usually discharged one day after tube removal and reviewed after 10 days in the outpatient clinic.

An operative video of a right S1 SVAT segmentectomy (http://www.asvide.com/articles/1243) and a left S1 SVAT segmentectomy (http://www.asvide.com/articles/1254) are available for demonstration of the technique.

Results

Between September 2014 to April 2017 at Shanghai Pulmonary Hospital, 242 patients diagnosed with stage IA primary non-small cell lung cancer or small benign lesions, and underwent SVATS segmentectomy. The general preoperative characteristics of the patients are detailed in *Table 1*.

Most patients underwent unilateral SVATS segmentectomy with details of segments resected presented in *Table 2*. All segments were accessible and resected by SVATS. Twenty-nine patients (12%) presented with lesions bilaterally, and underwent bilateral procedures (*Table S1*). SVATS provides access to both pleural spaces and therefore is particularly suited to bilateral procedures which can be performed with a single incision.

Table 2 Details of the site of segmentectomies performed in this series

Left side	n	Right side	n
Apical [S1]	22	Apical [S1]	32
Anterior [S3]	3	Anterior [S3]	8
Posterior [S2]	4	Posterior [S2]	20
Apicoanterior [S1+3]	3	Apicoanterior [S1+3]	3
Apicoposterior [S1+2]	6	Apicoposterior [S1+2]	15
		Anteroposterior [S2+3]	2
Trisegmectomy [S1+2+3]	28		
Lingual [S4+5]	11	Medial [S5]	2
		Lateral [S4]	11
Superior [S6]	2	Superior [S6]	8
		Superior and anterior basal [S6+8]	1
Basal [S7-S10]	11	Basal [S7-S10]	7
Anterior basal [S8]	5	Anterior basal [S8]	6
		Anteriolateral basal [S8+9]	1
		Lateral basal [S9]	1
Posterior basal [S10]	1		

Table 3 Operative and postoperative parameters

Variables	Values
Operation time (hours)	2.14±0.78 (65–322)
Intraoperative blood loss (mL)	93.33±91.27 (20–1,000)
Lymph node stations sampled	4.00±1.00
Number of lymph nodes sampled	10.64±3.38
Chest drainage volume (L)	260.94±162.38 (50–1,150)
Chest tube drainage duration (days)	4.25±2.68 (1–15)
Postoperative hospital stays (days)	4.67±9.54 (2–30)

For continuous variables the value represents: mean ± standard deviation (range).

Intraoperative and postoperative characteristics are presented in *Table 3*. The mean duration of surgery was 2.14±0.78 hours. Lymph node stations were accessible and a mean of 4.00±1.00 lymph node stations and 10.64±3.38 lymph node were sampled. The mean postoperative hospital length of stay was 4.67±9.54 days.

Table 4 Postoperative complications

Complications	Incidence (number, %)
Reoperation for bleeding	1 (0.4%)
Change to lobectomy	3 (1.2%)
Prolonged air leak	6 (2.4%)
Thoracic haematoma	2 (0.8%)
Arrhythmia	9 (3.7%)

In total there were 15 cases requiring conversion to alternative operation or approach (6.2%). In eight patients there was conversion to standard uniportal VATS (3.3%, 4 due to technical difficulties, 2 due to arrhythmia and hypotension, 1 due to bleeding and 1 due to injury to the bronchus). Four patients were converted to thoracotomy due to iatrogenic injury to blood vessels (1.7%). A further 3 patients (1.2%) required conversion to a SVAT lobectomy due to iatrogenic injury to blood vessels.

The incidence of postoperative complications was 8.26% (*Table 4*). No patients suffered from bronchopleural fistula or have developed an incisional hernia to date. There were no perioperative deaths, with 30-day survival of 100%.

The histopathological results of the 271 resected lesions is displayed in *Table 5*. In 219 (80.4%) the lesions were proven to be a malignancy. All of these were stage T1a according to the 7th edition The American Joint Committee on Cancer (AJCC)/Union for International Cancer Control (UICC), tumour, node, metastasis (TNM) staging system. The remainder were found to be benign or pre-malignant lesions.

Discussion

This report demonstrates that the subxiphoid uniportal VATS approach can be safely and effectively utilised to perform pulmonary segmentectomies. Our series demonstrates that it is possible to access and resect all segments by this novel approach to VATS surgery. It was previously considered that posterior segments (S2, S6, S9 and S10) would not be accessible by SVATS (13). However, with further experience, development of specific SVATS instruments and increased confidence we have been able to demonstrate that these more challenging segmentectomies can be performed safely by the subxiphoid route. We would however, emphasise that surgeons considering developing

Table 5 Histopathology of resected nodules

Pathological diagnosis	n
Malignant	
Invasive adenocarcinoma	76
Micro-invasive adenocarcinoma	50
Adenocarcinoma in situ	88
Squamous cell carcinoma	1
Metastatic tumor	2
Carcinoid	1
Lymphoma	1
Benign	
Atypical adenomatous hyperplasia	21
Hamartoma	3
Fibroplastic proliferation	7
Inflammatory pseudotumour	4
Tuberculosis	8
Aspergillosis	2
Cryptococcus infection	2
Lymph node	2
Bronchial cyst	2

experience in SVATS should first be experienced in performing lung resections by standard uniportal VATS surgery

There remains some debate as to the equivalence of long-term outcomes for patients undergoing segmentectomy versus lobectomy—which remains the gold-standard resection for non-small cell lung cancer. In 1995 a randomised controlled trial comparing lobectomy with sub-lobar resection reported inferior long-term survival and higher rates of local recurrence in the sub-lobar resection group (22). Despite studies like this, there are now many proponents of parenchymal sparing segmentectomy for early stage lung cancer, particularly revived by more recent studies, such as the major propensity matched study by Landreneau *et al.* identifying no significant difference in recurrence free survival or overall survival (23); and a recent meta-analysis suggested that for patients with tumours smaller than 2cm, overall survival and cancer-specific survival were equivalent between anatomical segmentectomy and lobectomy (24). The advantage of performing segmentectomy over lobectomy is the preservation of pulmonary function, which can have a significant impact on patients quality of life (25). As such, segmentectomy has remained a treatment option, particularly for patients with poor lung function and/or multiple comorbidities who would not be a candidate for lobar resection.

Minimally invasive techniques are increasingly being utilised for advanced thoracic surgical procedures at experienced centres (1,2). In the case of segmentectomy, there are now several reports describing the use of thoracoscopic techniques (26,27). The rationale to pursue a thoracoscopic approach are the reported benefits observed for other procedures such as lobectomies, where postoperative pain, length of hospital stay and time to return to normal function have been demonstrated to be lower in comparison with open surgery (4-6).

More recently, the subxiphoid uniportal VATS technique has been described, avoiding any intercostal incision or instrumentation (12-19,28,29). Additionally, since the chest drains are not entering the thoracic cavity through intercostal spaces postoperatively, they do not impinge on the intercostal neurovascular bundle during mobilization of the patient. This has the potential benefit of allowing for early aggressive mobilization and clearance of secretions with the benefit of reducing the incidence of venous thromboembolism and lower respiratory tract infection and therefore possibly reduced length of hospital stay (30). To support these potential benefits of SVATS, a randomised controlled trial randomised 43 patients to either subxiphoid or standard uniportal VATS bullectomy and pleurectomy for the management of pneumothorax. Postoperative pain scores were significantly lower in the subxiphoid group which results in improved mobilisation and reduced risk of complication (31). Although evidence to date is limited, our experience is in agreement with this finding and we are currently recruiting to a randomised controlled trial with the aim of further exploring the potential benefits of SVATs for patients undergoing lung resection.

In terms of comparing outcomes between patients undergoing SVATS versus standard VATS anatomical lung resection, the literature is limited to date. One study reported 105 patients undergoing SVATS lobectomy and compared outcomes to 90 unmatched patients undergoing uniportal VATS lobectomy (19). They reported a 23-minute prolonged mean operative time with SVATS (165 *vs.* 142 minutes) but similar duration of post-operative length of stay (5.39 *vs.* 5.37 days). These results are comparable to our findings although our operative time (mean 134 minutes) and length of hospital stay (mean 4.67) are both shorter.

In view of the above perceived benefits in terms of pain and our increasing experience with the subxiphoid VATS approach, the move to subxiphoid VATS segmentectomy was without complication. From the perspective of performing a segmentectomy, the ability to retrieve the whole in-tact specimen due to the absence of rigid boundaries of the incision, is an additional attraction of potential oncological significance.

The subxiphoid VATS technique can be learned by surgeons experienced in uniportal VATS. The camera views and instrument positioning will require practice but the necessary skills can be acquired over a relatively short learning curve. There are advantages though, for example, stapler angles, which can be sometimes quite challenging with uniportal VATS are much more favourable with the subxiphoid approach which is a significant advantage of this technique.

We would recommend surgeons looking to gain experience should identify a proctor and focus initially on minor procedures. Once more confident with the technique, experience can be extended to lobectomies and then segmentectomies.

We acknowledge that the SVATs technique for segmentectomy will not be for all surgeons. There are some challenges: for example, left sided procedure can be more difficult depending on the position of the heart; and for segmentectomies—the posterior segments should be attempted once confidence and experience in the more accessible segments has been achieved. Furthermore, it can be challenging to achieve a complete and radical lymph node dissection until the surgeon becomes more confident and adept at the SVATS technique.

Conclusions

Subxiphoid VATS is a novel approach to thoracic surgery which is becoming increasingly popular. Early studies suggest that this approach has the potential to reduce the amount and duration of postoperative pain, which may facilitate the move to enhanced recovery programmes and improved patient experience. We have reported our experience with subxiphoid VATS segmentectomy demonstrating that all pulmonary segments can be accessed by this route. Our data supports that this is a safe and feasible surgical approach to segmentectomy that surgeons should consider gaining experience of.

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None.

Footnote

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

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Supplementary

Table S1 Details of patients undergoing bilateral procedures

Left segmentectomy	Right procedure	n	Right segmentectomy	Left procedure	n
S1	Upper lobectomy	1	S1	S1	2
	Lower lobectomy	1		Upper lobectomy	1
				Lower lobectomy	1
			S3	Middle lobectomy	2
				Upper lobectomy	1
S1+2	Right pericardial cyst	1	S2	Mediastinal cyst	1
				Upper lobectomy	1
S1+2+3	S1	1			
	S2	1			
	S6	1			
S4+5	S4	1	S4	Lower lobectomy	1
	S2	1		S4	
	Lower lobectomy	1	S6	S4	1
				Upper lobectomy	1
S7–S10	S2	2	S7–S10	S2	1
			S8	Middle lobectomy	1
				S1	1
S10	S4	1	S10	S6	1

Subxiphoid complex uniportal video-assisted major pulmonary resections

Diego Gonzalez-Rivas[1,2], Francisco Lirio[3], Julio Sesma[3], Firas Abu Akar[2]

[1]Department of Thoracic Surgery, Coruña University Hospital and Minimally Invasive Thoracic Surgery Unit (UCTMI), Coruña, Spain; [2]Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University School of Medicine, Shanghai 200433, China; [3]Department of Thoracic Surgery, Hospital General Universitario Alicante, Alicante, Spain

Correspondence to: Diego Gonzalez-Rivas. Department of Thoracic Surgery and Minimally Invasive Thoracic Surgery Unit (UCTMI), Coruña University Hospital, Xubias 84, Coruña 15006, Spain. Email: diego.gonzalez.rivas@sergas.es.

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Introduction

Adoption of video-assisted thoracic surgery (VATS) as the standard approach for major lung resections has been the quantum leap of modern thoracic surgery. Minimally invasive procedures offer today unprecedented outcomes in morbidity and patient comfort (1).

Conversely, this technique has been continuously evolving as surgeons push the boundaries to cause no postoperative pain at all by reducing the number of intercostal spaces involved (2). Uniportal VATS lobectomy is considered a safe and effective approach for major and even complex lung resections, but some degree of chronic pain and chest wall numbness is still present.

In 2014 Liu *et al.* performed the first uniportal subxiphoid VATS left upper lobectomy (3) with the aim to avoid pain related to the aggression of intercostal nerves. Recent observational studies showed that subxiphoid approach is a safe and feasible procedure for early-stage lung cancer (4), significantly relieves postoperative incision pain and is also useful for the treatment of bilateral pathology (5).

In this paper we report some of our experience with complex surgical situations managed by uniportal subxiphoid approach such as big tumors, incomplete or absent fissures, hilar calcified lymph nodes, control of active bleeding and massive adhesions.

Patients and workup

All six procedures were done in high volume institutions by the same experienced surgeon. The lesions were confirmed or highly suspected malignant lung tumors. Four complex uniportal subxiphoid VATS major resections (fissureless left upper lobectomy, middle lobectomy, left lower lobectomy with uncomplete fissure, and right upper lobectomy for big size tumor with tracheal bronchus) were included beside two difficult intraoperative situations that can be resolved with this approach (massive adhesions in left upper lobectomy and bleeding control).

Procedure

Under general anesthesia and double-lumen endotracheal tube the patients were positioned in a lateral position inclined at 60–70° to allow better access and view of the anterior mediastinum. A single 3–4 cm incision was made over the subxiphoid area to allow access to the thoracic cavity by a subcostal tunnel. The xiphoid process was cut and the pericardial fatty tissue was removed to avoid interference with instruments. Energy devices were used alongside special double-hinged, longer than regular, angulated instruments to perform dissection. Longer Endoscopic staplers were used for vascular lobar branches and bronchial stapling. Smaller vessels were ligated with polymer clips by using a 45° uniportal specific applier. The specimen was routinely extracted with a retrieval bag.

In the first case, left upper lobectomy was performed trough a left subcostal incision to minimize the chance of the heart to move the instruments. Fissure was incomplete so we decided to perform a fissureless resection (*Figure 1*). After transecting left upper pulmonary vein, carina between upper

Figure 1 Uniportal subxiphoid VATS fissureless left upper lobectomy (6). VATS, video-assisted thoracic surgery.
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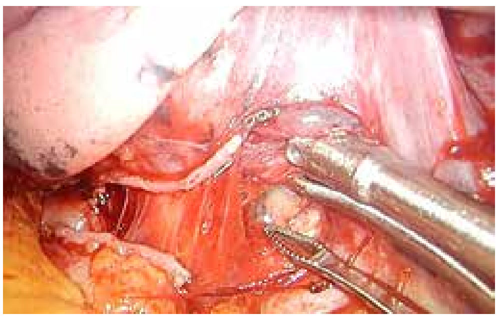

Figure 2 Pulmonary artery can be identified behind the carina between upper and lower bronchi.

Figure 3 Suction device can be used for both protecting the lingular branch and opening the pathway for the stapler.

and lower lobe bronchi is defined (*Figure 2*). Pulmonary artery is identified over the bronchial plane and fissure can be divided anteriorly with the anvil of the stapler pointing over the artery. This step allows us to dissect the bronchus, which is transected protecting the lingular branch with the

Figure 4 Uniportal subxiphoid VATS middle lobectomy (7). VATS, video-assisted thoracic surgery.
Available online: http://www.asvide.com/articles/1599

Figure 5 Calcified lymph nodes were blocking the plane between the bronchial stump and the middle lobe artery.

sucker (suction device trick) (*Figure 3*). Lingular artery is exposed after cutting the bronchus and is transected. The fissure is then completed posteriorly with staplers.

In the second case, a subxiphoid middle lobectomy was performed (*Figure 4*). Bronchus and artery for the middle lobe were surrounded by calcified lymph nodes. After careful and difficult dissection, bronchus was dissected and divided. Middle lobe artery was very risky to separate from the calcified lymph nodes (*Figure 5*), so we retracted the lymph nodes to use a stapler to complete the fissure including the artery (*Figure 6*).

In the third case, uncomplete fissure was found while performing a left lower lobectomy (*Figure 7*). It is important to notice that in this lobectomy, space is more limited because of the proximity of the heart. Left inferior vein is divided after cutting the pulmonary ligament. In this point, bronchus can also be transected, but we preferred to expose the pulmonary artery first. Dissecting over the carina

Figure 6 A stapler was used to divide the fissure and the middle lobe artery after lifting the lymph nodes as much as possible.

Figure 7 Uniportal subxiphoid VATS left lower lobectomy with uncomplete fissure (8). VATS, video-assisted thoracic surgery. Available online: http://www.asvide.com/articles/1600

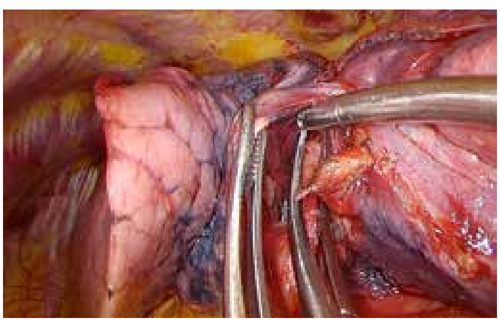

Figure 8 Once the artery is identified, a tunnel over it can be made to safely place the stapler.

between upper and lower lobe bronchus, artery is identified (*Figure 8*) and fissure is divided anteriorly aiming the anvil of the stapler over the vessel (*Figure 9*). This maneuver is repeated if needed. Once the artery is fully exposed, lower lobectomy is completed with the usual operative steps.

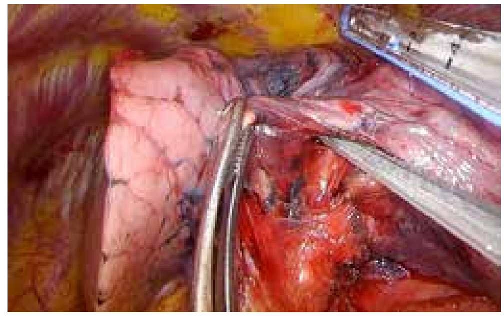

Figure 9 The anvil of the stapler is placed in the plane over the artery and below the parenchyma.

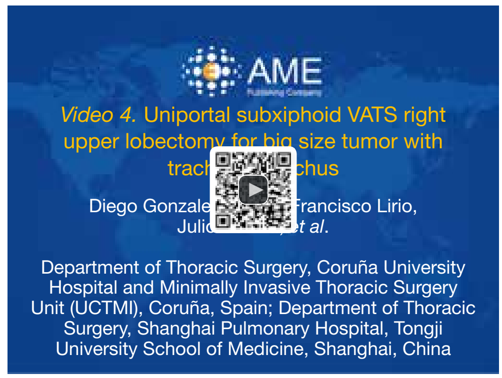

Figure 10 Uniportal subxiphoid VATS right upper lobectomy for big size tumor with tracheal bronchus (9). VATS, video-assisted thoracic surgery.
Available online: http://www.asvide.com/articles/1601

In the fourth case, right upper lobectomy was performed for a big mass with strong adhesions and abnormal anatomy (*Figure 10*). A tracheal bronchus for the apical segment was diagnosed preoperatively in both the CT scan and bronchoscopy (*Figure 11*). A combination of blunt and sharp dissection was needed to liberate the right upper lobe from the chest wall (*Figure 12*). Mediastinal pleura was opened beside a phrenic nerve lymph node and artery, vein and tracheal bronchus were exposed and divided. Station eleven lymph nodes were lifted to gain access to the origin of the remaining right upper bronchus and lobectomy was completed with the usual operative steps. The apical and posterior-anterior trunk of bronchus were divided individually.

In the fifth case, uniportal left upper lobectomy was performed despite extensive adhesions (*Figure 13*). Lung could be completely liberated combining blunt and sharp

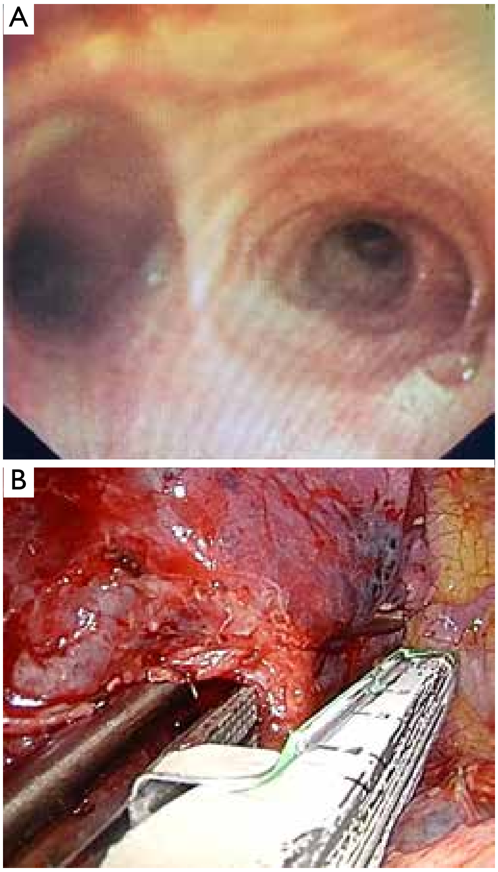

Figure 11 Bronchoscopic (A) and intraoperative view (B) of the tracheal bronchus.

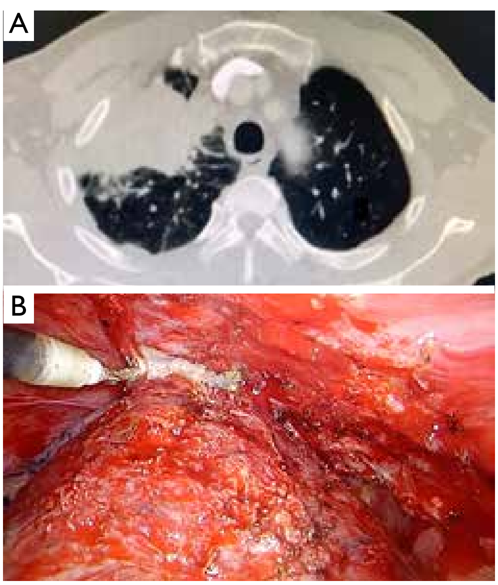

Figure 12 CT scan of the mass (A) and intraoperative view (B) of adhesions that require the use of the electrocautery to be liberated.

Figure 13 Uniportal subxiphoid VATS approach for massive adhesions in left upper lobectomy (10). VATS, video-assisted thoracic surgery.

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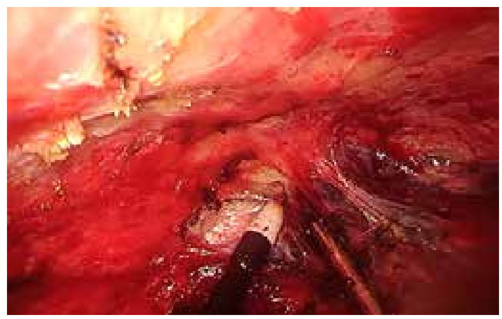

Figure 14 Sucker is used for traction, dissection and aspiration allowing us to have only two instruments trough the incision.

dissection using only two instruments at a time (*Figure 14*). Sucker was used for dissection, aspiration and traction. Long curved electrocautery was used to dissect and cut in the vicinity of the chest wall and an energy device was used when near the mediastinum and hilar structures.

In the sixth case, bleeding occurred during right upper lobectomy and was safely controlled maintaining subxiphoid approach (*Figure 15*). A 3/0 non-absorbable monofilament suture was used to give a u-shaped stitch around the vascular tear (*Figure 16*).

Discussion

The uniportal subxiphoid approach is a novel technique initially described in 2014 with the aim to reduce the risk of intercostal nerve injury and paraesthesia, avoiding the intercostal space (3).

Due to the vision is more limited than transthoracic

Figure 15 Uniportal subxiphoid VATS bleeding control (11). VATS, video-assisted thoracic surgery.
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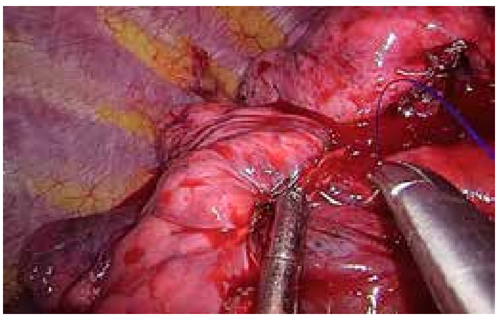

Figure 16 3/0 non-absorbable monofilament suture is used while providing exposure with the sucker.

approach, the assistant has to be very focused in using the proper angulation of the camera to show clearly the structures the surgeon is dissecting. The assistant can also provide aid with retraction of the lung with another instrument, so that the surgeon can use bimanual instrumentation in the dissection process.

The previous experience in Uniportal VATS major pulmonary resections and a skilled assistant are mandatory requirements to performed subxiphoid resections especially when dealing with difficult cases (12). As it happens with the transthoracic uniportal approach, bimanual instrumentation is crucial to achieve a good anatomic hilar dissection through a single subxiphoid incision. The view is caudal-cranial and anterior to posterior, so the access for the view of the posterior mediastinum is difficult, resulting in the need for the lung requiring more traction to assess the lesions in this area. The complete dissection of the subcarinal lymph nodes is more difficult to accomplish than transthoracic approach, especially on the left side (13). When a bleeding is difficult to control by this approach, an extension of the subxiphoid incision is unlikely to be useful so an additional thoracic port must be performed (3–4 cm utility incision).

On the left side, the instrumentation over a beating heart is more challenging, so extra care must be taken to avoid arrhythmias or other kind of cardiac complications.

We strongly believe this novel approach has potential for widespread use after developing of new technology, wireless cameras, magnetic graspers, more angulated instruments and single port robotic technology adapted through the subxiphoid approach (14).

Further studies are necessary to compare clinical outcomes of the subxiphoid versus other transthoracic approaches, in order to show clear advantages from this technique.

Conclusions

Uniportal subxiphoid VATS approach for major pulmonary resections is a safe and feasible procedure for complex resections, even when technically challenging difficulties arise during the procedure. However, these procedures must only be performed by skilled and experienced surgeons with the technique.

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None.

Footnote

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

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Subxiphoid pneumonectomy: the new frontier?

Jason M. Ali[1,2#], Pradeep Kaul[1#], Lei Jiang[2], Chenlu Yang[2], Jian Chen[2], Yunsong Zhang[2], Zhigong Zhang[2], Giuseppe Aresu[1,2]

[1]Thoracic Surgery, Papworth Hospital NHS Foundation Trust, Papworth Everard, Cambridge, UK; [2]Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University, Shanghai 200433, China

[#]These authors contributed equally to the manuscript.

Correspondence to: Lei Jiang, MD. Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University, Shanghai 200433, China. Email: jiangleiem@aliyun.com.

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Introduction

Over the last decade there has been a significant drive towards minimally invasive thoracic surgery. The reported benefits of video-assisted thoracic surgery (VATS) over open surgery include reduced postoperative pain, reduced postoperative complications, reduced length of hospital-stay and period of recovery to normal function (1-4). With increased experience, more advanced procedures are now reportedly performed by VATS in high volume centres, including sleeve and carinal resections (5,6).

Over the last decade, there have been several reports of pneumonectomy being performed by VATS in experienced centres (7-10). The majority of cases have been performed by multi-port VATS, although more recently, as for standard lobectomies (11,12), there has been evolution to uniportal VATS surgery as a means of potentially further reducing pain by utilising a single incision (13). A potential disadvantage of an intercostal VATS approach to pneumonectomy is the requirement to remove the lung through the intercostal space which may require a degree of rib spreading, cause intercostal nerve compression and damage, and in some series is achieved by taking the lung out in pieces which has potential oncological consequences, especially with regard to staging assessment and to pleural spread of malignant cells.

More recently, the subxiphoid-VATS approach has been described and is increasingly utilised for a range of thoracic operations including thymectomy, lobectomy, segmentectomies and resection of giant solitary fibrous tumours of the pleura (14-21). In this technique, a single vertical muscle-sparing incision is made in the subxiphoid space permitting thoracic surgery to be performed without requiring intercostal incisions. The specific potential advantages of this approach for pneumonectomy include reduced pain—both acute and chronic, in comparison to intercostal VATS surgery, and the ability to retrieve the lung whole from the pleural cavity without needing to spread ribs or run the risk of intercostal nerve injury.

Here we describe our technique for performing pneumonectomy by subxiphoid uniportal VATS, which has been successfully performed in three patients to date.

Operative technique

The operation is performed with the patient under general anaesthesia and double lumen endotracheal tube intubation to allow for selective lung ventilation. The patient is placed in a lateral decubitus position slightly rotated posteriorly in order to optimize exposure of the subxiphoid region. The operating surgeon is positioned in front of the patient and the assistant stands more caudally on the side being operated on to provide the optimal endoscopic view.

A 3–5 cm midline vertical incision is made below the sternocostal triangle to expose the xiphoid process. Dissection of the linea alba is performed and the pleural cavity was entered by blunt finger dissection above the level of the diaphragm. An Alexis soft tissue wound retractor (Applied Medical CA, USA) is positioned to create a space for instrument and a 30-degree 10 mm camera insertion (Karl Storz, Tuttlingen, Germany). Subxiphoid VATS instruments were used to perform the procedure (*Figure 1* Shanghai Medical Instruments Group Ltd, Shanghai,

Figure 1 Instruments used for subxiphoid surgery (Shanghai Medical Instruments Group Ltd, Shanghai, China).

China).

The pneumonectomy is performed as demonstrated in *Figures 2,3* (a left sided pneumonectomy) and *Figures 4,5* (a right sided pneumonectomy). The mediastinal pleura is divided to expose the hilum with diathermy. The superior pulmonary vein is dissected and a sling positioned in order to offer some retraction. The main pulmonary artery is then dissected, slung and divided with an Endo-GIA surgical stapler with vascular reload (Medtronic EndoGIA, MA, USA). Next, the previously prepared superior pulmonary vein is divided with a vascular reload. The inferior pulmonary ligament in then divided and inferior pulmonary vein dissected, slung and then divided with a vascular reload. Finally the main bronchus is dissected and divided with a green Endo-GIA stapler reload. The specimen was removed using an endoscopic retrieval bag (EndoBag, Covidien, Mansfield, MA, USA). It may be required to extend the skin incision to facilitate retrieval of the specimen. A full lymphadenectomy is performed. The bronchial stump is checked under water for air leak and a drain positioned. The subxiphoid incision site is then closed.

Results

To date we have performed this procedure in three patients at the Shanghai Pulmonary Hospital, Shanghai, China. Preoperative characteristics of the three patients are summarised in *Table 1*.

Intraoperative and postoperative characteristics are presented in *Table 2*. The mean duration of surgery was 119 minutes. Lymph node stations were accessible and a mean of six lymph node stations were sampled. There were no intraoperative complications encountered and no cases of conversion to multiport VATS or thoracotomy. No patient experienced an arrhythmia during the procedure. All patients made a good recovery from surgery and were discharged between the 6th and 7th post-operative day. Mean follow up is 181 days. There has been no mortality to date.

Discussion

This report demonstrates that the subxiphoid uniportal VATS approach can be safely and effectively utilised to perform a pneumonectomy.

Minimally invasive techniques are increasingly being utilised for advanced thoracic surgical procedures at experienced centres (5,6). In the case of pneumonectomy, there are now several reports describing the use of thoracoscopic techniques (7-10). The rationale to pursue a thoracoscopic approach are the reported benefits observed for other procedures such as lobectomies, where postoperative pain, length of hospital-stay and time to

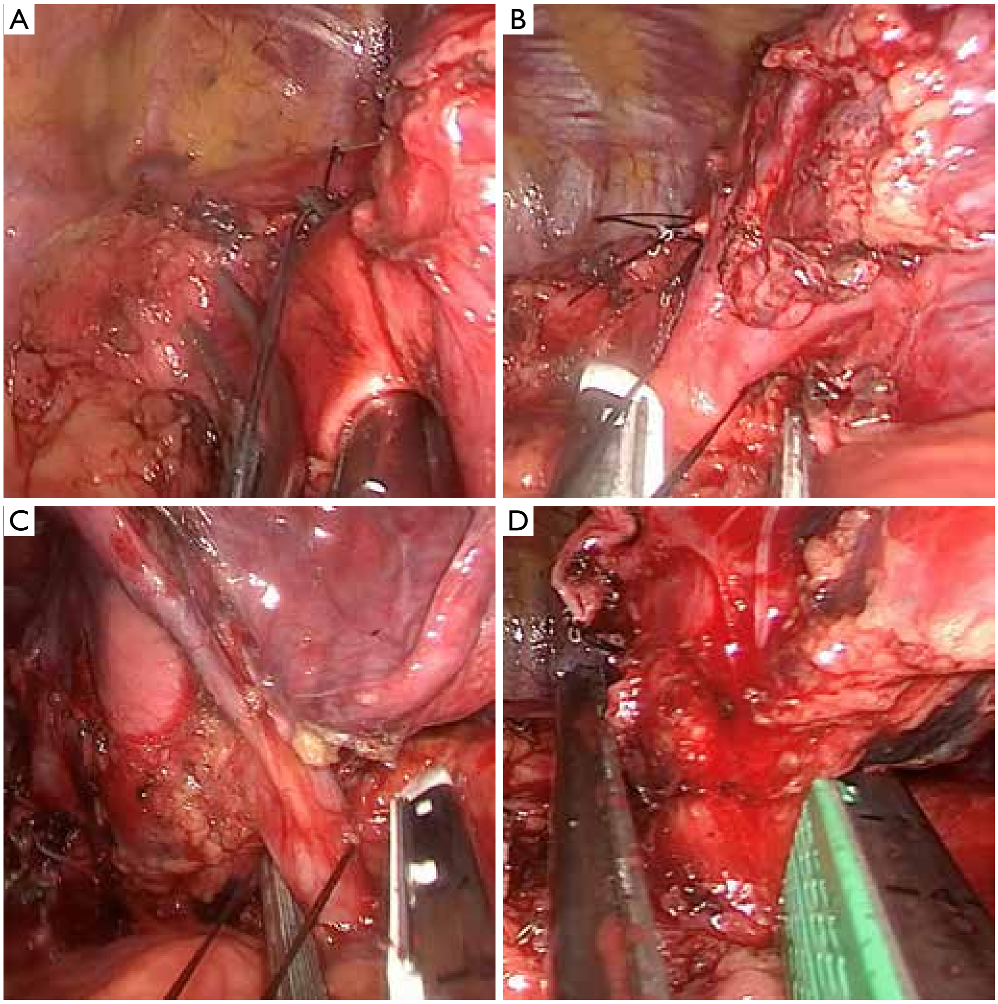

Figure 2 Left pneumonectomy. Intraoperative photos demonstrating division of the (A) pulmonary artery, (B) superior pulmonary vein, (C) inferior pulmonary vein and (D) main bronchus.

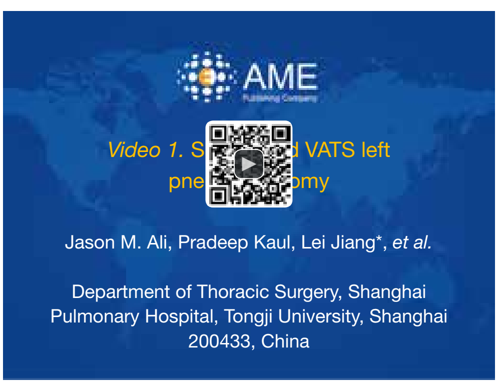

Figure 3 Subxiphoid VATS left pneumonectomy (22). VATS, video-assisted thoracic surgery.
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return to normal function have been demonstrated to be lower in comparison with open surgery (1-3).

Reports from animal model work in both pigs and dogs has suggested that VATS pneumonectomy results in a smaller incision, less acute-phase reaction, less stress and less pain compared with thoracotomy pneumonectomy suggesting that there will also be benefits to patients (24,25).

To date there has not been any randomised controlled trial comparing open versus VATS pneumonectomy allowing a robust comparison of clinical outcomes. The closest is a study from a US centre reporting their 11-year experience of performing thoracoscopic pneumonectomy (7). In this report, authors compared patient outcomes of 40

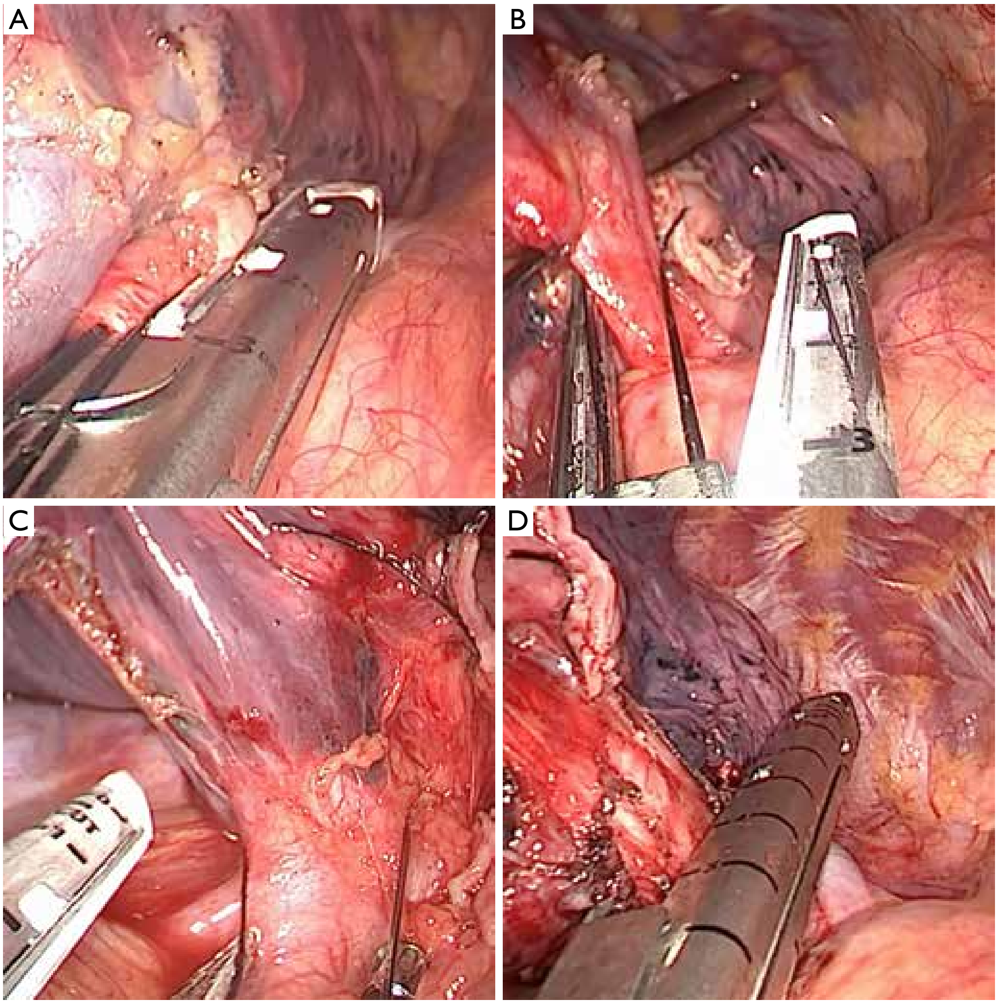

Figure 4 Right pneumonectomy. Intraoperative photos demonstrating division of the (A) pulmonary artery, (B) superior pulmonary vein, (C) inferior pulmonary vein and (D) main bronchus.

Figure 5 Subxiphoid VATS right pneumonectomy (23). VATS, video-assisted thoracic surgery.
Available online: http://www.asvide.com/article/view/26150

open and 50 VATS consecutive pneumonectomies. As this was not randomised patient characteristics varied between the groups. However, the incidence of postoperative complications, length of ICU and hospital stay and mortality were similar between the two groups. Notably, although in-hospital analgesic requirements were similar, there was a significant difference in the proportion pain free at 1-year (53% *vs.* 19%).

Another important consideration is the ability to achieve an equivalent oncological result. For VATS lobectomy oncological validity has been confirmed. Again, it is difficult to comment without randomised controlled data for VATS pneumonectomy, but the rate of locoregional recurrence and

Table 1 Preoperative characteristics

Parameter	Patient 1	Patient 2	Patient 3
Sex	Male	Male	Male
Age	57	69	63
BMI	19.8	20.8	22.4
Smoker	No	No	No
Lesion site	Left upper lobe	Left upper and left lower synchronous	Right upper lobe
Lesion size (mm)	42	28 (upper lobe); 30 (lower lobe)	37
FEV1 (% predicted)	81.8	95.9	87.4
FVC (% predicted)	65.9	89.6	77.2
Preoperative albumin	44	37	41
Preoperative haemoglobin	144	133	130

Table 2 Intraoperative and postoperative characteristics

Parameter	Patient 1	Patient 2	Patient 3
Duration of operation (minutes)	132	129	98
Operative blood loss (mL)	100	100	50
Number of lymph node stations sampled	7	6	5
Number of lymph nodes sampled	23	12	12
Postoperative length of stay (days)	6	6	7
Final histology	Squamous cell carcinoma	Large cell carcinoma (upper lobe) adenocarcinoma (lower lobe)	Adenocarcinoma

long-term survival were no different in the above study (7). A further study also examined the long term survival of patients after thoracoscopic pneumonectomy and found there to be no difference in survival when stratified for stage between their cohorts of patients who underwent thoracoscopic vs. open pneumonectomy (26).

It should be emphasised that pneumonectomy is only performed when it is confirmed that parenchymal-sparing alternative approaches are not feasible, for example sleeve resections. These will always be attempted in the first instance and thorough assessment made prior to proceeding with pneumonectomy. With increased experience, there are reports of these advanced parenchymal-sparing resections being performed by VATS, even uniportal, at our centre, confirming that adequate assessment can be made by VATS (5,6,27).

There is increasing experience of performing VATS pneumonectomy throughout the world. We feel that subxiphoid VATS offers the advantage of not having an entry into the pleural cavity that is bound by the ribs. Retrieval of the specimen can be challenging and depending on the size of the tumour may require extension of the incision in both approaches. In the case of standard VATS, there are reports of requiring rib spreading and the lung being retrieved in pieces. Furthermore, retrieval may result in compression of the intercostal nerves which can result in chest wall pain which may be chronic in some patients

More recently, the subxiphoid uniportal VATS technique has been described, avoiding any intercostal incision or instrumentation (14-21,28,29). Additionally, since the chest drains are not entering the thoracic cavity through intercostal spaces postoperatively, they do not impinge on the intercostal neurovascular bundle during mobilization of the patient. This has the potential benefit of allowing for early aggressive mobilization and clearance of secretions with the benefit of reducing the incidence of venous thromboembolism and lower respiratory tract infection and therefore possibly reduced length of hospital stay (30).

To date, there have been three studies comparing subxiphoid and uniportal VATS techniques. The first was in a dog model of pulmonary lobectomy where 19 dogs were divided into a subxiphoid and uniportal groups. This study concluded that the subxiphoid approach was comparable with the standard transthoracic approach for anatomic pulmonary lobectomy, in terms of feasibility and effectiveness based on their physiological assessments (31). Another study retrospectively reviewed cohorts of patients undergoing subxiphoid or standard VATS thymectomy. This study observed similar operative times for the two groups, but the amount and required duration of analgesia was significantly reduced in the subxiphoid VATS group (32). The third study is a randomised controlled trial randomised 43 patients to either subxiphoid or standard uniportal VATS bullectomy and pleurectomy for the management of pneumothorax. Postoperative pain scores were significantly lower in the subxiphoid group, although the operative time was longer in this group, perhaps reflecting lower experience (33). From these studies, it appears that although further work is necessary, that the subxiphoid VATS approach is associated with reduced post-operative pain. As such, there are increasing reports of the use of this technique in the literature for a growing range of thoracic procedures.

It should also be highlighted that stapler angles, which can be sometimes quite challenging with uniportal VATS are much more favourable with the subxiphoid approach. The subxiphoid VATS technique can be easily learnt by surgeons experienced in uniportal VATS. The camera views and instrument positioning can be more challenging than for conventional VATS but the necessary skills can be acquired over a short learning curve, particularly for minor procedures.

Limitations of the technique

Particularly in left sided procedures there can be compression of the heart by the instruments. This occasionally can result in arrhythmias and reduced cardiac output requiring an alternative approach. In our experience of subxiphoid lobectomy and segmentectomy, an intra-operative arrhythmia has been experienced in about 7% of cases, but in almost all cases was transient and mild and did not require changing technique. None of the patients in this series though experienced these problems. All patients have an arterial line and the blood pressure is monitored throughout the procedure. We do consider that cardiomyopathy and poor left ventricular function to be a contraindication to subxiphoid VATS surgery.

Access to some areas of the pleural cavity can be challenging with subxiphoid VATS. Access to the posterior hilum, lymph node station 7 and posterior pulmonary segments [2, 6, 8, 9] can be more challenging than with standard VATS. In fact, early in our experience with this technique we considered that these segmentectomies could not be performed. However, with increased experience and availability of bespoke subxiphoid instruments (*Figure 1*) these are now performed readily. In terms of pneumonectomy, the lymph node dissection can be performed easily following removal of the specimen. A key factor to being able to perform this surgery is expert assistance with the camera, as achieving satisfactory visualisation can be challenging initially.

In view of the above perceived benefits in terms of pain and our increasing experience with the subxiphoid VATS approach, the move to subxiphoid VATS pneumonectomy was without complication. From the perspective of performing a pneumonectomy, the ability to retrieve the whole in-tact specimen due to the absence of rigid boundaries of the incision, is an additional attraction of potential oncological significance. As described in this case series, subxiphoid uniportal VATS pneumonectomy is safe and feasible with several potential benefits that may result in faster patient recovery.

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None.

Footnote

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

Ethical Statement: The study was approved by the Shanghai Pulmonary Hospital Ethical committee (number 002536) and informed consent was obtained from all patients.

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Subxiphoid uniportal video assisted thoracoscopic surgery lobectomy, evolution of the technique and progress of learning curve

Amr Abdellateef[1,2], Chenlu Yang[2], Jian Chen[2], Jichen Qu[2], Jing Huang[3], Lei Jiang[2]

[1]Department of Cardiothoracic Surgery, Mansoura University Hospital, Mansoura School of Medicine, Mansoura University, Mansoura, Egypt; [2]Department of Thoracic Surgery, [3]Department of Respiration, Shanghai Pulmonary Hospital, Tongji University School of Medicine, Shanghai 200433, China

Contributions: (I) Conception and design: L Jiang, A Abdellateef; (II) Administrative support: L Jiang; (III) Provision of study materials or patients: J Huang, L Jiang; (IV) Collection and assembly of data: A Abdellateef; (V) Data analysis and interpretation: J Chen, C Yang, J Qu; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Lei Jiang. Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University School of Medicine, Shanghai 200433, China. Email: jiangleiem@aliyun.com; Jing Huang. Department of Respiration, Shanghai Pulmonary Hospital, Tongji University School of Medicine, Shanghai 200433, China. Email: 15821065281@163.com.

Background: Subxiphoid uniportal video-assisted thoracoscopic surgery (SVATS) has been known as feasible and safe approach for lobectomy with acceptable results. Its learning curve is slightly harder than the intercostal approach. The aim of this article is to view the evolution of the surgical technique and the change in results with the progress of learning curve in a trial to guide surgeons aiming to apply this technique.

Methods: Four hundred and thirty-eight patients underwent SVATS lobectomy from September 2014 to November 2017. The patients were divided into four groups chronologically according to date of operation. Group 1, group 2, group 3 and group 4 comprise 1st 100 cases, 2nd 100 cases, 3rd 100 cases and 4th 138 cases respectively. Perioperative data was analyzed between the four groups to study the change of different variables with progress of the learning curve.

Results: Operative time, intraoperative blood loss, number of dissected lymph nodes, rate of conversion and duration of postoperative stay have significantly improved with progress of learning curve.

Conclusions: Adjustment of some surgical steps and instrumentation along with developing experience have helped SVATS lobectomy to be easier, safer and faster.

Keywords: Subxiphoid; uniportal; lobectomy

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Introduction

Video assisted thoracoscopic surgery (VATS) lobectomy has been considered as safe, feasible and effective tool in both benign and early malignant lung diseases (1-4). Evolution from multiport to uniportal VATS lobectomy has been progressing in a way aiming to lessen surgical trauma with reported benefits in favor of uniportal approach (5,6). Liu and his colleagues reported the first uniportal subxiphoid VATS (SVATS) lobectomy in 2014 (7). That has been followed by multiple case series and case reports showing feasibility and safety of the SVATS lobectomy in selected cases with results similar to those of intercostal uniportal VATS approach in terms of duration of chest drain, length of postoperative stay, operative time, conversion rate and complications (8-10). The aim of this study is to further evaluate the uniportal SVATS lobectomy in terms of operative technique and perioperative results with deeper insight into changes associated with the progress in the learning curve.

Methods

Patients

This comparative cross-sectional study was conducted on 438 patients who underwent uniportal SVATS lobectomy from September 2014 to November 2017 at Thoracic Surgery Department in Shanghai Pulmonary Hospital, Shanghai, China. All data were collected from patient computerized records and medical notes. Written informed consent was obtained from the patient for the surgical procedure and possible use of the data and/or any accompanying images or videos in scientific publication. A copy of the written consent is available for review by the Editors-in-Chief of this journal. The study was approved by the hospital's Institutional Review Board (IRB).

Inclusion criteria

Preoperative discussion is held by our team to select patients most suitable for SVATS lobectomy. We select cases with:

- Lung cancer with T1, T2 status of tumor <7 cm with lesion suspicious for malignancy in positron emission tomography (PET) scan and located within the vicinity of the lobe with no possibility of wedge resection nor segmentectomy;
- N0 status for tumor;
- Localized infectious lung disease;
- Forced expiratory volume in 1 s (FEV1) and diffusing capacity of the lungs for carbon monoxide (DLCO) >40% postoperative predicted.

Exclusion criteria

Exclusion criteria were the following: central masses, enlarged lymph nodes with confirmed N1 or N2 disease, chest wall involvement, previous thoracic surgery, cardiomegaly and BMI >30. We also excluded cases underwent SVATS resections of bilateral pulmonary or concomitant mediastinal and pulmonary lesions.

All patients were subjected to the followings

Preoperative full history taking and clinical examination. Preoperative full laboratory investigations, computed tomography (CT) scans of the chest, PET scans, pulmonary function tests, flexible bronchoscopy, histological diagnostic tests if possible and echocardiogram. Intraoperative histology was carried out in all cases using frozen tissue sections followed by detailed confirmatory pathological report postoperatively. Postoperative follow up of our patients ranged from 3 months to 3 years.

Perioperative demographic data, intraoperative and postoperative findings and complications were collected and analyzed. The patients were divided into four groups chronologically according to date of operation. Group 1, group 2, group 3 and group 4 comprise 1st 100 cases, 2nd 100 cases, 3rd 100 cases and 4th 138 cases respectively. All data was analyzed for all patients as a whole then the most important findings were analyzed between the four groups to study the change of different variables with progress of the learning curve.

General operative set up

Only one monitor is used and placed cranially above the head of the patient, the surgeon and the scrub nurse stand on the abdominal side of the patient with the assistant stands on the opposite side. All SVATS lobectomies are performed with a 10 mm, 30-degree angled HD video-thoracoscope. Usual VATS instruments plus self-made dedicated instruments specially designed for SVATS which is longer, harder with more angled ends (Shanghai Medical Instruments Group Ltd.) are used during the operations (*Figure 1*).

Anesthesia and positioning of the patients

All cases are performed under general anesthesia with double lumen tube (single lung ventilation). The patient is placed in the lateral decubitus position with a backward inclination of 30°. The operative field is sterilized widely, to allow conversion to uniportal, multiple port approaches or thoracotomy once needed (*Figure 2*).

Surgical technique

A 3–4 cm longitudinal incision is made extending from xiphisternal junction to 1 cm below xiphoid process (*Figure 2*). The subcutaneous tissue is dissected then the rectus abdominis muscle is exposed and its fibers dissected longitudinally to expose the xiphoid process that is completely resected to provide a widened operative access. By index finger dissection, a retrosternal tunnel is created above the diaphragm with moving of the index finger more toward the operated side in a trial to open the pleura

Figure 1 A special surgical instrument set for SVATS. There are three features of the patented instruments, including extended length, 41.5 cm long, curved tip and double-articulated clamps. SVATS, subxiphoid video-assisted thoracoscopic surgery.

Figure 2 Patients' body position of SVATS. The patient is placed in the lateral decubitus position with a backward inclination of 30°. SVATS, subxiphoid video-assisted thoracoscopic surgery.

Figure 3 Cooperation with assistant. The assistant stands on the opposite side of the surgeon, with his one hand holding the thoracoscopy, and another helping to exposure.

bluntly. A wound protector (Chinese Manufacture wound protector, Changzhou, China) is inserted giving more space for the camera and instruments.

A 10-mm, 30° video camera is placed on the caudal side of the incision with the assistant holding the camera and pressing the camera slightly against the lower costal margin using it as a fulcrum for the camera. VATS instruments are placed from the cranial side of the incision (*Figure 3*).

The pleura of the operated side is opened under thoracoscopic visualization and the pericardiophrenic fat is removed which facilitates the passage of instruments and staplers. The pleural cavity is evaluated for unexpected pathology and the site of the lesion is ensured. The interlobar fissural status is assessed upon which approach of lobectomy is determined.

The lung is retracted using specially designed long curved lung grasper held by the other hand of the assistant and dissection is carried out by the surgeon using a suction instrument in the left hand and a laparoscopic hook, long electrocautery or 5 mm LigaSure blunt 37 mm tip (Covidien Ltd., Dublin, Ireland) in the right hand.

As general, we follow the order of stapling the artery first followed by vein then bronchus. If the fissure is well developed, we try to open it early to delineate the vascular anatomy, but if not well developed, we leave it as the last step or follow the fissureless technique by stapling the interlobar arteries and fissure last.

The vessels, bronchus and fissures are exposed and divided with appropriate strait or articulated endostaplers.

Figure 4 Chest tube placement. A 28 F pleural drainage tube is inserted at the inferior end of the incision passing laterally to the thoracic apex.

In some cases, a curved-tip stapler technology is used to facilitate the passage around the structures. To transect minor pulmonary arteries, we use proximal and distal silk ligature or polymer clips (Click'a V® Endoscopic Polymer Clip Appliers 45°, Grena Ltd., Brentford, England) then resect in between with LigaSure. A specimen pouch Endo Catch bag 10 mm (Covidien Ltd.) is used to remove the specimen, with prior removal of the wound protector.

Systemic lymph node dissection is performed from at least three N2 stations according to the IASLC/Mountain classification. We prefer usage of energy devices in lymph node dissection which helps with extracapsular dissection along with optimum hemostasis.

After surgery, a 28 F pleural drainage tube is inserted at the inferior end of the incision passing laterally to the thoracic apex, and then connected to a drainage bottle (*Figure 4*). A deep venous puncture catheter is inserted at the 8th intercostal space on lateral chest wall then connected to a drainage bag as a basal drain. The incision is closed in layers. All patients are extubated on table.

Postoperative care

Postoperatively, all patients are shifted to the intensive care ward then further transferred to the normal ward if there is no complication or drainage more than 500 mL in the first 6 hours. Postoperative pain is managed using a patient-controlled analgesia pump, as required, with sufentanil citrate 1 mL: 50 µg, and regular medication with flurbiprofen 50 mg every 6 h, alternating with paracetamol 1 g every 6 h. We follow early mobilization policy and chest physiotherapy. The tube is removed when there is no air-leakage and fluid drainage less than 300 cc in 24 hours. Patients are usually discharged one day after tube removal and seen 2 weeks, 1 month, 3 months then every 6 months intervals in the outpatient clinic.

Statistical analysis

Statistical analysis was carried out via Statistical Package for Social Science (SPSS) version 20 program on Windows 7. Qualitative data were represented by number and percent. Quantitative data were represented by mean ± standard deviation (mean ± SD) for normally distributed data, while non-normally distributed and discrete data were described by median, minimum and maximum. Kolmogorov-Smirnov test was used to test normality of quantitative data. Kruskal-Wallis test and Mann-Whitney test were used to compare non-normally distributed variables. One-way ANOVA was used to compare between means in the four different groups. Chi square test was used to compare qualitative data. Results were considered statistically significant if P value is less than or equal to 0.05.

Results

Patients characteristics

The study included 438 patients, 221 males (50.5%) and 217 females (49.5%) with mean age of 60.7±9.2 (range, 32–82) years. Lesion diameter mean size was 24.7±11.9 mm (range, 8–80 mm) with 2 reported cases with lesions diameter of 80 mm which was larger than the preoperative CT measured size. We didn't exclude them as they didn't affect the surgical technique or results.

Right upper lobectomy was the most common performed procedure (224 cases, 51.1%), right upper and middle bilobectomy were performed in 6 cases (1.4%) and right middle and lower bilobectomy was performed once (0.2%). Rest of the cases underwent other types of single lobectomies.

Our series included both malignant (362 cases, 82.6%) and benign (76 cases, 17.4%) pathologies. Infiltrating adenocarcinoma was the most common malignant pathology (261 cases, 59.6%) while tuberculous cavitary lesions (21 cases, 4.8%) was the most common benign pathology.

Table 1 Operative and postoperative findings in the 4 groups

Findings	Group 1 (n=100)	Group 2 (n=100)	Group 3 (n=100)	Group 4 (n=138)	P value
Operative time***	2.82±0.82	2.38±0.72	1.98±0.6	1.62±0.6	<0.001*
Intraoperative blood loss	100** [40–600]	100** [0–200]	50** [0–600]	50** [0–500]	<0.001*
Number of dissected LN stations	4** [3–6]	5** [3–7]	5** [3–7]	5** [2–9]	<0.001*
Number of dissected LN	13** [7–22]	14** [6–20]	12** [6–18]	12** [4–24]	<0.001*
Postoperative stay	4** [2–13]	4** [2–11]	4** [2–14]	3** [1–11]	0.001*
Postoperative drainage	250 [10–850]	300 [0–800]	200 [0–700]	200 [0–800]	>0.05

Data are presented as mean ± SD or median [range]. *, P value less than 0.05 is considered statistically significant. **, (I) intraoperative blood loss decreased with statistical significance in groups 2, 3 and 4 in relation to group 1; (II) number of dissected LN stations increased with statistical significance in groups 2, 3 and 4 in relation to group 1; (III) number of dissected LN increased with statistical significance in groups 3 and 4 in relation to group 1. Also, increased with statistical significance in group 4 in relation to group 2; (IV) postoperative stay decreased with statistical significance in group 4 in relation to groups 1, 2 and 3. ***, operative time reduced progressively between all groups with statistically significant difference. LN, lymph node.

Operative and postoperative findings and the significance of their difference between the 4 groups are described in *Table 1*.

- ❖ Operative time reduced progressively between all groups with statistically significant difference.
- ❖ Intraoperative blood loss decreased with statistical significance in groups 2, 3 and 4 in relation to group 1.
- ❖ Number of dissected lymph node (LN) stations increased with statistical significance in groups 2, 3 and 4 in relation to group 1.
- ❖ Number of dissected LN increased with statistical significance in groups 3 and 4 in relation to group 1. Also, increased with statistical significance in group 4 in relation to group 2.
- ❖ Postoperative stay decreased with statistical significance in group 4 in relation to groups 1, 2 and 3.
- ❖ There was no statistical significance between all groups regarding postoperative drainage (P>0.05).

Operative and postoperative complications in the 4 groups are shown in *Table 2*. Postoperative complications occurred in 28 cases in an overlapping form (sometimes, one patient had more than one complication). Prolonged air leak (more than 7 days) was the most common complication (15 cases, 3.4%) followed by arrhythmia (14 cases, 3.2%). We had only one case of accidental cerebral infarction followed by mortality. Only one case had postoperative bleeding and reoperation through thoracotomy. There was no statistical significance between all groups regarding rate of conversion nor complications (P>0.05).

Postoperative follow up resulted in discovery of metastasis in 7 patients (1.6%), described in *Table 3*. No local recurrence was reported.

Discussion

Subxiphoid approach has been widely used in thoracic surgery for various indications such as thymectomy, metastasectomy., and pneumothorax (11-13). Role of subxiphoid approach in major lung resection with its early learning curve has been addressed through some case series (9,14). In this article, we present our up to date experience for SVATS lobectomy from the surgical point of view with a trial to show the evolution of the technique and change in the results through the progress of learning curve.

This study included 438 patients who underwent uniportal SVATS lobectomy from September 2014 to November 2017 with exclusion of cases underwent SVATS resections of bilateral pulmonary or concomitant mediastinal and pulmonary lesions (10). We included cases with lesion size less than 7 cm diameter. Actually, we started our subxiphoid experience by selecting lesions of less than 5 cm diameter (9) which was increased with gaining experience (after 200 cases) to meet the same size criteria of intercostal uniportal approach. In group 4, we met two cases of tumor size of 8 cm with no invasion of visceral pleura. The size of the lesions in these two cases was 1 cm larger than the preoperative CT assessment. However, we didn't exclude them as that size didn't increase the difficulty of lobectomy or extraction of the resected lobe.

The patient is positioned in lateral decubitus position. The 30° posterior inclination helps to move the lung backwards giving clearer view of the hilum, more spacious

Table 2 Operative and postoperative complications in the 4 groups

Variables	Group 1 (n=100)	Group 2 (n=100)	Group 3 (n=100)	Group 4 (n=138)
Conversion	10 (10%)	4 (4%)	1 (1%)	1 (0.7%)
Uniportal intercostal approach	6 (6%)	1 (1%)	1 (1%)	1 (0.7%)
Bleeding				1
Adhesions	4		1	
Technical difficulty	2	1		
Thoracotomy	4 (4)	3 (3%)	0 (0%)	0 (0%)
Bleeding	3			
Adhesions	1	3		
Postoperative complications				
Prolonged air leak	4 (4%)	2 (2%)	6 (6%)	3 (2.2%)
Arrhythmia	4 (4%)	3 (3%)	2 (2%)	5 (3.6%)
Thoracic hematoma	1 (1%)	1 (1%)		1 (0.7%)
Wound infection		1 (1%)	2 (2%)	
Empyema			1 (1%)	
Pneumothorax with reinsertion of ICD		1 (1%)		
Pulmonary embolism				1 (0.7%)
Post-operative bleeding/reoperation				1 (0.7%)
Cerebral infarction/mortality			1 (1%)	

ICD, intercostal chest drain.

Table 3 Discovered postoperative metastasis on follow up

Metastasis	Group 1 (n=100)	Group 2 (n=100)	Group 3 (n=100)	Group 4 (n=138)	Total (n=438)
Number of cases	3 (3%)	2 (2%)	2 (2%)	0	7 (1.6%)
Type of metastasis	Pleural [2]; cerebral [1]	Pleural [1]; distant [1]	Distant [2]	–	Pleural [3]; cerebral [1]; distant [3]
Interval between surgery and appearance of metastasis (months)	9–33	6–20	9–12	–	6–33

space for instruments with less interference between the instruments and the mediastinum specially with the heart on the left side. Moreover, it gives the surgeon's hand more space to move and handle the instruments freely. We noticed also that 30° backward inclination makes better ergonomics for the surgeon's wrist as it makes hilar and fissural structure come at right angle with the long curved tipped instruments which facilitates dissection with less effort.

Longitudinal subxiphoid incision is currently made routinely in almost all cases regardless the degree of infrasternal angle. We previously operated via a horizontal incision if the infrasternal angle was ≥70° or via a longitudinal incision if the infrasternal angle was <70° (15). With time, we have thought that a longitudinal incision with its upper end at the xiphisternal junction makes the working port nearer to the hilum. In addition, the longitudinal incision goes with the same underlying dissected longitudinal planes of subcutaneous tissue, rectus muscle fibers and xiphoid process minimizing the degree of tissue trauma and giving an even and wider retraction by the wound retractor. As the incision is totally above the diaphragm, we haven't had any cases of abdominal herniation.

Previous experience in uniportal intercostal VATS lobectomy is a very helpful for the surgeon specially at the early learning curve. It eases surgeon's hands coordination in such technique with difficult angles. Also, presence of experienced assistant is vital for keeping the maneuver smooth and safe. The assistant's movement should be fully coordinated with the surgeon to view difficult angles specially at apical arterial trunks and posterior mediastinal structures. The assistant should go back by the camera till the wound retractor each time the surgeon introduces new instrument to the field to make that instrument under vision to avoid overseen accidental injury of the heart specially on the left side.

With ongoing experience, special self-made instruments for SVATS were designed to overcome the relatively longer track and different axis of subxiphoid approach than the intercostal one. Those instruments are longer, harder with more curved tips, including lung graspers, dissectors and electrocautery blades. They actually have helped in lesser instruments interference, easy and comfortable exposure, dissection and cauterization of tissues. Also, use of curved tips staplers facilitates easier division of different structures during the procedure.

Order of dissection and dividing of pulmonary vessels and bronchi had been followed classically by starting with the artery, vein then the bronchus specially at the start of our learning curve associated with precise selection of strait forward cases with classic anatomy and minimal or no adhesions. With experience, we started to accept operating more challenging cases with more advanced adhesions or anatomical variations required us to follow the role of "whatever easy comes first", we no longer stick to a specific order in all cases including sometimes the fissureless technique following the same way as in intercostal approach.

In all indicated cases, systemic lymph node dissection of at least three N2 lymph nodes stations is performed according to the IASLC/Mountain classification. Subcarinal lymph node sampling or dissection is routinely done. The first 100 cases experience were enough to show statistical significance increase in the number of dissected LN stations starting from group 2 with steady learning curve through groups 3 and 4. Number of dissected lymph nodes increased significantly in group 3 and 4 in relation to group 1. Actually, we started our experience by lymph node sampling with some difficulty in lymph node dissection specially with posteriorly located subcarinal lymph nodes. With getting more experience and adjustment of special instrument set, we started to get more lymph nodes.

Cardiac compression and arrhythmia are challenges on left sided operations. Improved handling skills, backward tilting of the patient, longer and specially curved instruments making the concave edge of the instruments toward the heart during the operation have enabled us to make better retraction and dissection of pulmonary structures with lesser compression on the heart. We adopt the longitudinal midline incision in our cases even in the left sided ones and we didn't find statistically significant change in the rate of arrhythmia between all groups. So, we haven't found any more importance to make left sided subcostal incision as a tool to decrease cardiac arrhythmia (10), but actually it is still an option according to surgeon's preference.

Sometimes in case of bleeding, extensive adhesions or technical difficulty, we convert to intercostal approach through adding of extra intercostal incision at the 5^{th} intercostal space between anterior and mid axillary lines which is then converted to anterior thoracotomy if needed. The rate of conversion has decreased from 10 cases in group 1 to only one case in group 3 and group 4. In group 1, the main cause of conversion to intercostal approach was adhesions (4 cases) and technical difficulty on left side (2 cases), and the main cause of conversion to thoracotomy was bleeding (3 cases) and adhesions (1 case). With experience and specially designed instruments, we have been able to deal with bleeding and cases with more extensive adhesions through SVATS, only one case was converted to intercostal approach in group 3 due to adhesions and another one in group 4 due to bleeding without the need to thoracotomy.

Intraoperative blood loss significantly decreased starting from group 2 going through groups 3 and 4 in relation to group 1. That has been attributed to occurrence of 3 cases of intraoperative bleeding in group 1 at the beginning of our experience with relatively prolonged unsuccessful trials to stop bleeding which led to significant blood loss before conversion to thoracotomy. With better instrumentation and experience, incidence of accidental intraoperative bleeding has decreased with more ability to faster control through SVATS if occurs. According to such finding, we consider SVATS as a safe approach for lobectomy.

We had only one case of mortality in 75 years old male with postoperative accidental coma and cerebral infarction with no response to specific treatment. The cause of death wasn't related to a surgical cause. Only one case who underwent right upper lobectomy had postoperative bleeding and reoperation through thoracotomy.

Postoperative metastasis was discovered on follow up in only 7 patients (1.6%) with interval of 6 to 33 months between surgery and discovered metastasis. No local recurrence was reported. That may denote the effective oncological clearance of SVATS approach. Off course further studies with longer follow up are needed to confirm that.

As in other approaches of VATS lobectomy, operative time has been going inversely with the increasing experience and number of cases (16-18). However, learning curve for SVATS lobectomy may be harder and more prolonged because of the different caudal-cranial view and longer distance to the hilum causing more difficult handling of instruments (14). The operation time in our series has significantly decreased after the first 100 cases (group 1), continuing to go down progressively through all groups. We see that is the net result of evolution of all components of the learning curve in the form of; getting the key to the best ergonomics for positioning and general set, being more familiar with the view, optimized instruments, easier handling for lobectomy and LN dissection and more effective and faster dealing with intraoperative difficulties.

Limitation of the study

Postoperative follow up of our patients ranged from 3 months to 3 years. From our point of view, longer uniform follow up is required for all patients to investigate long term effectiveness of SVATS lobectomy. Also, we consider that presence of selection criteria for patient who will undergo SVATS lobectomy is still a restricting point to show its generalizability. So, we believe that the next step should be a randomized trial through which the SVATS lobectomy is operated without specific inclusion criteria different from that of intercostal approach.

Conclusions

Adjustment of some surgical steps and instrumentation along with developing experience have helped SVATS lobectomy to be easier, safer and faster. Complete oncological clearance and adequate lymph nodes dissection is feasible in cases with malignant pathology.

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Footnote

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Ethical Statement: The study was approved by the hospital's Institutional Review Board (K17-160). Written informed consent was obtained from the patient for publication of this manuscript and any accompanying images.

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Subxiphoid mediastinal lymphadenectomy

William Guido Guerrero[1,2], Luis Angel Hernandez Arenas[1], Gening Jiang[1], Yang Yang[1], Diego Gonzalez-Rivas[1,3], Lei Jiang[1]

[1]Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University School of Medicine, Shanghai 200433, China; [2]Department of Thoracic Surgery, Rafael Angel Calderón Guardia Hospital, San José, Costa Rica; [3]Department of Thoracic Surgery, Coruña University Hospital and Minimally Invasive Thoracic Surgery Unit (UCTMI), Coruña, Spain

Correspondence to: Dr. Lei Jiang. Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University School of Medicine, 507 Rd Zhengmin, Yangpu District, Shanghai 200433, China. Email: leijiang2356@yahoo.com.

Abstract: Video-assisted thoracoscopic surgery (VATS) has experience an exponential growth in lung anatomic resections. Since its beginnings in early 90s with the conventional multiport VATS to the more recent uniportal approach, a continuous search for a less invasive procedure has fueled the development of minimally invasive thoracic surgery. In this sense, subxiphoid uniportal VATS has surge as a uniportal option that avoids damage to the intercostal nerve created in a transthoracic approach. In order for this technique to become as an acceptable choice for lung cancer, oncologic principles must be respected, including a feasible and safe mediastinal lymphadenectomy. Although technically more difficult than other VATS approaches, a complete lymphadenectomy is possible in the hands of expert VATS surgeons through a subxiphoid approach.

Keywords: Uniportal video-assisted thoracoscopic surgery (VATS); lymph node dissection; lymphadenectomy; minimally invasive; subxiphoid; novel procedure

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Introduction

The surgical treatment of lung cancer has evolved considerably in the last two decades and video-assisted thoracic surgery has played a key role in this development. The first video-assisted thoracoscopic surgery (VATS) lobectomy was performed in the early 90s (1) starting the trend of VATS for the curative treatment of lung cancer. Initially the surgery was typically performed with three small incisions without rib spreading (2) and large case series were reported with good results last decade (3). Variations of the approach were made in the quest for a less invasive surgery and needlescopic and 2-port VATS were also performed successfully for anatomic lung resections. By 2010, the first uniportal VATS lobectomy was achieved by the team lead by Dr. Gonzalez (4), which started the era of uniportal VATS lobectomies. Since then large series with this approach has been reported by different groups around the world, establishing the safety and feasibility of the technique (5-7). As an alternative single port approach, a variety of thoracic procedures were performed through a subxiphoid incision, avoiding a transthoracic approach and preventing intercostal nerve damage. In 2016, the team from Shanghai Pulmonary Hospital published their results with more than 100 cases performed through a single port subxiphoid approach (8).

Some studies have suggested that avoiding a transthoracic approach could prevent nerve damage, resulting in less postoperative pain and neuralgia (9).

The consolidation of uniportal VATS surgery has been achieve since the oncologic principles of an anatomic lung resection are not compromise using this approach, and mediastinal lymph node dissection can be performed as efficient and safe as in other VATS approaches or open surgery. Mediastinal lymph node dissection in uniportal subxiphoid VATS is more demanding and technically difficult, so a lot of training and experience is necessary before attempting a lobectomy or segmentectomy for lung cancer (10).

Patient selection and workup

Uniportal subxiphoid VATS lobectomy is a novel technique, few cases are reported in the literature, and the experience performing these cases is limited to few groups (8-11). It is very important to select proper cases for this approach. Subxiphoid surgery is technically more difficult compared to intercostal VATS and has some limitations that are related to the site of the incision. Patients with obesity should not be selected for a subxiphoid approach since increased mediastinal and subcutaneous fatty tissue would increase the difficulty of the operation due to a larger tunnel and compromise exposure. A highly located diaphragm due to abdominal pressure in obese patients would obstruct maneuvering and also compromise adequate exposure for dissection, especially station 7.

Patients with cardiac comorbidities should also be avoided since heart compression and retraction is frequent during the surgery, especially in the left side and this can even be persistent when dissecting stations 2R, 4R, 5 and 6. Patients with suspected N2 disease should also be discard for this approach since the complexity and extension of the dissection could be very difficult to complete successfully with a subxiphoid approach, compromising oncologic results. In this stage of the evolution of the technique, complex cases such as an advance or centrally located tumors, patients with prior ipsilateral thoracic surgeries or severe adhesions should not be selected for a uniportal subxiphoid lobectomy.

Proper staging and preoperative workup is very important to select the correct candidate for this approach. The chest CT has to be examined carefully to detect enlarged interlobar or mediastinum lymphadenopathy. When documented in the preoperative CT a transthoracic approach should be preferred.

Equipment preference card

Special equipment is not mandatory but it does facilitate the procedure since there are some special considerations regarding the instruments. Since the distance from the incision to the thoracic cavity is longer and the ribs are not there to prevent the collapse of the tunnel, a wound retractor should be used to keep the incision tunnel open, prevent smearing of the camera and facilitate the introduction of the instruments. Instruments must be longer, thin and better angled (8). A 30 degree 10 mm camera provides a good visualization of the operative field, and is critical when performing station 7 dissection, since changing the angle of the lens can provide a good visualization in a very narrow field. Energy devices such as Ligasure or Harmonic Scalpel can help maintaining hemostasis during lymph node dissection, although sometimes, since they are not angled, the correct plane of dissection is difficult to achieve.

Procedure

Under general anesthesia, with double lumen endotracheal intubation, the patient is placed in 60–70 degree lateral decubitus position, elevating the side in which the surgery is going to be performed.

The monitor is usually placed at the head of the patient; the surgeon is located in front of the patient and the assistant holding the camera, in the opposite side. The role of the assistant is of key importance, it should have prior experience assisting in uniportal subxiphoid VATS and the surgeon should not attempt anatomic lung resections unless this is the case. Achieving the correct view of the surgical field is very difficult and more challenging in subxiphoid VATS than in any other VATS procedure. Constant communication and coordination between both is critical.

A 4–5 cm subxiphoid incision is made; the incision can be made in different ways according to the preference of the surgeon. It can be a vertical midline incision or a horizontal incision below the sternocostal triangle. A one sided, oblique incision from the xiphoid process and alongside the costal arch can be used also, and it diminishes compression to the heart (8) and facilitates the access to station 7 during lymph node dissection.

After completing the lobectomy, mediastinal lymph node dissection or sampling should be undertaken according to the case.

In the right side station 2 and 4 are dissected with the help of longer and more curve instruments that facilitates de exposure. Bimanual instrumentation and proper retraction of the lung facilitates exposure and visualization (*Figure 1*). When exposure is not ideal and dissection is technically difficult, the azygous vein can be transected with a stapler or separated with a silk. This would improve visualization of the operative field and can prevent bleeding from rupture of the azygous vein during dissection, since is in the path of the instruments in order to gain access to the paratracheal

Figure 1 Right paratracheal lymphadenectomy. The video shows a radical lymph node dissection, which is possible thanks to proper lung retraction and bimanual instrumentation (12). Available online: http://www.asvide.com/articles/1002

Figure 2 Subcarinal lymph node dissection. This video shows the difficulty and complexity of station 7 lymph node dissection, exposure and instrumentation is complicated by the diaphragm and heart (13). Available online: http://www.asvide.com/articles/1003

Figure 3 Aortopulmonary window. This video shows the use of long and curve instruments and the precision require to complete a radical lymph node dissection of station 5 and 6 (14). Available online: http://www.asvide.com/articles/1004

space. The next step is to remove the pulmonary ligament (in upper lobectomies) in order to expose the subcarinal space, the lower lobe must be retracted upwards and medially and the diaphragm pushed away with another instrument to facilitate exposure and visualization. After liberating the ligament, the lung must be retracted medially and the subcarinal space cleared. This is the most complex and difficult step of the lymph node dissection in both sides, because the access, instrumentation and dissection are very challenging. Radical lymph node dissection of station 7 should only be attempted by expert surgeon with experience in subxiphoid lobectomies in order to reduce the incidence of complications (*Figure 2*). A unilateral oblique incision can reduce heart compression and facilitate the access to the subcarinal space, making the dissection easier.

In the left side, retraction of the lung downwards and putting the patient in anti-Trendelenburg position improve the exposure of station 5 and 6. Care should be taken to avoid injury to the recurrent laryngeal nerve (*Figure 3*). The heart is in the path of the instruments in the left side, so care should be taken to avoid injury or minimized compression during dissection of station 5 and 6. As in the right side, the lower pulmonary ligament is divided in order to facilitate exposure of station 7 and 8. The subcarinal space is even more complicated in the left side, since the heart beating and compression becomes troublesome for the surgeon.

Only after acquiring considerable experience a surgeon is able to complete a mediastinal lymph node dissection in a uniportal subxiphoid lobectomy, the learning curve is very steep and caution is advice to avoid complications.

Role of team members

When performing a uniportal VATS subxiphoid lymph node dissection, it is important that every team member has previous experience in single port VATS, since it will smooth the learning process and technical challenges inherent to subxiphoid VATS (10).

The anesthesiologist should provide a good lung collapse and take care to avoid diaphragm movement, because in case the diaphragm starts to contract, the surgery through a subxiphoid approach, and specially the lymph node dissection would be impossible to perform.

The assistant has to keep a very good coordination and communication with the surgeon and be very focused in using the proper angulation of the camera to show clearly the structures the surgeon is dissecting. The assistant can also provide aid with retraction of the lung with another instrument, so that the surgeon can use both of his instruments in the dissection process.

The surgeon must be the leader of the procedure, addressing to the other team members about the steps ahead and letting the assistant know what is the vision angle needed and proper retraction in order to facilitate the step being performed in any moment of the surgery.

Post-operative management

The postoperative management should not differ from other VATS procedures. One 28F chest tube is placed in the thoracic cavity for unilateral resections and bilateral drainage is carried out, inserting both chest tubes through the same subxiphoid incision. Pain medication requirements may be lower, since less postoperative pain is expected as suggested by some studies (11), but more studies and randomized trials are needed to confirm this.

Tips, tricks and pitfalls

- Previous experience with transthoracic uniportal VATS is required, and only expert VATS surgeons should attempt uniportal subxiphoid VATS lymph node dissection;
- Placement of a wound retractor helps to maintain the subxiphoid surgical tunnel patent, simplifying instrument introduction and instrumentation during surgery;
- In paratracheal right side dissection, looping or dividing the azygous vein is needed in some cases for better exposure and retraction while removing lymph nodes;
- Lymph node dissection in station 7 is the most difficult step, and should only be performed by expert surgeons in subxiphoid VATS lobectomies;
- Proper traction of the lung and changes in bed positioning are required to access the subcarinal space.

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Footnote

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Subxiphoid approach for spontaneous bilateral pneumothorax

Matthew Fok[1], Jay Karunanantham[1], Jason M. Ali[1], Serena Concina[2], Shruti Jayakumar[2], Adam Peryt[1], Aman Coonar[1], Giuseppe Aresu[1]

[1]Department of Thoracic Surgery, Papworth Hospital NHS Foundation Trust, Cambridge, UK; [2]Department of General Surgery, Santa Maria della Misericordia University Hospital, Udine, Italy

Correspondence to: Mr Giuseppe Aresu, MD, PhD. Department of Thoracic Surgery, Papworth Hospital NHS Foundation Trust, Papworth Everard, Cambridge, CB23 3RE, UK. Email: giuseppe.aresu@nhs.net.

Abstract: The development of video-assisted thoracoscopic surgery (VATS) has contributed to reduced pain and improved recovery following thoracic surgery. However, pain remains a major issue. Patients with bilateral pulmonary pathology requiring operative intervention may have even more pain due to bilateral transthoracic incisions. The recently described uniportal subxiphoid VATS approach provides an opportunity to undertake bilateral thoracic surgery through a single incision that avoids the bilateral intercostal nerve damage caused by transthoracic incision and drainage. Here we report a case of a patient requiring bilateral bullectomy and pleurectomy for the management of pneumothorax that was performed successfully by the subxiphoid VATS approach.

Keywords: Subxiphoid; video-assisted thoracoscopic surgery (VATS); bilateral pneumothorax; uniportal

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Introduction

Primary spontaneous pneumothorax (PSP) is a common emergency room presentation typically occurring in young, low body weight males, who are otherwise healthy without clinically apparent lung disease in their late teens or third decade of life. Bilateral PSP is a rare condition, accounting for ~1.3% of spontaneous pneumothoraces (1). Surgical resection of the blebs or bullae typically found in these patients, offers good long-term outcomes significantly decreasing the risk of recurrence (2).

At present the most common surgical practice in patients presenting with bilateral pneumothoraces is with multiport bilateral video-assisted thoracoscopic surgery (VATS). This technique has evolved to the use of bilateral uniportal VATS requiring one incision on either side to perform pleurectomy and bullectomy (3,4). Recently, to further minimise the surgical impact, a select number of centres has adopted the uniportal subxiphoid VATS (SVATS) technique which could offer several advantages including reducing acute and chronic postoperative pain by avoiding damage to the intercostal nerves, with consequential benefit in terms of recovery and quality of life (5-9). The ability to access both pleural cavities using a single incision is a further advantage of uniportal subxiphoid VATS which can be utilized in the management of patients with can bilateral pneumothoraces. This case report describes our procedure and technique for performing uniportal subxiphoid bilateral bullectomy and pleurectomy.

Case presentation

An 18-year-old man presented to the Emergency Department (ED) with sudden onset chest pain and a non-productive cough. He had no significant past medical history or underlying pulmonary disease and there was no history of trauma preceding the onset of symptoms. On admission the patient was dyspnoeic and had decreased breath sounds over the right hemithorax. He was haemodynamically stable with oxygen saturation of 94% on room air. Complete blood count and biochemistry results were within normal limits. A chest radiograph demonstrated a large right sided pneumothorax which was treated with insertion of a 14 Fr

Figure 1 Subxiphoid VATS instrument set [Shanghai Medical Instruments (Group) Ltd]. VATS, video-assisted thoracoscopic surgery.

Figure 2 Positioning of patient for left sided subxiphoid approach VATS surgery. VATS, video-assisted thoracoscopic surgery.

Seldinger chest drain and resolved spontaneously during a 2-day admission and he was discharged home. One month later he presented to the ED with similar symptoms and at this time chest radiography demonstrated a left sided pneumothorax which was treated with insertion of a 14 Fr Seldinger chest drain but had a persistent air leak. Chest computed-tomography (CT) revealed multiple sub-centimeter blebs of variable size in the apical portion of both lungs. He was referred to our tertiary cardiothoracic centre for consideration of surgical treatment.

Patient selection and workup

Indications for thoracoscopic pleurectomy and bullectomy include patients following a second ipsilateral spontaneous pneumothorax or a first contralateral pneumothorax. Other patients who warrant consideration for surgical management include patients with spontaneous pneumothorax with: prolonged air leak, incomplete lung expansion, bilateral pneumothorax, tension pneumothorax or blebs on CT imaging (10). Contraindications to a subxiphoid approach include high BMI, patients with cardiomegaly and reoperative procedures.

Instruments

Standard VATS instruments with dedicated instruments specially designed for SVATS [Shanghai Medical Instruments (Group) Ltd., Shanghai, China] are used during the operations (*Figure 1*).

Surgical procedure

A single staged bilateral surgical intervention was planned. The operation was performed with the patient under general anaesthesia and double lumen endotracheal tube intubation to allow for selective lung ventilation. Patient was placed in a left lateral decubitus position slightly rotated posteriorly in order to optimize exposure of the subxiphoid region for the left-sided procedure (*Figure 2*). The operating surgeon is positioned in front of the patient and the assistant stands more caudally on the side being operated on to provide the optimal endoscopic view. Once the left side was completed the patient was positioned similarly, to the right, in order to access the right pleural cavity.

A 3 cm midline vertical incision was made below the sternocostal triangle to expose the xiphoid process. Dissection of the linea alba was performed and the pleural cavity was entered by blunt finger dissection above the level of the diaphragm. An Alexis soft tissue wound retractor (Applied Medical CA, USA) was positioned to create a space for instrument and a 30 degree 10 mm camera insertion (Karl Storz, Tuttlingen, Germany).

The left lung was excluded from ventilation and the pleural inspected. All instruments to complete the procedure were placed through the single port, cranially to the camera. An experienced assistant is required to provide the operator with the appropriate views at all times and to avoid instrument clashes.

Blebs were identified at the apex of both the left and

Figure 3 Immediate post-operative appearance with drains to each pleural space.

Figure 4 Chest radiograph demonstrating drain position post-operatively.

Figure 5 Appearances of surgical wound following drain removal.

right upper lobes and were resected using a surgical stapler (Medtronic EndoGIA, MA, USA). Apical and mid-zone pleurectomy was performed bilaterally with pleural abrasion to the lower zones. Two 28 Fr drains were placed via the subxiphoid incision (*Figures 3* and *4*) and placed on −2 KPa suction using a Thopaz system (Medela, Switzerland). The patient was mobilized from day 0 with minimal pain. The drains were removed once the air leak had ceased on the 4^{th} postoperative day (*Figure 5*).

Discussion

VATS is associated with decreased postoperative pain, reduced length of hospital stay and fewer postoperative complications compared to open thoracotomy (11). VATS is now regarded by many surgeons as the gold standard in the surgical management of a variety of thoracic conditions such as spontaneous pneumothorax, pleural disease and for lung resections. In 2004 Rocco *et al.* described the uniportal VATS technique for the treatment of PSP with the potential advantage of reducing postoperative pain and faster recovery (3). Nonetheless even small chest wall incision cause intercostal neuralgia and can result in chronic thoracic pain. The subxiphoid approach is a novel technique which is only performed in a select number of centres worldwide but its use has been described in a variety of cardiothoracic operations including pericardial window creation, coronary artery bypass surgery, thymectomy, lobectomy and pulmonary wedge resections (5-9,12).

Since the chest drains are not entering the thoracic cavity through intercostal spaces, they do not impinge on the intercostal neurovascular bundle during mobilization of the patient. This has the potential benefit of reducing post-operative pain and allows for early aggressive mobilization and clearance of secretions with the benefit of reducing the incidence of venous thromboembolism and lower respiratory tract infection (6). Earlier mobilization may also facilitate reduced length of hospital stay.

The subxiphoid VATS technique can be easily learnt by surgeons experienced in uniportal VATS. The camera views and instrument positioning can be more challenging than for conventional VATS but the necessary skills can be acquired over a short learning curve, particularly for minor procedures.

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None.

Footnote

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

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Uniportal subxiphoid video-assisted thoracoscopic bilateral segmentectomy for synchronous bilateral lung adenocarcinomas

Giuseppe Aresu[1,2,3], Helen Weaver[3], Liang Wu[2], Lei Lin[2], Sandro Sponga[1], Gening Jiang[2], Lei Jiang[2]

[1]Department of Thoracic Surgery, Santa Maria della Misericordia University Hospital, Udine 33100, Italy; [2]Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University, Shanghai 200433, China; [3]Department of Cardiothoracic Surgery, Papworth Hospital, Cambridgeshire, UK

Correspondence to: Lei Jiang, MD. Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University, No. 507 Zhengming Road, Shanghai 200433, China. Email: Jiangleiem@aliyun.com.

Abstract: Uniportal subxiphoid video assisted bilateral segmentectomy is a minimally invasive option for the treatment of synchronous bilateral lung lesions. Its advantages over conventional multiportal or uniportal video assisted thoracoscopic surgery include avoidance of damage to the intercostal neurovascular bundle and allowance of bilateral lesion resection as a combined procedure via a single incision. This article presents a case from our centre to describe our surgical technique for this procedure.

Keywords: Bilateral procedures; segmentectomy; lung resection; uniport; subxiphoid; thoracoscopy/video-assisted thoracic surgery (VATS); subxiphoid thoracoscopy/video-assisted thoracic surgery (SVATS)

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Introduction

Synchronous, bilateral, early-stage primary non-small cell lung cancers (NSCLC) are not uncommon and an aggressive surgical approach may offer the greatest chance of long-term survival (1). However, the decision to undertake bilateral concomitant surgical resection should be made carefully, taking into consideration the higher risk of post-operative morbidity and mortality related to performing bilateral lung procedures in a single operation. In these cases, a minimally invasive approach could lead to a reduction in post-operative complication risks without compromising the oncological result. We present a case of bilateral synchronous NSCLC successfully treated by uniportal subxiphoid video-assisted thoracic surgery (SVATS) bilateral segmentectomies and discuss our experience developing the SVATS technique.

Clinical summary

A 60-year-old female presented with a month long history of a persistent cough. Preoperative high-resolution computed tomography revealed a 1.6 cm solid lesion located at the confluence of the three apical segments of the left upper lobe and a 0.8cm ground glass opacity lesion in the apical segment of the right upper lobe. There was no evidence of lymph node involvement (*Figure 1*). Bronchoscopically-guided biopsies failed to reveal the nature of the lesions. As there were no surgical contra-indications, concomitant bilateral segmentectomies via a uniportal subxiphoid incision (SVATS) were planned.

Surgical technique

Operating room set up

After induction of general anesthesia and intubation with a double-lumen endotracheal tube, the patient was positioned in the right semidecubitus position at a 60° angle to the table.

The standard set-up of the operating room consisted of a single monitor, positioned cranially, above the head of the patient. The first surgeon and the scrub nurse are positioned on the ventral side of the patient with the assistant surgeon on the opposite side.

A 10-mm, 30° angled thoracoscope and dedicated

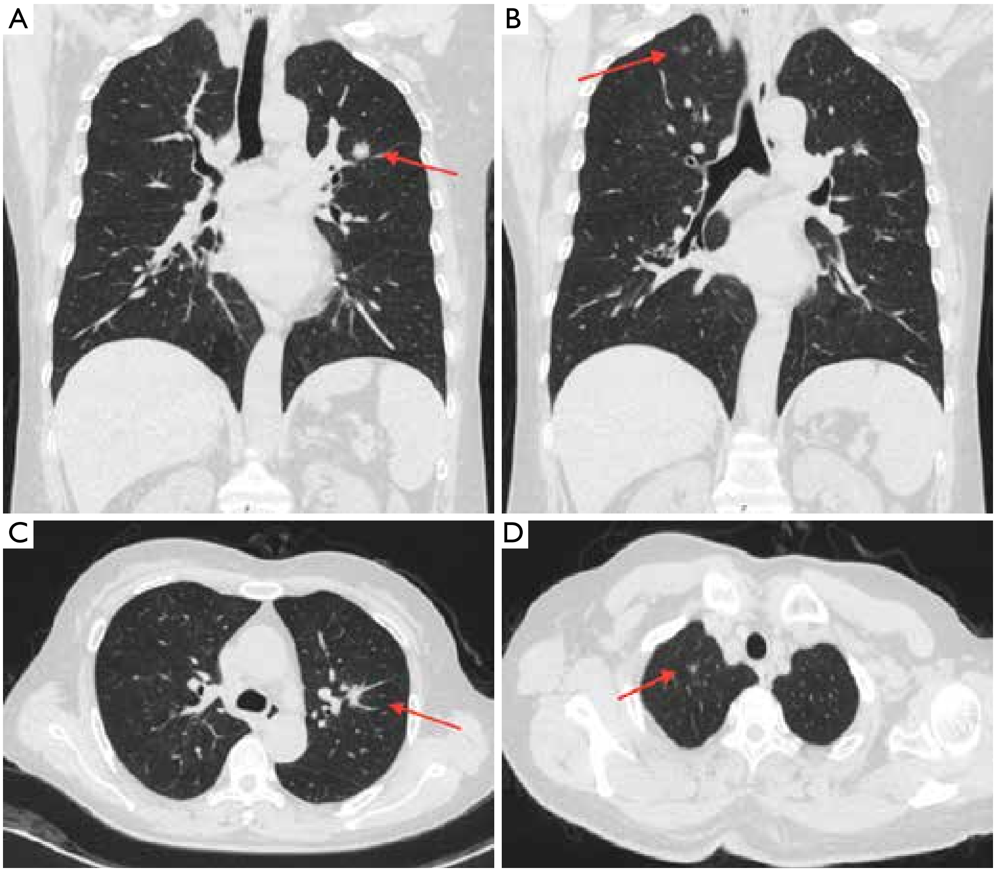

Figure 1 Thoracic CT scan: (A,C) left side lesion; (B,D) right side lesion.

instruments designed for SVATS (Shanghai Medical Instruments Group Ltd.) were used during the operation (*Figures 2,3*).

Creation of the subxiphoid single port

A 4-cm longitudinal incision was made over the subxiphoid area, the xiphoid process was cut and blunt dissection was carried out under the sternum to reach the right pleural cavity. A wound protector was placed to provide optimal exposure.

Right upper lobe upper segmentectomy (Figure 4)

The lung was retracted posteriorly and inferiorly using a specifically designed lung grasper. Dissection was performed along the border of the superior pulmonary vein and around the superior part of the hilum, inferior to the azygos vein. The apical branch of the superior pulmonary vein was dissected, ligated with a non-absorbable suture, and divided using the LigaSure device.

The mediastinal trunk of the pulmonary artery was identified and after a further distal dissection, A1 and A3 branches were visualized. The upper segment artery (A1) was ligated and divided in the same manner as the apical vein branch.

The apical segmental bronchus was then identified and was divided using a stapler. The intersegmental plane was identified by ventilating the lung and then divided using staplers. The resected apical segment was extracted using an endobag. Lymph node sampling was then carried out for stations 12R, 11R, 4, and 2.

Left upper lobe apical trisegmentectomy (Figure 4)

After the right side lung resection, the patient was rotated and re-positioned in the left semidecubitus position at a 60º angle in preparation for the left sided resection.

Using the same 4-cm longitudinal subxiphoid incision, blunt dissection was performed to reach the left pleural

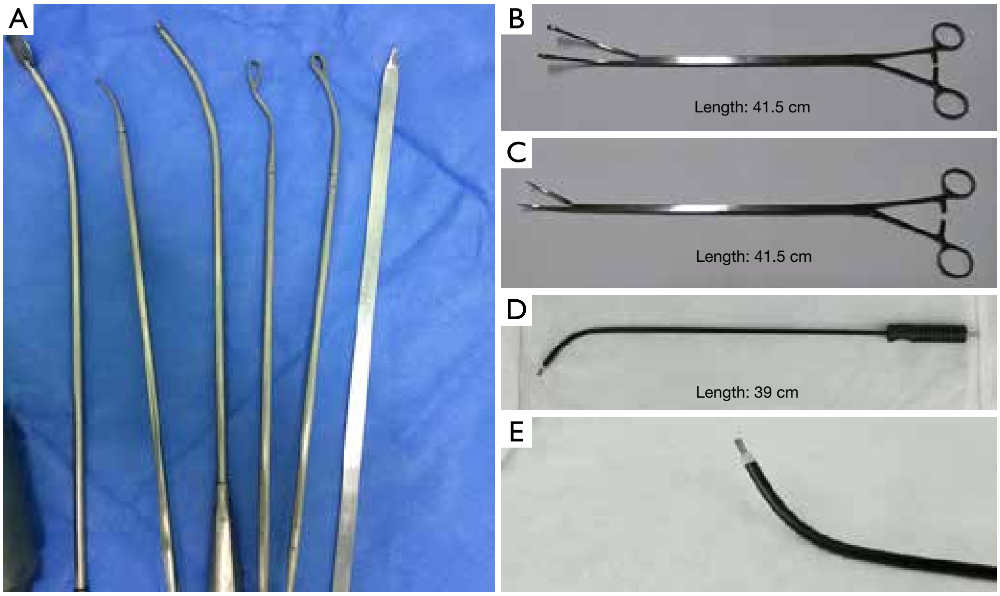

Figure 2 Instruments designed for subxiphoid video-assisted thoracic surgery (SVATS) (Shanghai Medical Instruments Group) (http://www.jzsf.com/en/index.aspx).

Figure 3 Instrumentation through the subxiphoid port.

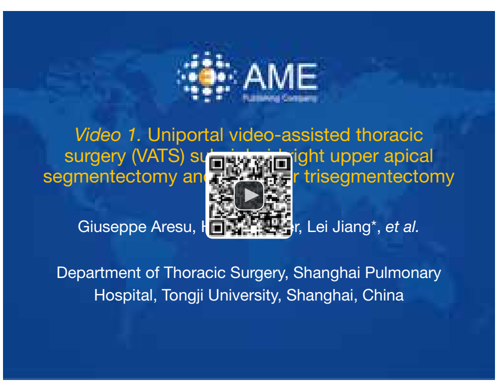

Figure 4 Uniportal video-assisted thoracic surgery (VATS) subxiphoid right upper apical segmentectomy and left upper trisegmentectomy (2).
Available online: http://www.asvide.com/articles/1229

cavity and the wound protector adjusted to provide optimal access.

The lung was retracted posterolaterally and dissection carried out along the superior border of the superior pulmonary vein until the descending aorta was visualized. Following inspection of the superior pulmonary vein the veins draining the three superior segments were identified, isolated and transected using a stapler. The lingular vein was identified and spared.

The lung was then re-positioned with postero-inferior traction and the anterior trunk was dissected and transected using a stapler. The lymph nodes on the left upper lobe bronchus were excised to improve dissection of the plane between the bronchus and the posterior ascending artery. This artery was then ligated using a non-absorbable suture and transected using the LigaSure device.

The bronchus was dissected towards the lung parenchyma and the upper bronchial division transected using a stapler. Special care was taken to ensure preservation of the lingular bronchus.

The lung was ventilated to visualise better the fissure between the apical trisegment and the lingula and this was then divided using multiple staplers, taking care not to injure the lingular artery.

The lung specimen was extracted through the subxiphoid incision and lymph node sampling performed for stations 5, 6, 7, 9L, 11L,12L.

Prior to closure, a 28F straight chest tube was inserted in each pleural cavity via the subxiphoid incision. The total operative time was 180 minutes, and the total blood loss was 150 mL.

Results

Postoperative results

The patient was extubated in the operating room. She was then transferred to the post-operative intensive care unit where she remained stable and after 16 hours she was transferred to the surgical ward.

The post-operative course was uneventful. The drains were removed on the forth post-operative day and the patient discharged on the fifth post-operative day.

The intensity of post-operative pain was evaluated every 8 hours by means of a visual analog scale, which ranged from 0 (painless) to 10 (worst pain ever experienced). The maximal mean pain score at rest was 4 (immediately post-procedure) and this declined steadily to 0 by the 2nd post-operative day. The pain was limited to the subxiphoid area and did not restrict mobility or routine activities of daily living.

Pathological results

Histopathology revealed invasive adenocarcinoma in the left-sided lesion and an adenocarcinoma *in situ* on the right. All the sampled lymph nodes were negative for malignancy.

Discussion

As shown by Jung *et al.* concomitant surgical treatment for synchronous, multiple, bilateral NSCLC can offer the greatest chance of long-term survival (1). Also, recent meta-analyses have shown that segmentectomy may be considered an oncologic equivalent treatment to lobectomy for NSCLC sized 20 mm or smaller (3,4). In this case, performing bilateral uniportal SVATS segmentectomies achieved the oncological goal of simultaneous, anatomically-complete, bilateral lesion resection with reduced peri-operative morbidity compared to conventional approaches.

Uniportal video-assisted thoracic surgery (VATS) through an intercostal space has been shown to have reduced post-operative rates of acute and chronic pain, allodynia, hypaesthesia and numbness compared to the conventional multiportal VATS approach (5). Patients undergoing a uniportal procedure, therefore report better quality of life post-lung resection than the multiportal patients (5). However, as any intercostal approach still involves an element of rib spreading and potential damage to the intercostal neurovascular bundles, these complications are not completely eradicated (5). Uniportal SVATS avoids any intercostal approach and so reduces the risk of damage to the neurovascular bundle, theoretically, improving upon the benefits of uniportal VATS. Furthermore, uniportal SVATS makes bilateral procedures possible through a single incision (6) and therefore makes this a reasonable approach to consider in patients with bilateral, synchronous tumours.

Previously, uniportal SVATS had only been described for non-anatomical lung resection or upper lobectomies and the reported clinical experience and evidence for this technique is still sparse (6-8). In Shanghai Pulmonary Hospital, after extensive experience in multiportal and uniportal VATS, we started the uniportal SVATS program for lobar and sublobar anatomical lung resections in September 2014 and our preliminary results showed the feasibility and the safety of the subxiphoid approach (9-11).

The subxiphoid approach presents some additional challenges and limitations compared to the standard VATS approach; however, with experience we have overcome several of the initial technical difficulties and these are described below:

- ❖ Access to the posterior anatomy can be more difficult using the subxiphoid approach but with appropriate retraction of the lung and optimization of the thoracoscope position it is possible to achieve good exposure of almost every portion of the chest cavity;
- ❖ At the beginning of our SVATS programme we were able to perform just lymph node sampling but with experience we gradually increased the number of lymph nodes dissected. We are now able to perform a systematic lymph node dissection with removal of lymph nodes from at least 3 N2 stations (as per the IASLC/Mountain classification). Dissection of the station 7 lymph node is particularly difficult and has been one of the toughest elements in our 'subxiphoid learning curve';
- ❖ Working on the left pleural cavity can be very challenging, especially in case of cardiomegaly, because the cardiac pulsation is transmitted to the instruments. Another issue, when working on the left side, is that the compression of the heart can lead to intra-operative arrhythmias and hypotension;
- ❖ Despite, overcoming several technical challenges of the subxiphoid approach, there remain several

segments that are not amenable to resection via SVATS and that require a more conventional VATS technique. In particular, S2 and S6 segmentectomies on the left and S9 and S10 bilaterally.

Conclusions

In our experience uniportal SVATS offers post-operative recovery benefits that over conventional intercostal uniportal VATS. Whilst there is a significant learning curve for this SVATS technique, we believe that the benefits for selected patients make this an important approach for thoracic surgeons to develop. In conclusion, this case highlights the feasibility of uniportal SVATS bilateral segmentectomy as a minimally invasive treatment option in patients with bilateral, synchronous NSCLC.

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None.

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 manuscript and any accompanying images.

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Subxiphoid or subcostal uniportal robotic-assisted surgery: early experimental experience

Diego Gonzalez-Rivas[1,2,3], Mahmoud Ismail[3]

[1]Department of Thoracic Surgery, Shanghai Pulmonary Hospital, Tongji University School of Medicine, Shanghai 200433, China; [2]Department of Thoracic Surgery, Coruña University Hospital and Minimally Invasive Thoracic Surgery Unit (UCTMI), Coruña, Spain; [3]Department of Thoracic Surgery, Klinikum Ernst von Bergmann Potsdam, Academic Hospital of the Charité – Universitätsmedizin Humboldt University Berlin, Berlin, Germany

Correspondence to: Diego Gonzalez-Rivas. Department of Thoracic Surgery, Coruña University Hospital and Minimally Invasive Thoracic Surgery Unit (UCTMI), Coruña, Spain. Email: diego.gonzalez.rivas@sergas.es.

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Introduction

During the past several years minimally invasive thoracic surgery has evolved from thoracoscopic approaches using 3–4 ports to a single incision video-assisted thoracoscopic surgery (VATS) techniques (1-3). Recently, the experience acquired with the uniportal VATS technique through the intercostal space has allowed the development of use of a uniportal VATS subxiphoid or subcostal approach for major pulmonary resections (4,5). The advantage of using a subxiphoid or subcostal entry is to reduce pain by avoiding possible trauma of intercostal nerves caused by thoracic incisions. However, the longer distance from the subxiphoid or subcostal incision to the hilum makes this approach more difficult to perform major pulmonary resections. Nevertheless, in expert hands this technique allows the possibility to perform complex resections (6), lymph node dissection (7) and anatomic segmentectomies (8).

During this same period of evolution into uniportal VATS surgery, robotic thoracic surgery has gained popularity as an alternative to traditional VATS. In some areas of the world such as the United States, robotic multiport thoracic surgery is more popular than uniportal VATS (9).The advantages of robotics are the ability to perform surgery more precisely with articulated or wristed instruments, motion scaling, and tremor filtration, as well as improved visualization thanks to 3D high definition video. However, currently 4–5 incisions are still necessary to perform anatomic robotic resections through the interspaces (10).

Recently, there has been a convergence of these two trends—uniportal surgery and robotic-assisted surgery—and has resulted in a single port robotic system, the da Vinci SP by Intuitive Surgical (Sunnyvale, California, USA). The single port (SP) platform is notable for a single 2.5 cm cannula through which an articulating 3D camera and 3 fully articulating instruments with 7 degrees of freedom can be passed. With its commercial introduction, we became interested in developing a robotic uniportal thoracic application by conducting experimental cadaver labs in the research setting. As of this writing (December 2018) the da Vinci SP has Food and Drug Administration (FDA) clearance in the US for urological procedures only, and the contents of this chapter are based on cadavers.

Overview of the da Vinci SP system

Like the conventional multiportal da Vinci Xi or X robotic platform, the SP system includes a free-standing surgeon console, a vision cart, and the patient side cart that consists of a single arm that controls up to 3 wristed instruments and the 3D articulating camera (*Figure 1*).

Movements performed by the surgeon's hands, wrists, and arms in the console are mimicked by the robotic instruments and camera. Similar to da Vinci Xi and X technology, this allows range of motion to be beyond what is capable with the human hand inside the chest cavity, thanks to 7 degrees of freedom (rotation, in-out, pitch, yaw, grasp, wristed pitch, and wristed yaw) (*Figure 2*).

The surgeon manipulates 2 master controls at the console and accordingly the finger and hand movements of the surgeon the sensors transmit the same movements inside the body. In addition, the system adds more precisión than VATS thanks to 3D magnified high definition video, the elimination of physiologic tremor, and the use of scaling from the motion of the surgeon movement to the surgical instruments which allows large motion to be scaled down to small motion.

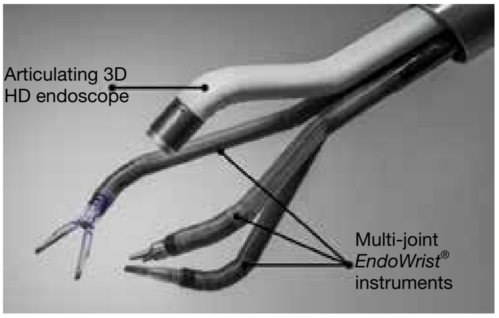

Figure 1 Close up view of da Vinci SP system by Intuitive. There are 3 multi-joint Endowrist® instruments and an articulating camera. Various instruments may be exchanged and placed into different configurations. The camera may be oriented from above as shown or from below. The da Vinci SP is 510(k) cleared in the United States for urological procedures only at the time of this writing. (Image ©2018 Intuitive Surgical).

Subxiphoid or subcostal incision

Based on our uniportal VATS surgical experience we sought to develop a uniportal robotic approach to perform thoracic procedures through a single incision to decrease pain. Due to the size of the trocar (2.5 cm) and the characteristic of the new platform (*Figure 3*) we concluded that this would not be an easy and reliable fit in the interspaces, and that the most suitable approach was to develop the procedure through the subxiphoid (preferred for thymectomy) or subcostal space (preferred for lobectomy).

For major pulmonary resections, based on cadaver experiments, we believe the patient should be placed in a lateral decubitus position or semi-decubitus position (60–70 degrees inclination), similar to positioning for the subxiphoid VATS or intercostal approach (*Figure 4*). For thymectomy, the ideal approach is in the supine position. Moreover, in the supine position it may be advantageous to flex the bed to open more space in the epigastric region.

For the subxiphoid approach, a 4 cm vertical incision is made just over the prominence of the xiphoid process. The subcutaneous tissue is opened, and the rectus muscles are incised near the insertions to the costal arches at the midline. The cartilaginous xiphoid process is excised using scissors. The anterior mediastinum is opened from below the sternum, and a retrosternal tunnel is created by blunt finger dissection to open the pleural cavity. Importantly, the diaphragm is not violated in order to prevent the risk of a

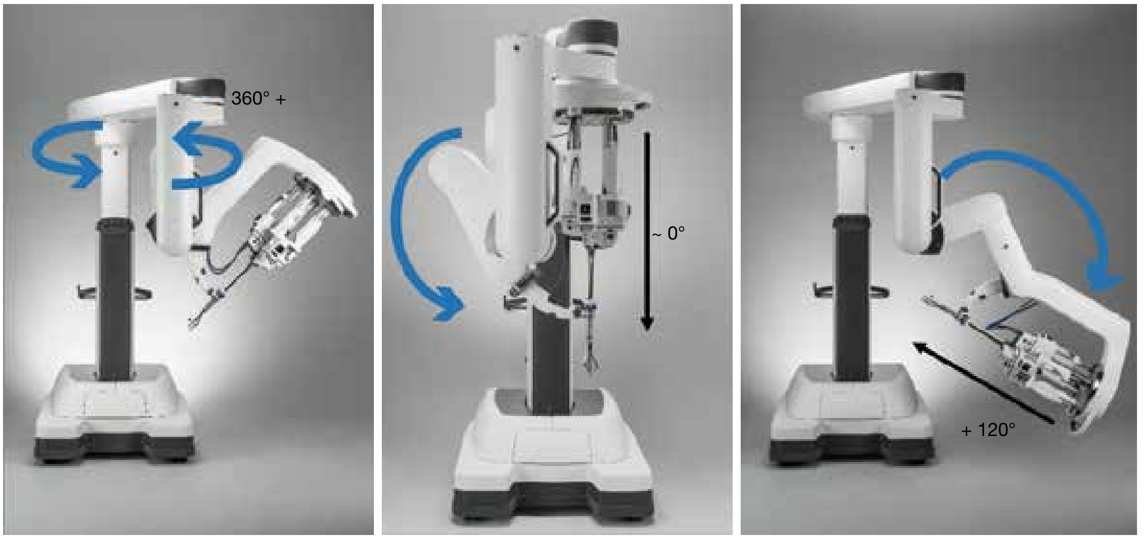

Figure 2 Overview of da Vinci SP system by intuitive. The da Vinci SP is 510(k) cleared in the United States for urological procedures only at the time of this writing. (Image ©2018 Intuitive Surgical).

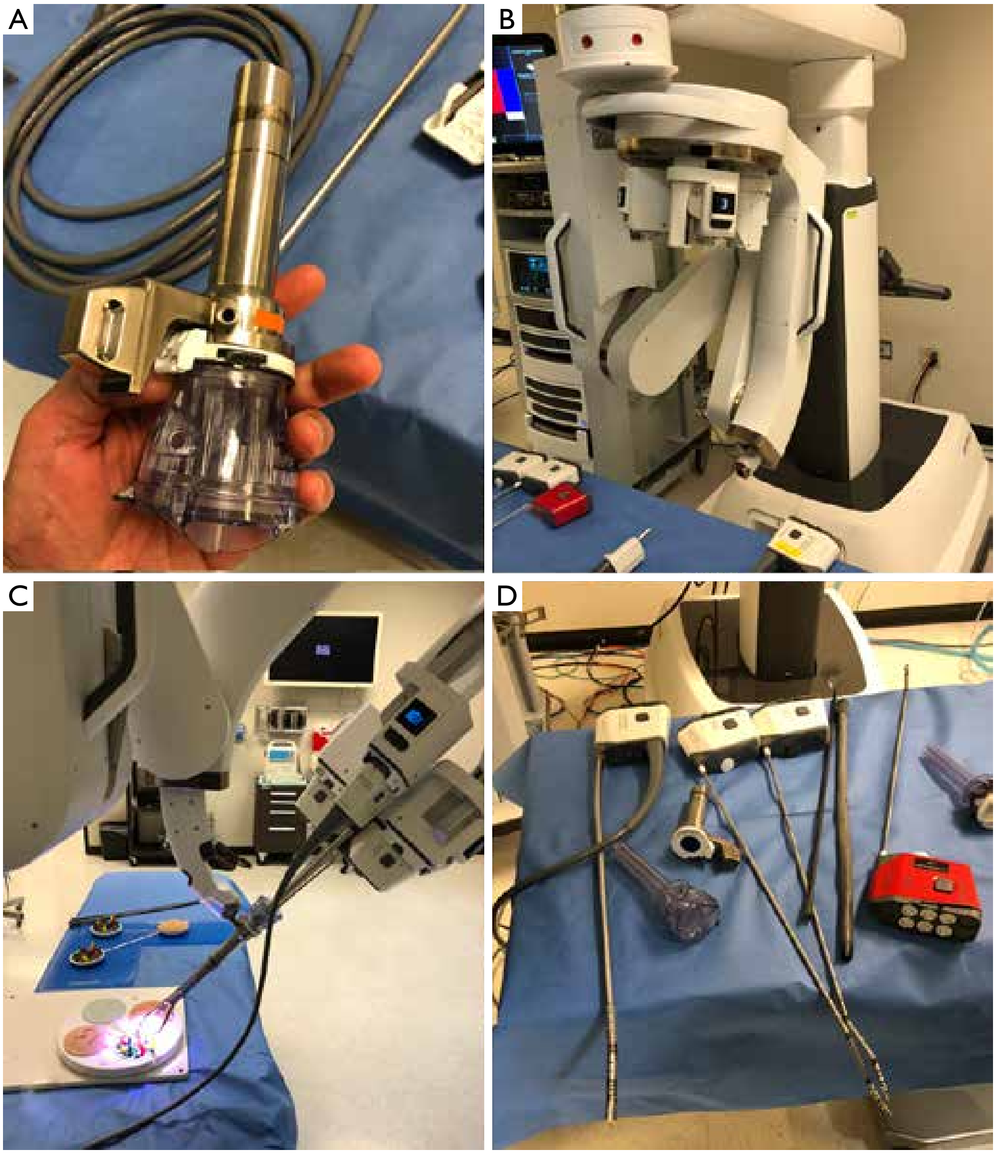

Figure 3 Components of SP system. (A) 2.5 cm trocar with 4 working parallel channels (3 arms and camera); (B) robotic platform with a single arm; (C) SP robotic arm for training; (D) instruments and camera before being inserted in the system. SP, single port.

future diaphragmatic hernia. An access gel port is placed (GelPOINT, Applied Medical Corporation, Rancho Santa Margarita, California, USA) through which the 2.5 cm SP robotic trocar is placed (*Figure 4A*). The GelPoint access port allows CO_2 insufflation, which increases the space and visibility in the chest and should be set to a pressure of 6–8 mmHg.

For the subcostal approach, an incision is placed lateral to the xiphoid process approximately 1 cm and is parallel to the subcostal margin (in the oblique direction). (*Figure 4B*). For pulmonary resection, an additional 12 mm trocar is inserted through the GelPOINT device side by side to the SP robotic trocar for the assistant to insert staplers, for suctioning, or to facilitate lung retraction and exposure if needed, especially for complex surgeries (*Figure 4C*).

Pros and cons

Based on our observations in cadavers, the da Vinci SP system overcomes many of the limitations of subxiphoid

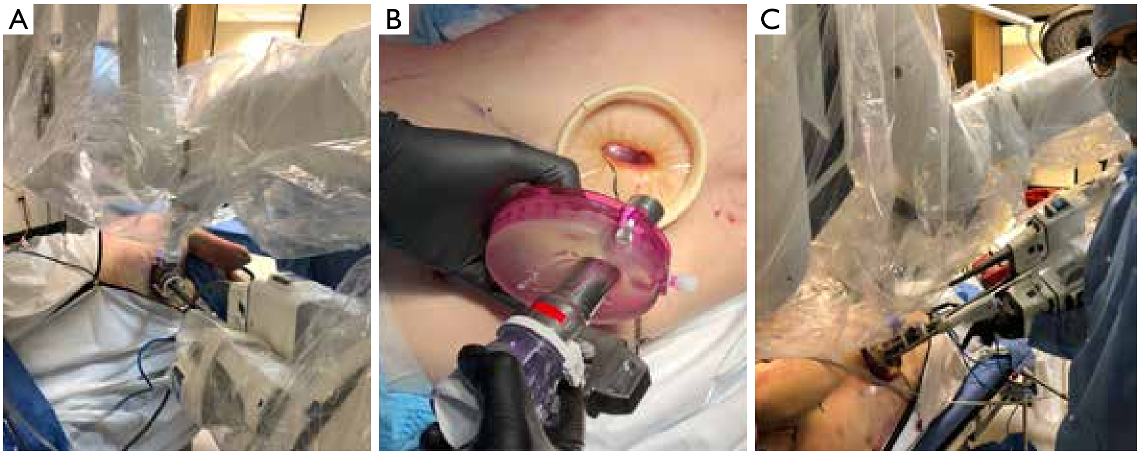

Figure 4 Position for subxiphoid and subcostal approach. (A) Lateral decubitus position, subxiphoid incision with Gel point system adapted and 2.5 cm trocar showing the 4 working channels; (B) right subcostal incision and direction of gel point system to be adapted to the wound protector (the additional thoracic incision is made to control from inside movements of the robot during experimental surgery); (C) stapler insertion by the surgeon for during a left upper lobectomy.

or subcostal VATS surgery. Compared to a subxiphoid thoracoscopic technique the robotic system provides several advantages, which we will describe below:

- ❖ The whole lung exposure and dissection (except stapler insertion) is performed by a single operator confortably seated in the console.
- ❖ Unlike with VATS where the instruments are coming in parallel with the camera, the articulation of the instrument elbows and wrists as well as articulation of the camera creates more natural triangulation to the area of interest.
- ❖ The enhanced view provided by the robotic platform is one the most important benefits. The 3D view with depth perception is a remarkable improvement over conventional VATS cameras. The ability of the surgeon to have full control the camera directly in a stable manner, with better maneuverability and magnification of the field is also an important advantage.
- ❖ The design of the robotic platform also filters unintended movements caused by physiologic tremor. This increases dexterity, restores proper hand-eye coordination and the surgeon maintains a natural ergonomic position.
- ❖ It eliminates the fulcrum effect of VATS instruments, making the instrument manipulation more ergonomic and intuitive.
- ❖ Based on these advances, we believe the SP system will allow the possibility to perform complex robotic procedures not easily possible with the conventional thoracoscopic subxiphoid approach, such as the sleeve bronchial and vascular resections.
- ❖ An extensive and complete lymph node dissection is very difficult to achieve via subxiphoid or subcostal VATS approach; however the design of the SP system with its snake-like configuration makes this step of procedure easier. We were able to expose the deeper subcarinal and paratracheal spaces for lymph node dissection much better that subxiphoid or subcostal VATS (*Figure 5*). Improved access to the posterior anatomy is a significant advance over the subxiphoid VATS approach, where this is very limited.
- ❖ When we perform a left sided uniportal VATS subxiphoid procedure, the instrumentation over the beating heart is one of the most difficult problems during surgery. For this reason in our experience the use of a subcostal approach for the left side may reduce this compression but not avoid it totally. With the robotic platform, this issue seems to be alleviated through the use of CO_2 (by pushing the diaphragm and heart down and increasing the space, especially in the left cavity) and the extreme maneuverability of the robot, which seems to diminish the compression on the heart. The cases performed in the cadaver lab showed better exposure on the left side compared with the VATS subcostal or subxiphoid approach.

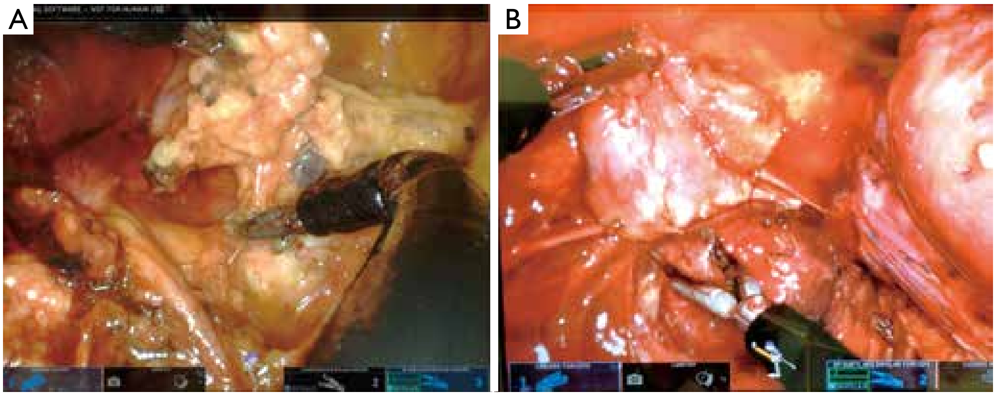

Figure 5 Lymph node dissection. (A) Paratracheal lymph node dissection; (B) right subcarinal lymph node dissection.

However, we will need to determine if this translates in real patients.

We still find several disadvantages in the SP system that we expect to overcome in the future after clinical trials and further procedure development.

- ❖ It is anticipated that the initial cost will be higher compared with the conventional robotic platform, although this is not well detailed since the SP system is not widely available at the time of this writing.
- ❖ The SP instrumentation is initially designed primarily for dissection, and robotic staplers for resection are not yet incorporated into the system. We expect robotic staplers will eventually to be included into the platform. However, at this time, all stapling would be performed with a hand-held stapler by the bedside assistant through an additional trocar placed parallel to SP robotic trocar within the same subxiphoid incision. The main surgeon is seated at the console, away from the patient so the assistant must be experienced with VATS stapling as well as familiar with the subxiphoid technique. This is similar to the requirements of the older robotic platforms such as the da Vinci S or Si, for which all stapling was done by the bedside assistant. We recommend to use curve tip staplers for the subxiphoid or subcostal approach to facilitate passage of the tip around vascular structures. However, contrary to the uniportal VATS technique, the staplers are normally inserted with no angulation for most structures bilaterally, due to the oblique direction and low position of the subxiphoid and subcostal space.
- ❖ In case of bleeding a thoracoscopic suction can be inserted through the Gel Point access port. However, with CO_2 insufflation and a closed chest, the surgeon and assistant will need to be careful not to suction aggressively and cause the lung to re-expand and lose visibility. For VATS subxiphoid or subcostal lung resections, we routine mark an additional thoracic incision before starting the case, at the level of 4th or 5th intercostal space, especially when the case is expected to be not easy in case direct control is needed quickly. This is also the reason for positioning lateral decubitus for lung resections from a subxiphoid or subcostal approach. As during thoracoscopic subxiphoid or subcostal cases, when bleeding is encountered, compression must be the first step. As with conventional robotic surgery, a cigar sponge should also be inserted into the chest cavity at the beginning of the procedure for ready availability. If the bleeding cannot be controlled by subxiphoid approach, a 2–3 cm thoracic incision can be performed to control it through the chest or in combination to both incisions (double port technique). If conversion to open surgery is needed the thoracic incision should be enlarged to a lateral thoracotomy.
- ❖ The learning curve for the surgeon using the SP system could be difficult if the surgeon is not familiar with the existing da Vinci multiport robotic platforms. During the learning curve, the movements of the instruments could interfere with one another during some parts of the procedure. However, once the technique is correctly adopted the interference is avoided and the instrumentation is fluid and ergonomic. Camera control to maximize the full capability of the articulation also requires a

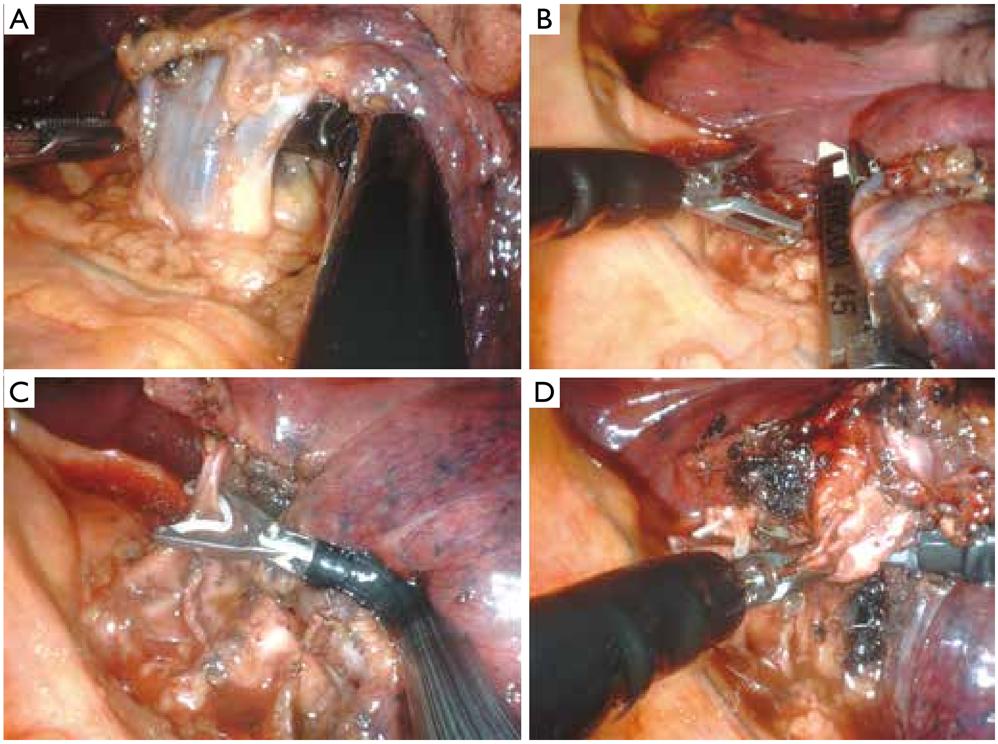

Figure 6 Left upper lobectomy. (A) dissection of LUL vein; (B) division of LUL by using staplers; (C) use of vascular clips for apical artery; (D) dissection of LUL bronchus. LUL, left upper lobectomy.

learning curve, even for existing robotic surgeons.

- The lack of tactile feedback in robotic systems could be a disadvantage especially during the learning curve. We think this issue will not be a problem for the majority of thoracic surgeons due to visual haptics, or the ability to sense tissue tension based on visual cues.

Subcostal SP uniportal robotic-assisted lobectomy

During the subcostal VATS thoracic approach, the lower lobectomies (especially the left side) and left sided resections and anatomic posterior segmentectomies are more difficult. In contrast, in the experimental cadaver labs with the SP system, we found that lower lobes and left side resections are not more difficult than the other locations due to the more curved movements of the instruments and articulated camera combined with the CO_2 insufflation, which pushes the diaphragm and mediastinum out of the way (*Figures 6,7*).

The sequence of dissection for vessels during robotic subcostal lobectomies should be similar to conventional intercostal robotic or subcostal VATS techniques, and ultimately depends on the surgeons preference and completeness of the fissure. For right upper lobes we normally prefer to divide first the apical-anterior trunk of the artery and then the upper vein (*Figure 8*). For left upper lobectomies, the division of the upper lobe vein exposes the artery more clearly (*Figure 6*). If the fissure is incomplete, a fissureless lobectomy is performed either for upper or lower lobes (*Figure 8*). For lower lobes if the artery is exposed in the fissure we start with this dissection (*Figure7B*)

The middle lobe is probably the easiest lobe to start with the subcostal technique and we normally follow the same sequence: vein, anterior part of major fissure, bronchus, artery and minor fissure last.

Compared with the VATS technique, there are distinct differences in instrumentation with the SP platform. For the SP robotic platform there is no right-angle clamp for dissection, ultrasonic shears, or robotic suction. The use of a wristed instrument with 7 degrees of freedom offsets the need for a right-angle clamp, and bipolar energy is the primary energy mode used instead of ultrasonic shears for dissection. There is an SP clip applier for vascular polymer clips that has a wristed design to achieve optimal angles for small vessels through the subcostal view (*Figure 6C*).

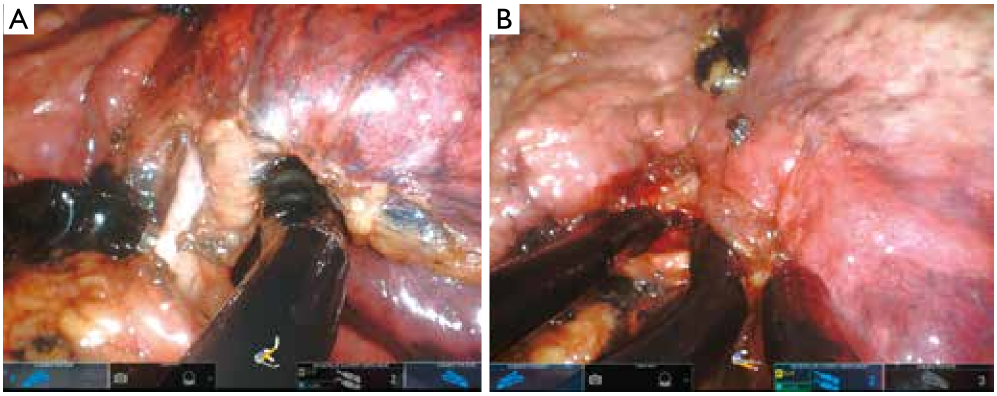

Figure 7 Left lower lobectomy. (A) dissection of LLL vein; (B) dissection on the fissure of artery. LLL, left lower lobectomy.

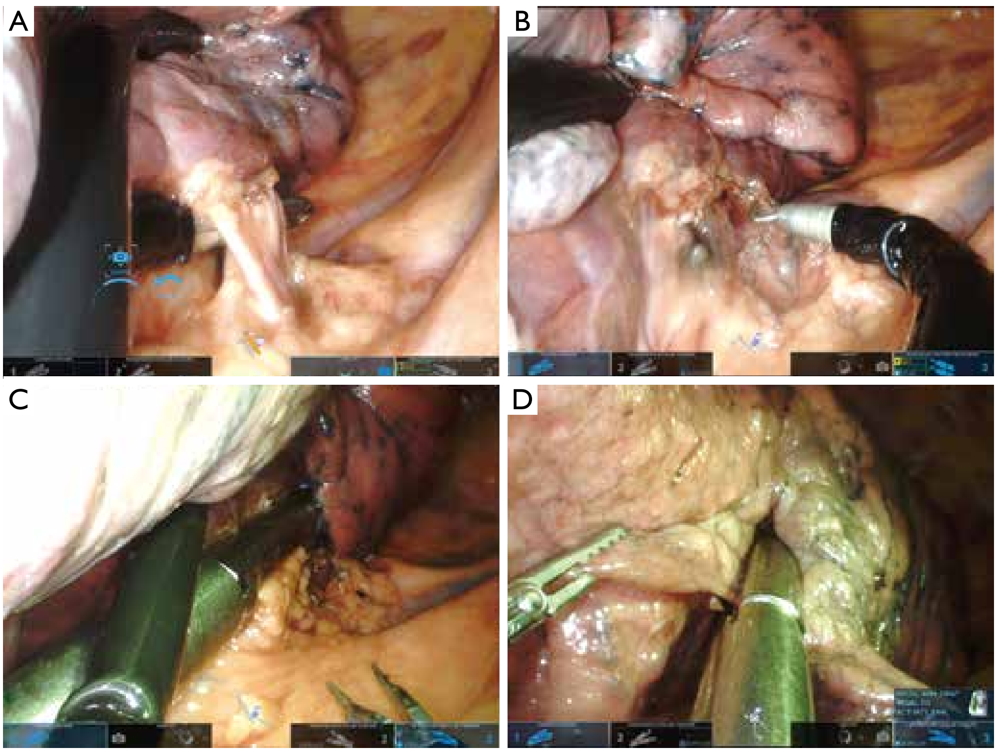

Figure 8 Right upper lobectomy. (A) Dissection of apico-anterior trunk of artery; (B) dissection of peribronchial tissue; (C) division of RUL vein; (D) completion of fissure (fissureless technique). RUL, right upper lobectomy.

We are very confident that improvements in technology with the development of new SP instruments and experience with the system will overcome these disadvantages in a near future. As surgical experience grows, we believe the indications for SP robotic lobectomy will be extended to include an increasing number of procedures including complex resections. In the future, the implementation of SP robotic staplers will allow the surgeon at the console to perform alone the whole anatomic resection, which may increase the efficiency of the operation.

Despite having proven the feasibility of performing lobectomies in the cadaveric model during experimental labs, evaluation in the clinical setting is mandatory to demonstrate feasibility and safety.

Figure 9 Set up of console and robot during a subxiphoid robotic uniportal thymectomy (supine position of cadaver).

Subxiphoid uniportal SP robotic-assisted thymectomy

The subxiphoid uniportal VATS approach is the ideal technique to perform thymic resections due to bilateral exposure of both pleural cavities, both phrenic nerves, and less postoperative pain (11). However, the VATS technique is not easy because instrumentation is more difficult as the area of dissection is further away, especially for the bilateral upper horn dissection at the thoracic inlet. The use of CO_2 could improve the view and exposure by increasing the distance of sternum to mediastinum in more than 1 cm (12). Recently a combination of robotic thoracic surgery and subxiphoid incision was also described (13). The use of sternal retractor is also very helpful to increase the intrathoracic space and improve exposure. Some groups have added an additional small neck incision for a double retraction with a hook on the manubrium, and other groups have added bilateral thoracic or subcostal incisions (14).

This da Vinci SP robotic system could improve on the VATS approach for subxiphoid thymectomy due to the more versatile instrumentation and visualization. This could facilitate more extended thymectomies and larger anterior mediastinal masses compared with VATS techniques. We have found the cadaver labs to be very promising. As in VATS, the patient is placed in a supine position and we recommend removing the xiphoid process to have more space for the trocar and reduce compression on the heart (*Figure 9*). Thanks to the subxiphoid approach we can expose both cavities by opening both pleuras and expose

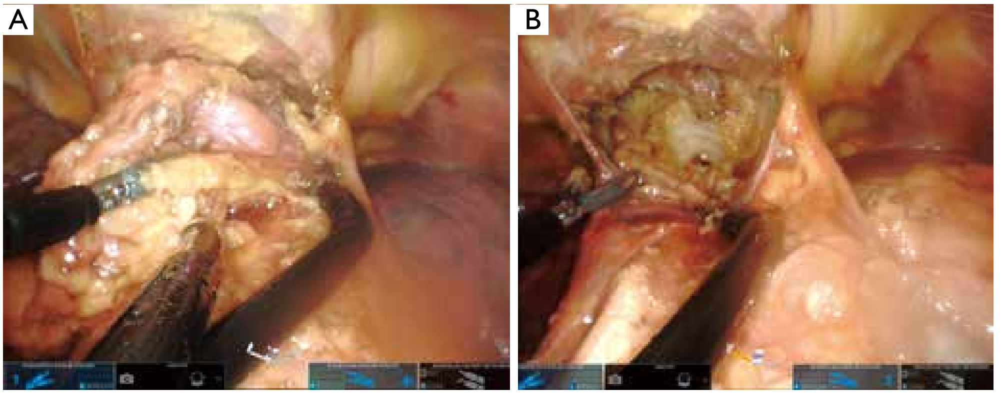

Figure 10 Thymectomy. (A) Dissection of left thymic lobe; (B) exposure of trachea and supraaortic trunks after complete thymectomy.

both phrenic nerves (*Figure 10A*). The use of CO_2 at 6–8 mmHg in combination with an optional sternal retractor clearly improves the visualization. In addition, thanks to the use of wristed instruments with more freedom of movement, the upper thymic horns are easily removed compared with other single incision techniques with visualization well into the lower neck from the subxiphoid access (*Figure 10B*). Moreover, we believe we can achieve a radical resection of thymus with no need for a cervical incision for sternal retraction.

Conclusions

The da Vinsi SP robotic platform has been evaluated in the experimental lab setting on cadavers for both subcostal lobectomy and subxiphoid thymectomy with promising exposure and workflow. The visualization and ability to perform a precise dissection appears significantly improved over the existing VATS approaches. Further studies in the clinical setting will be necessary to prove feasiblity and safety, but this appears to be the future platform for thoracic approaches due to the lack of an intercostal incision and less pain.

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None.

Footnote

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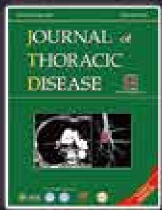

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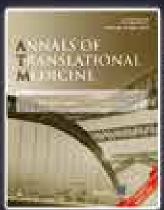

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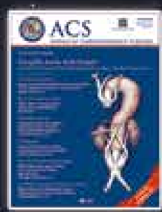

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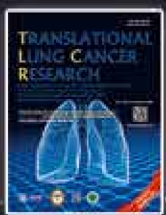

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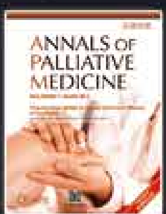

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