SEGMENTECTOMY FOR THORACIC DISEASES

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Foreword

We are pleased to announce that the "AME Research Time Medical Book Series" co-launched by AME Publishing Company, Central South University Press and DXY.cn will be published as scheduled.

Finishing my medical degree after 4 years and 3 months of study, I decided to quit going on to become a doctor only after 3 months of training. After that, I had been muddling through days and nights until I started engaging in medical academic publishing. Even 10 years after graduation, I had not totally lost the affection for being a doctor. Occasionally, that subconscious feeling would inadvertently arise from the bottom of my heart.

In April 2011, Mr. Tiantian Li, the founder of DXY.cn, and I had a business trip to Philadelphia, where we visited the Mütter Museum. As part of The College of Physicians of Philadelphia, the museum was founded in 1858 and has now become an exhibition hall of various diseases, injuries, deformities, as well as ancient medical instruments and the development of biology. It displays more than 20,000 pieces of items including pictures of wounded bodies at sites of battle, remains of conjoined twins, skeletons of dwarfs, and colons with pathological changes. They even exhibited several exclusive collections such as a soap-like female body and the skull of a two-headed child. This museum is widely known as "BIRTHPLACE OF AMERICAN MEDICINE". Entering an auditorium, we were introduced by the narrator that the inauguration ceremony of the Perelman School of Medicine at the University of Pennsylvania would take place there every year. I asked Mr. Li, "If it was at this auditorium that you had the inauguration ceremony, would you give up being a doctor?" "No," he answered.

In May 2013, we attended a meeting of British Medical Journal (BMJ) and afterwards a gala dinner was held to present awards to a number of outstanding medical teams. The event was hosted annually by the Editor-in-Chief of BMJ and a famous BBC host. Surprisingly, during the award presentation, the speeches made by BMJ never mentioned any high impact papers the teams had published in whichever prestigious journals over the past years. Instead, they laid emphasis on the contributions they had made on improving medical services in certain fields, alleviating the suffering of patients, and reducing the medical expenses.

Many friends of mine wondered what AME means.

AME is an acronym of "Academic Made Easy, Excellent and Enthusiastic". On September 3, 2014, I posted three pictures to social media feeds and asked my friends to select their favourite version of the AME promotional leaflet. Unexpectedly we obtained a perfect translation of "AME" from Dr. Yaxing Shen, Department of Thoracic Surgery, Zhongshan Hospital, Shanghai, who wrote: enjoy a grander sight by devoting to academia (in Chinese, it was adapted from the verse of a famous Chinese poem).

AME is a young company with a pure dream. Whilst having a clear focus on research, we have been adhering to the core value "Patients come first". On April 24, 2014, we developed a public account on WeChat (a popular Chinese social media) and named it "Research Time". With a passion for clinical work, scientific research and the stories of science, "Research Time" disseminates cutting-edge breakthroughs in scientific research, provides moment-to-moment coverage of academic activities and shares rarely known behind-the-scene stories. With global vision, together we keep abreast of the advances in clinical research; together we meet and join our hands at the Research Time. We are committed to continue developing the AME platform to aid in the continual forward development and dissemination of medical science.

It is said that how one tastes wine indicates one's personality. We would say how one reads gives a better insight to it. The "AME Research Time Medical Books Series" brings together clinical work, scientific research and humanism. Like making a fine dinner, we hope to cook the most delicate cuisine with all the great tastes and aromas that everyone will enjoy.

Stephen Wang
Founder & CEO,
AME Publishing Company

“Which vein shall be transected during the left upper lobe apical/posterior segmentectomy?”, the question was put forward by Dr. Morihito Okada, representative of Japanese team during the postgraduate symposium Master Cup of the 2017 Annual Meeting of the European Society of Thoracic Surgeons (ESTS). Young representative thoracic surgeons from European and American countries seemed completely dazed on site. “$v1+2^{b+c}$”, their Chinese and Japanese counterparts vied to answer without hesitation on the other hand, thinking it too straightforward a question to answer. It is a young surgeon who shared the above episode with me in surprise. For him, and other Asian surgeons, it’s hard to imagine such a basic anatomical question would turn out to be a big headache for surgeons in western countries. The generally lacking of anatomy knowledge for thoracic surgeons in European and American countries reveals the unpopularity and rawness of anatomical segmental resection among them. After all, theoretical knowledge and practical experience cooperated each other in surgery field.

It’s been definitely established that China is trailing the West in medical sciences in the past century; however, unwavering efforts made by generations of Chinese doctors have earned us a good reputation in the international community of medical sciences, and had the “voice of China” heard. Specifically in the field of thoracic surgery, China is now basically on the same page with the advanced nations after two decades of blistering catch-up endeavors. We also improved the surgical technologies to satisfy people’s growing demand in China for better healthcare. Thanks to a series of comprehensive training on standardized treatment for lung cancer and esophageal cancer, a large majority of minimally invasive thoracic surgeries have been successfully carried out even in small hospitals. As a result, patients no longer have to rush to big medical centers which are already overcrowded.

Within two decades, technology will remain the primary driving force in thoracic surgery and witness the establishment and maintaining of thoracic surgery an advantaged specialty with efforts of all thoracic surgeons. An advantaged specialty like thoracic surgery, which grows rapidly relying on technology, normally takes two steps to get there, technology adoption and popularization. It can be easily observed in the development of a specific surgery procedure, minimally invasive segmentectomy. Adopting and popularizing the technology smoothly and quickly, eastern countries now seem leading the trend in the field. Japanese thoracic surgeons have been well recognized and favored by their peers worldwide in translating and concluding their valuable experience as academic accomplishments. Chinese thoracic surgeons on the other hand would take over the task to transcend, enlarge the leading trend and converting it into a leading advantage.

Segmentectomy for Thoracic Disease, compiled by Drs. Qun Wang, Shugeng Gao and K. Robert Shen, is a primary achievement of Chinese thoracic surgeons in building thoracic surgery an advantaged specialty worldwide. The book covers a full range of information from basic settings, indications, technical essentials, to treatment of complications, in relation to anatomical segmental resection and encompasses a series of academic literature selected from journal titles published by AME Publishing Company over the years. It will definitely serve as a guidebook for thoracic surgeons and help popularizing segmentectomy.

If history is to be reviewed in the future, the current should no doubt make us proud. For this is the moment when we are fluttering our wings and ready to soar, clearing our throats and ready to sing. We are ready to transcend which is more significant than just to lead. As a book collecting experience of generations of surgeons, hopefully it will enlighten more surgeons and patients benefit eventually.

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Preface

One of the most important advances in the recent history has been the demonstration of the value of screening for lung cancer using low dose computed tomography. With the introduction of screening for lung cancer, the development of more precise radiographic techniques, and an aging population worldwide, increasing numbers of patients will be identified with small, early stage lung cancer, for which sublobar resection will be the procedure of choice. In many centers worldwide, wedge resection is too often performed, and segmentectomy remains the preferred approach for sublobar resection of selected patients with early stage lung cancer detected with screening.

This volume, "*Segmentectomy for Thoracic Diseases*" presents to most up to date data available regarding the use of segmentectomy for both malignant and benign conditions. The current evidence, relevant controversies, and future directions are critically discussed by an international panel of experts, from Asia, Europe, and North America. The editors have compiled more than 30 outstanding contributions, which describe in detail the evidence regarding the benefits of anatomic segmentectomy, the anatomic details of segmentectomy, and conduct of specific procedures, and a discussion of many specific clinical scenarios.

The volume is well-written and well-edited, providing much necessary information for experienced surgeons and surgeons in training alike, without unnecessary repetition. In addition, the spectrum of clinical approaches is represented—thoracoscopic, robotic, uniportal and hybrid approaches—allowing the reader to assess the relative benefits of each approach. This is an outstanding reference, that will be extremely useful for the modern management of lung cancer in the era of lung cancer screening.

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"What are you doing, doc?" a radiologic technologist asked me when I was using a computed tomography workstation at night about 10 years ago. "I'm looking at data from a patient on whom we are planning to perform an operation tomorrow," I replied. At that time, there were only two CT machines/workstations in our hospital, and only a few technologists could reconstruct 3-D images from computed tomography volume data. Furthermore, it took them more than 2 hours to do so, so we were generally hesitant to ask them to perform these complex tasks. In those days, I usually obtained and installed the patients' data on my PC and made the 3-D images using free software. However, it was complex work, so I sometimes used the workstation after the technologists who worked day shift were finished. Over time, I became close with this technologist. For some difficult segmentectomies, we manipulated real-time images using my PC and a sterilized mouse in the OR to rotate and resize the 3-D images until they appeared just as in the surgical view. This technologist became the head of the technologists and helped me introduce a client reconstruction system to our hospital's OR. Many things have changed since that time, including imaging technology, which has in turn led to surgical advances.

Although the standard surgical procedure for resection of lung cancer has been lobectomy, the demand for sublobar resection has increased because the detection of small-sized lung nodules considered malignant has increased as CT resolution continues to develop. Wedge resection is simple but has some problems, such as surgical margins, non-palpable features, depth of nodules, and so forth. I thought that the resolution of these problems should be through the development of anatomical segmentectomy, especially via thoracoscopy. Basal, superior, lingular, and left upper division segmentectomies are simple to dissect in the intersegmental plane. However, both lungs can be divided into 18 segments, and each segment has 2 or 3 subsegments; therefore, there are various segmentectomy patterns for resecting tumors with sufficient margins but without excessive volumes. Moreover, the segmental anatomy of one patient is quite different from that of another. I began designing resections using 3-D reconstruction from multidetector CT for respective anatomical interpretation.

If our hospital had had a sufficient number of radiologic technologists or radiologists who could have easily handled the 3-D imaging of patients, we would not have understood lung anatomy in such detail and would not have been able to perform the various kinds of precision anatomical segmentectomies. I have to appreciate the environmental circumstances of that era, as we discovered a lot about anatomy and surgical procedures during the process of overcoming these difficulties. Lung segmentectomy might be considered a complex or difficult procedure in some aspects, but I do not think it is. It has become easy with the development of imaging technology. I also believe that this procedure will become the standard of care even for lung cancer in the near future of personalized medicine. Therefore, every lung surgeon should get rid of hesitation about using it.

This book, *Segmentectomy for Thoracic Diseases*, covers the background, logic, oncology, techniques, and more. A lot of important topics but concise data from outstanding contributors from all over the world are included. I would like to give my deep thanks for the outstanding work done by all of the contributors in the production of this timely textbook. I hope that all readers enjoy this book and that lung segmentectomy will become easy for you.

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Cometh the hour, cometh the surgery

There is a great momentum of progress in thoracic surgery today, driven by the explosion of innovative minimally invasive in recent years (1,2). The future holds many exciting developments for our specialty, and the forces in play are complex and myriad.

One of the most significant of these developments from the patient's perspective may be the re-evaluation of the extent of resection necessary for lung malignancy.

For the past several decades, the lobectomy was considered the gold standard for curative resection of primary non-small cell lung cancer. Although the first anatomic segmentectomy was described in 1939 by Churchill and Belsey for the treatment of benign lung conditions (3), its application for pulmonary neoplasms has been limited. The 1995 randomized trial by Ginsberg and colleagues was instrumental in stigmatizing sublobar resection as an 'inadequate' treatment modality (4). Its role was therefore largely reserved for patients unable to tolerate lobectomy because of compromised cardiopulmonary function or significant medical comorbidities. However, accumulation of clinical experience in recent years have demonstrated that anatomic pulmonary segmentectomy can be effective in the resection of small lung primary lung tumors (5). 'Intentional' segmentectomy—and maybe even wedge resection—has been suggested to offer equivalent therapy as lobectomy for selected lesions (namely small lesions with completely or predominantly ground-glass opacity appearances). The potential attraction of preserving more lung functional lung parenchyma is that patients should have better pulmonary function and better quality of life after surgery.

Interest in such intentional sublobar resections has been amplified by two complementary developments in lung cancer management. Firstly, it is becoming recognized that modern developments in CT imaging have made this an effective screening tool for early stage lung cancer that can directly impact on patient survival (6). The upshot of this is that increasing use of CT screening will corresponding increase rates of detection of asymptomatic, small, ground glass opacity (GGO) lesions in the years ahead—precisely the lesions that may benefit most from sublobar resection. Secondly, surgical approaches for lung neoplasm resection have evolved at a remarkable pace over the last 20 years. Conventional open surgery has been replaced by video-assisted thoracic surgery (VATS) as the preferred approach for early stage lung cancer, and conventional VATS has in turn evolved into 'next generation' techniques such as robot-assisted surgery, Uniportal VATS, subxiphoid VATS, and non-intubated thoracic surgery (1,2). This minimization of surgical access forms a natural synergy with the minimization of surgical extent through sublobar resection. Despite the anatomical challenges, it has been shown that segmentectomy is entirely feasible through these 'next generation' approaches and that this will produce a package for patients that is better than the sum of its parts.

Nevertheless, many technical questions remain regarding sublobar resection, such as in the areas of ideal operative strategy, lesion localization, and so on. Future prospective studies will also be required to compare treatment effectiveness of intentional sublobar resections versus lobectomy. More importantly, we believe that sublobar resection should not replace lobectomy as the gold standard, but rather supplement lobectomy in the surgeon's armamentarium. Those future studies need to precisely identify tumor-specific indications and patient-specific criteria for applying the sublobar strategy.

This book offers a magnificent compilation of articles demonstrating the technique and demonstrating the outcomes of sublobar resection, authored by some of the most experienced specialists in this field. It is hoped that these articles will not only show how and why sublobar resection is performed, but what work still needs to be done to define its ultimate role in the management of patients with lung neoplasms.

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Preface

Since the first successful segmentectomy (lingulectomy) performed by Churchill and Belsey in 1939, controversial debate has persisted regarding the surgical indications and strategies for treating thoracic malignancy through segmentectomy. Advocates have emphasized its advantages of being parenchymal sparing and less invasive to cardiopulmonary reserved function, having oncologic security equivalent to that of standard lobectomy, and being an alternative surgical application for patients with physical impairment. However, although opponents have criticized limited resection of segmentectomy for being complicated by a potentially inadequate safety margin, a randomized controlled trial study by the Lung Cancer Study Group (LCSG) in 1995 presented evidence of an additional local recurrence rate and strongly recommended that segmentectomy for non–small cell lung carcinoma (NSCLC) be limited to patients with marginal cardiopulmonary function.

However, the spectrum of thoracic malignancy has shifted and surgical techniques have evolved. Currently, a growing number of ground glass opacity (GGO) pulmonary lesions have been detected through low-dose high-resolution computed tomography scans in an increasing number of cases of peripheral smaller noninvasive lung adenocarcinoma. In addition, various innovations and surgical applications have been developed, including 3D CT configuration, preoperative localization, and intraoperative identification of tiny radiographic abnormalities and segmental structures; all of which have been combined with the development of minimally invasive surgery, such as video-assisted thoracic surgery (VATS), uniportal or single skin incision VATS, and robotic-assisted thoracoscopic surgery (RATS), to cooperate systemically and lead a new era of segmentectomy application.

Although anatomic segmentectomy is acknowledged to be more technically complex than lobectomy because of frequently encountered anatomic variation and deeply buried intra-parenchymal segmental branches, recently increasing evidences indicate that segmentectomy is a reasonable treatment option for patients with NSCLC (≤2 cm) when a sufficient segmental margin is obtainable, particularly in patients of advanced age, with poor performance status, or with poor cardiopulmonary reserve.

Furthermore, through minimally invasive procedures—whether classical VATS, uniportal VATS, or RATS—radically anatomic segmentectomy can achieve less invasive resection of a smaller volume of lung tissue; equivalent oncological outcomes; and the benefits of less postoperative pain, shorter lengths of stay, reduced rates of morbidity, and even lower costs.

On the basis of the discussion and summary, we recommend that readers maintain interest in and concern about current segmentectomy to realize comprehensively the rapidly shifting spectrum of thoracic malignancy and surgical innovations.

Finally, ongoing, well-designed prospective RCTs should receive continuing attention regarding the different outcomes of open, thoracoscopic, and robotic segmentectomy, such as CALGB140503 and JCOG0802/WJOG4607L, for further clarifying the role of segmentectomy in treating NSCLC.

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Preface

Lung cancer, being one of the most malignant tumours, is the second most commonly diagnosed cancer in both sexes. According to American Cancer Society, there will be an estimated 222,500 newly diagnosed cases of lung cancer in 2017, which makes up a quarter of all cancer cases in the States. It is by far the top cancer killer with roughly 1 out of 4 cancer deaths caused by lung cancer (an estimated 155,870 deaths in 2017).

Despite a drop in its incidence rates since 2004 (about 2% per year and 1% per year in men and women respectively), thoracic surgery experts have never given up on devoting themselves to studying intensively the most effective surgical method to treat early stage lung cancer so as to straighten out a brighter future of lung cancer cure. Among the most popular types of pulmonary resection for lung cancer treatment (i.e. pneumonectomy, lobectomy, sublobar resection, wedge resections and segmentectomy), whether lobectomy and segmentectomy is a better surgical approach in terms of preoperative criteria, operative techniques, and postoperative effects has been a subject of much controversy. No matter which approach to adopt, one common goal among surgeons is to minimize patient's surgical trauma while retaining his/her pulmonary function and avoiding as much recurrence as possible. With the advent of thoracoscopic and robotic technologies, surgeons and patients are now bestowed upon more available alternatives. In the meantime, two profound questions loom: What are the potential surgical risks and postoperative impacts of such techniques? How do we judge which method is most appropriate for a particular patient in the real world that is full of complexities?

In search of a common remedy, scholars from different parts of the world have been joining hands to gather diversified knowledge and experience through collaborative research and a variety of academic conferences, the most representative of which would be the European Society of Thoracic Surgeons (ESTS) annual meeting, in which a Sino-European special session regarding thoracic surgery have been held since last year with exceptionally high rating. As a product of the continuous co-operation and knowledge exchange among these world experts, this book *Segmentectomy for Thoracic Diseases* is undeniably a milestone in the field of thoracic surgery where most of the prevalent surgical approaches, including segmentectomy and lobectomy, are explored, discussed, and compared. Later on, readers will be able to keep abreast of the rapidly advanced technologies in thoracic surgery by having an in-depth look at different types of segmentectomies, such as uniportal video-assisted thoracoscopic surgery (VATS) segmentectomy, robotic segmentectomy, and subxiphoid uniportal VATS segmentectomy. Last but not least, the real case studies presented by multitudinous experts from all over the world will certainly serve as a useful learning gateway for physicians and researchers worldwide, whom we hope will make the best out of it and, thus, patients from all corners of the globe will be benefited. Together we will arm ourselves to fight against any form of lung tumours.

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Although pulmonary segmentectomy was initially described by Churchill and Belsey in 1939 as a treatment for infectious lung disease (1), there is a growing body of literature which has demonstrated favorable results using segmentectomy to treat small, early-stage non-small cell lung cancers. Yet despite numerous reports attesting to the technical feasibility of performing segmentectomy safely using open, video-assisted thoracoscopic, uniportal, and robotic approaches, the utilization of true anatomic segmentectomy for lung cancer resection remains very limited. Only 4.4% of all lung resections for primary lung cancers in the Society of Thoracic Surgery general thoracic surgery database were segmentectomies (2).

This reflects the general feeling even among seasoned thoracic surgeons that a true anatomic segmentectomy with dissection, isolation and division of individual segmental bronchovascular structures is more technically demanding than lobectomy or alternative sub-lobar techniques such as a wedge resection. These concerns over increased technical difficulty along with uncertainty whether segmentectomy provides equivalent oncologic outcomes compared to lobectomy, particularly in patients who have adequate pulmonary reserve to tolerate either operation, have limited wide adoption of segmentectomy in the treatment of lung cancer.

It is hoped that this monograph will help address some of these concerns as well as provide practical information on the latest techniques for performing segmentectomy from expert thoracic surgeons.

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General Introduction

One Step Further: Uniportal, Robotic and Subxiphoid

Case Presentations

Surgical atlas of thoracoscopic lobectomy and segmentectomy

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Abstract: Thoracoscopic lobectomy or segmentectomy via the posterior approach is a safe, reliable and reproducible technique. It was first developed by Mr. William Walker from Edinburgh in 1992. The main advantages of the posterior approach include: (I) easy access to posterior hilum and segmental bronchi; (II) safe dissection, as the tips of the instruments are coming towards the operating surgeon; and (III) complete ipsilateral lymph node clearance.

Keywords: Video-assisted thoracoscopic surgery (VATS); thoracoscopic; minimally invasive surgery; lobectomy; segmentectomy

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Video-assisted thoracoscopic surgery (VATS) is a well-established technique for major pulmonary resections (1). Since the first procedure was performed more than 20 years ago, the operative approach and instrumentation have matured. In 2007, CALGB 39802 trial established the most authoritative and accepted definition of the VATS lobectomy technique, i.e., 4-8 cm access incision, totally endoscopic approach, without rib spreading and individual anatomical dissection and division of pulmonary vein, artery and bronchus (2). Compared to open surgery, the minimally invasive approach has a number of benefits especially in the immediate post-operative period (3). A recent meta-analysis of propensity score matched patients demonstrated significantly lower incidences of overall complications, prolonged air leak, pneumonia, atrial arrhythmias and renal failure, as well as shorter hospitalization compared to open thoracotomy (4). This study further consolidated the benefits of VATS and offered the highest clinical evidence on this topic.

The posterior approach was first developed by Mr. William Walker from Edinburgh in April 1992. In contrast to the anterior approach, the main differences in techniques of the posterior approach include: (I) the surgeons stand posterior to the patient; (II) the utility incision is made at the 6th or 7th intercostal space anterior to latissimus dorsi muscle, instead of the 4th intercostal space; (III) the camera port is made through the auscultatory triangle, instead of lower anterior incision; and (IV) the order of dissection is from posterior to anterior, by opening up the fissure first to identify and isolate pulmonary arterial branches. The main advantages of the posterior approach include: (I) easy access to posterior hilum; (II) lymph nodes are clearly visualized; and (III) tips of the instruments are coming towards the camera, which allows safer dissection. The fact that the posterior hilum can be clearly seen greatly facilitates dissection of the segmental bronchial branches and pulmonary arteries. Hence, the posterior approach offers great advantages for VATS segmentectomy.

Preoperative considerations

I have adopted VATS resection as the preferred surgical strategy of choice for all cases of peripheral lung carcinoma of 7 cm or less in diameter and for suitable benign disease. Lobectomy and anatomic segmentectomy are standard procedures. It is possible to utilize VATS techniques in patients with more advanced disease such as moderate chest wall or pericardial involvement and, rarely, for pneumonectomy in patients with low bulk hilar involvement. However, with the trend towards lung conservation strategies, we now reserve pneumonectomy for individuals in whom bronchovascular reconstruction is not feasible.

Baseline pulmonary function is assessed by using a combination of spirometry and CO transfer factors. Additionally, selected patients undergo exercise testing. Cardiological assessment is carried out as relevant to the individual patient. Echocardiography assessment of pulmonary (PA) pressure is undertaken in patients at risk of pulmonary hypertension (PAP >45 mmHg). Few patients are declined surgery on the basis of poor pulmonary function data (e.g., both FEV_1 and FVC <35%) (1). In addition to a contrast-enhanced computed tomography scan of the head, chest, abdomen and pelvis, positron emission tomography-CT (PET-CT) with 18F-fluordeoxyglucose (^{18}F-FDG) is performed in all patients with bronchogenic carcinoma under consideration for resection. In patients considered suitable for lobectomy or segmentectomy, the VATS approach is attempted in all patients meeting size and stage criteria. The only absolute contraindications are those patients in whom the pleural cavity is obliterated on radiological grounds or who clearly have very proximal disease requiring a pneumonectomy. The requirement for sleeve lobectomy is a significant relative contraindication, but not absolute.

Operative techniques

Anesthesia and positioning

Following induction of anesthesia, the patient is positioned in the lateral decubitus position. The hands are placed unsupported in the "prayer" position in front of the face and the operating table is manipulated to extend the thorax laterally opening up the intercostal spaces. As soon as the double lumen endotracheal tube is confirmed to be in the correct position, whilst the patient is still in the anaesthetic room, ventilation is switched to the contralateral lung to optimize deflation of the lung that is to be operated upon. Suction is occasionally used if the lung does not deflate readily. The respiratory rate can be increased to 20 breaths/min or more in order to reduce the tidal volume and hence the degree of mediastinal excursion due to ventilation. This provides a more stable operating field. Central lines or urinary catheters are rarely used, but always use an arterial line and large bore venous cannulae.

The paravertebral catheter is inserted as soon as the chest cavity is entered, under thoracoscopic guidance. This is used for perioperative analgesia in preference to epidural anaesthesia and it remains in place for 48 hours. Furthermore, a patient-controlled pump is supplied to the patient for post-operative analgesia. The positioning of the surgical, anaesthetic and nursing teams and the equipment is illustrated in *Figure 1*. The surgeon and their assistants stand at the patient's back with the screen directly across the table and the scrub nurse obliquely opposite.

Instrument

I prefer a zero degree 5 mm high definition STORZ video thoracoscope, as it provides a single axis view allowing easy correction of orientation. A combination of endoscopic and standard open surgical instruments is used. Lung retraction and manipulation are performed using ring-type sponge-holding forceps. Long artery dissection forceps (30 cm) with or without mounted pledgets are employed for blunt dissection, which are particularly useful for exposing the PA at the base of the oblique fissure, cleaning structures and clearing node groups. A range of curved forceps and an endodissector are used gently as probes to create a passage between the lung parenchyma and major hilar structures. A right-angled dissector or long curved artery forceps is used to dissect out and pass slings around pulmonary arteries and veins. Endoscopic clips are used to ligate small vessels whilst large vessels and lung parenchyma are divided using endoscopic stapling devices to ensure haemostasis and aerostasis. Both endoscopic shears and specific VATS Metzenbaum type scissors to be helpful. The latter have the advantage of curved blade ends, which reduce the risk of vascular injury.

Incision

Three access ports are used and port position is standard irrespective of the lobe or segment to be removed (*Figure 2*). A 3-4 cm utility port site incision is made in the sixth or seventh intercostal space (whichever is the wider). The camera is temporarily introduced through this port to facilitate safe creation of a 0.5 cm incision posteriorly in the auscultatory triangle at the point nearest to the upper end of the oblique fissure. The anterior hilum dissection is not essential for the posterior approach. However, for completeness of this article, it is important to understand the segmental anatomy of the pulmonary veins viewed from the anterior hilum. The pulmonary veins are the most anterior structures in the hilum (*Figure 3*). Their tributaries

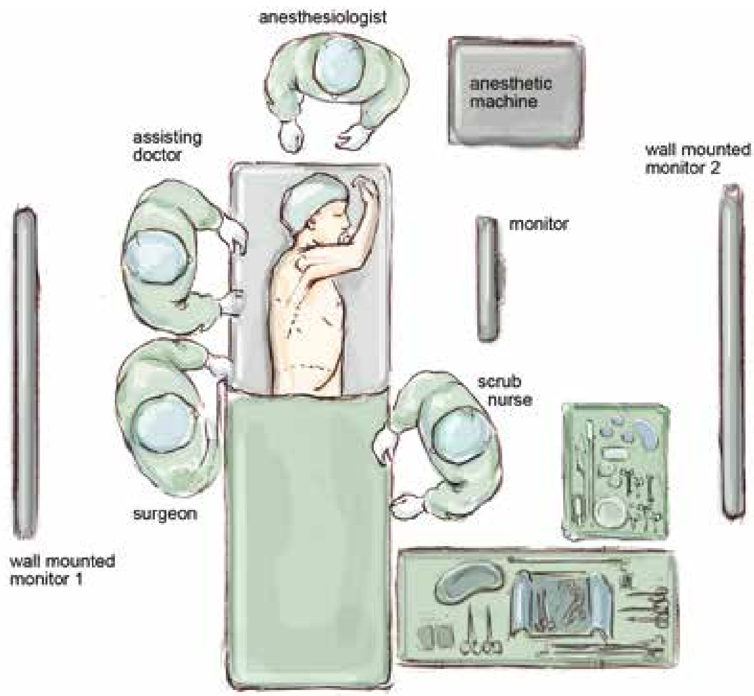

Figure 1 The positioning of the surgical, anaesthetic and nursing teams and the equipment for thoracoscopic surgery.

Figure 2 Standardized incisions for the posterior approach.

are also anterior to the segmental arteries and bronchi. The interlobar vein often traverses between the upper and lower lobes in the oblique and then the upper and middle lobes in the horizontal fissure before joining the superior pulmonary vein in the hilum. In majority of cases, the middle lobe vein drains into the right superior pulmonary vein.

A port is inserted to accommodate the camera, which is positioned in the auscultatory triagle for the remainder of the procedure. A further 1 cm port is created in the mid-axillary line level with the upper third of the anterior utility port. The anterior and posterior ports lie at opposite ends of the oblique fissure. A video-imaged thoracoscopic assessment is performed to confirm the location of the lesion, establish resectability and exclude unanticipated disease findings that might preclude resection. If the lesion is small or cannot be palpated easily, sound knowledge of segmental anatomy is crucial for determining the location of the lesion within the segment(s) of the respective lobe.

The 'landmark' lymph node

The first step is to identify the PA within the central section of the oblique fissure. In some patients the PA is immediately visible, but in the majority of cases, the PA is revealed by separating the overlying pleura using blunt dissection with mounted pledgets. If the fissure does not open easily or is fused, an alternative approach utilizing a fissure-last dissection should be considered. Once the PA has been identified, the sheath of the artery is grasped with a fine vascular clamp or long artery forceps and an endoscopic dissector is used to enter the sheath defining the anterior

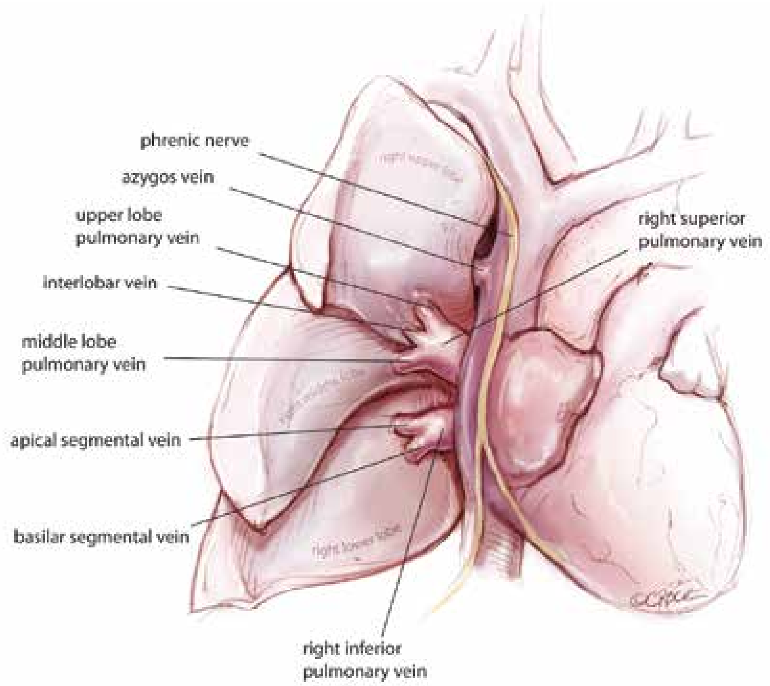

Figure 3 Segmental anatomy of the pulmonary veins viewed from the anterior hilum.

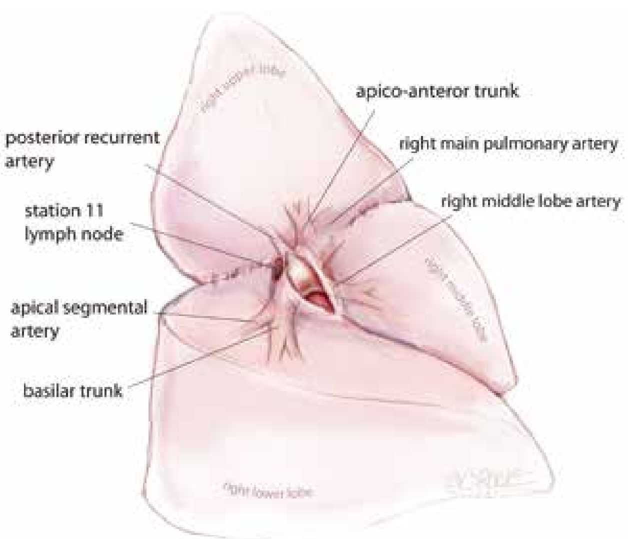

Figure 4 Pulmonary artery is revealed by separating the overlying pleura using blunt dissection.

and posterior margins of the artery. The apical lower branch of the PA is often exposed during this dissection (*Figure 4*).

For all lobectomy and segmentectomy procedures excepting middle lobectomy, the lung is then reflected anteriorly and the posterior pleural reflection is divided using sharp and blunt dissection. On the right, this process should clear lung tissue away from the angle between the bronchus intermedius and the upper lobe bronchus, exposing the posterior hilar lymph nodes in this position (*Figure 5*). One lymph node packet, the station 11 lymph node, sitting at the bronchial bifurcation between the right upper lobe and the bronchus intermedius is the 'landmark' lymph node to me, because just superficial to this, it indicates a safe passage from the interlobar fissure to the posterior hilum over the pulmonary artery. From the anterior port site, dissecting forceps are passed gently immediately superficial and posterior to this station 11 'landmark' lymph node, where it has been identified in the oblique fissure (*Figure 6*). When the lung is retracted anteriorly, the tips of the long artery forceps will emerge through the incised posterior pleural reflection, above the 'landmark' lymph node that is now viewed from the posterior hilum. This maneuver is the key step for any VATS lobectomy or segmentectomy via the posterior approach on the right side. Care should be taken during this maneuver not to disrupt this lymph node lying on the bronchial bifurcation. A sling is then passed behind the posterior fissure, which is divided with an endoscopic linear stapling device. The PA is now clearly seen and the distinction between the upper and lower lobes is established.

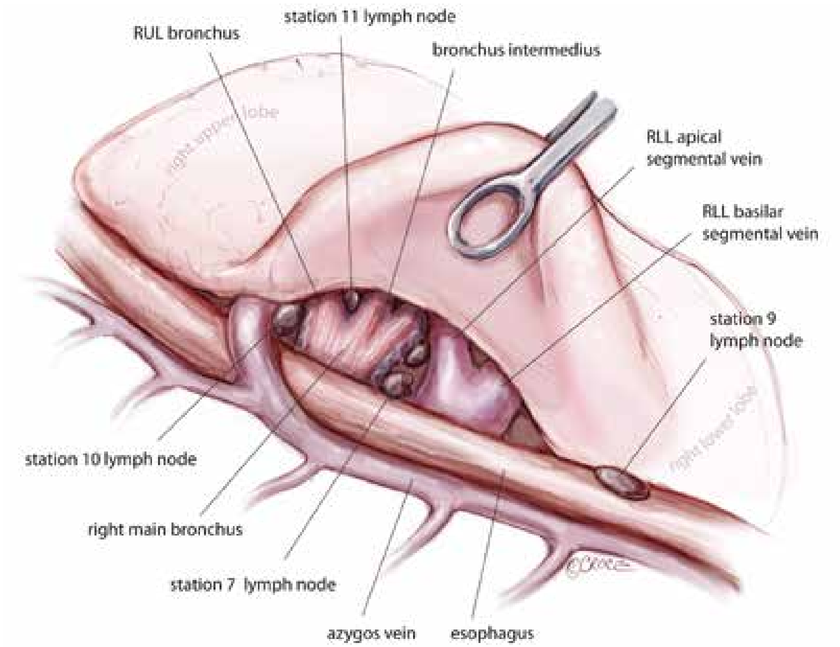

Figure 5 Viewed from the posterior hilum, the 'landmark' station 11 lymph node is exposed by clearing the lung tissue away from the bronchus intermedius and the upper lobe bronchus.

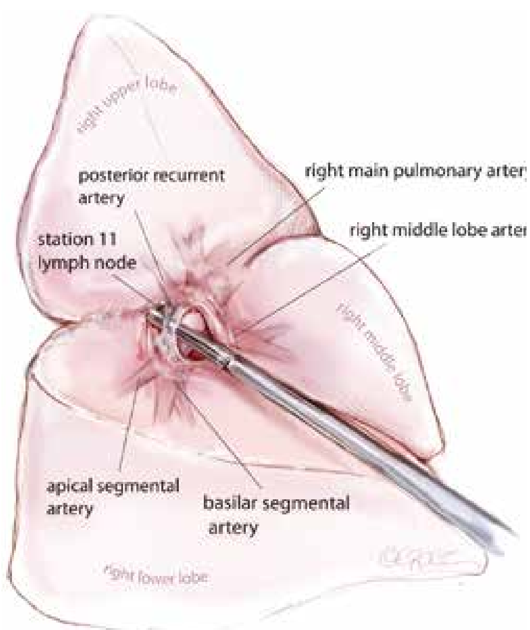

Figure 6 From the anterior port site, dissection forceps are passed gently immediately superficial and posterior to this station 11 'landmark' lymph node, where it has been identified in the oblique fissure. When the lung is retracted anteriorly, the tips of the forceps will emerge through the incised posterior pleural reflection, above the 'landmark' lymph node between the right upper lobe bronchus and the bronchus intermedius, as seen in the previous figure.

Dissection then proceeds according to the lobe or segment to be resected.

Right upper lobectomy

Having divided the posterior fissure, the posterior ascending segmental branch of the PA is often evident, and should be divided at this stage if appropriate. It is frequently small enough to clip. The upper lobe bronchus is then identified and dissected out. It is common to find a substantial bronchial artery running alongside the bronchus, which should be ligated with clips and divided. Note that clips are only used on the proximal end and the distal end is not clipped since clips in this position may interfere with subsequent stapling of the bronchus. The upper lobe is then retracted inferiorly and blunt dissection with mounted pledgets is used to free the cranial border of the upper lobe bronchus and define the apico-anterior trunk. The azygos vein is often closely related to the bronchus and can be pushed away using a gentle sweeping motion. Long artery forceps are passed around the upper lobe bronchus close to its origin in the plane between the bronchus and the associated node packet (*Figure 7*). It should be appreciated that the apico-anterior trunk lies immediately anterior to the bronchus, but sometimes separated by station 11 right

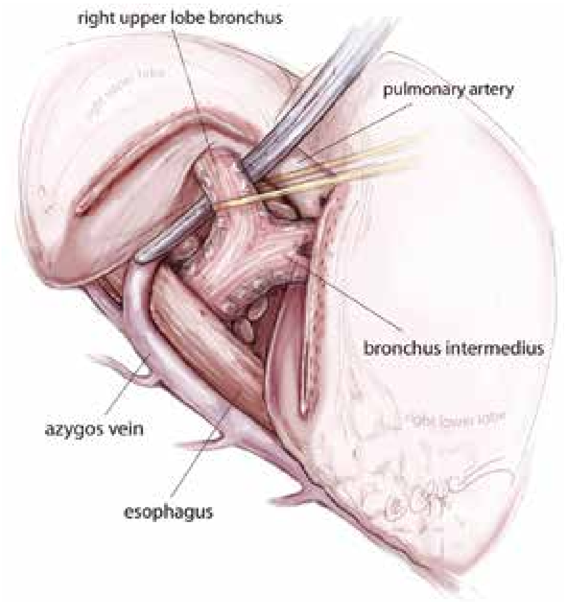

Figure 7 Long artery forceps are passed around the upper lobe bronchus close to its origin in the plane between the bronchus and the associated node packet.

upper lobe lymph nodes. The bronchus is transected at this level using an endoscopic linear stapling device. It is not necessary to inflate the lung to test that the correct bronchus is being divided, as the vision is invariably excellent via the posterior approach and the re-inflated lung may subsequently obscure the view for remainder of the resection.

Following division of the bronchus, the feeding vessels to the right upper lobe bronchus node packet are clipped and divided, allowing the nodes to be swept up into the operative specimen. Clasping the distal end of the transected bronchus with an endoscopic toothed grasper, the upper lobe can be reflected upwards. The posterior segmental artery is divided at this stage if not already dealt with and the apical and anterior segmental arteries or common stem artery are carefully cleaned, dissected out (*Figure 8*) and divided with an endoscopic stapler. Finally, the lung is retracted posteriorly facilitating dissection of the superior vein. This can be divided from either the posterior or anterior aspect as convenient, taking care in either case to identify clearly and preserve the middle lobe vein. The transverse fissure is then divided. The middle lobe artery is most easily identified and protected if the stapling device is first passed through the inferior port and fired from posterior to anterior. Division of the transverse fissure is

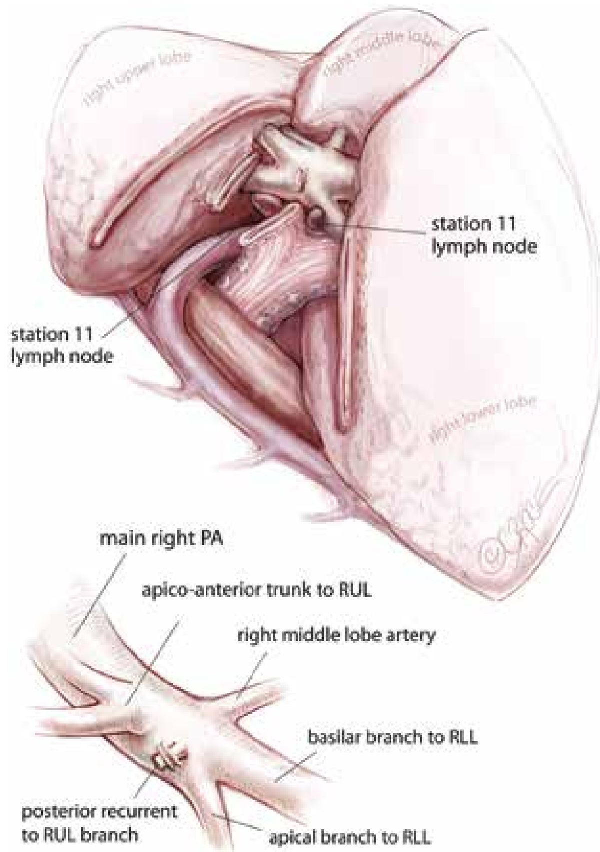

Figure 8 The posterior segmental artery is divided at this stage if not already dealt with and the apical and anterior segmental arteries or common stem artery are carefully cleaned, dissected out.

then completed, passing the stapling device through the anterior port. The inferior pulmonary ligament is divided to facilitate expansion of the right lower lobe.

Right lower lobectomy

Having identified the PA in the oblique fissure and divided the posterior oblique fissure, the pulmonary artery is then divided either in one or separately as a basal trunk artery and the apical segmental artery to the lower lobe. The space between the superior and inferior veins is developed and a long clamp is passed into this space emerging anterior to the PA in the oblique fissure. A sling is passed into this plane and the anterior oblique fissure is then divided. The lower lobe is mobilized by dividing the inferior pulmonary ligament. The inferior vein is dissected free from surrounding tissue and divided using an endoscopic linear stapling device. The bronchus is identified and the

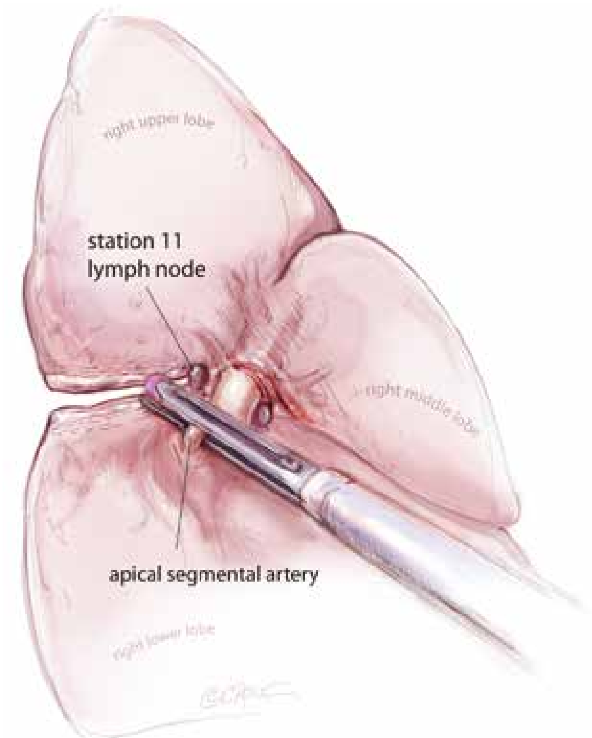

Figure 9 The apical segmental artery is divided using a vascular stapler.

bronchial vessels are clipped proximally. Lymph nodes are cleared from its medial and lateral margins. The lower lobe bronchus is divided through its apical and basal branches preserving airflow to the middle lobe. The middle lobe bronchus must be visualized prior to stapling.

Right middle lobectomy

The PA is identified and the anterior oblique fissure is divided as for right lower lobectomy. The vein, bronchus and arteries are then seen clearly, like three little 'soldiers' when the right upper lobe is retracted superiorly and are divided in sequence. The transverse fissure is divided as described for right upper lobectomy.

Left upper lobectomy

The PA is identified in the oblique fissure and the posterior aspect of the oblique fissure is divided in a similar way to the right side. The arterial branches to the left upper lobe are then divided sequentially. Division of the anterior aspect of the fissure is completed in similar manner to that on the right side. It is important to develop the space between the pulmonary veins and central to the fused anterior oblique fissure thoroughly. When passing a clamp through the utility incision and under the fused fissure, the surgeon will feel the lower lobe bronchus and should allow the clamp to pass superficially in order to preserve the airway to the lower lobe. Gentle blunt dissection is used to separate the superior pulmonary vein from the anterior surface of the bronchus. A long clamp is passed around the base of the bronchus, taking particular care not to damage the PA. Retraction of the PA using a mounted pledget may be helpful. A sling is passed around the bronchus and used to elevate it (crane maneuver) in relation to the pulmonary artery and create a space via which an endoscopic stapling device can be inserted to divide the bronchus. The superior vein is cleaned and divided. The inferior pulmonary ligament is divided up to the level of the inferior vein to facilitate expansion of the lower lobe.

Left lower lobectomy

As on the right side, having identified the PA and divided the posterior aspect of the oblique fissure, the arterial branches are identified. The anterior portion of the oblique fissure is divided as for left upper lobectomy and the arterial supply divided with an endostapler. The inferior pulmonary ligament is divided up to the level of the inferior pulmonary vein. The margins of the vein are clearly delineated and it is then divided. Bronchial vessels are clipped proximally and divided, and the lymph node chains are cleared off the medial and lateral aspects of the bronchus, which is divided at its base.

Segmentectomy-'three-directional' stapling technique

Apical segmentectomy of the lower lobe is a common procedure. In this article, I describe the technique of thoracoscopic apical segmentectomy using a 'three-directional' stapling technique. Having identified the PA in the oblique fissure and divided the posterior oblique fissure, the pulmonary artery is then prepared using blunt dissection by 'dragging' the lung tissue distally along the pulmonary artery until its bifurcation to apical and basal segmental branches is clearly seen. The apical segmental artery is divided using a vascular stapler (*Figure 9*). Once the apical artery is divided, the PA is pulled forward to reveal the bronchus intermedius posteriorly and its bifurcation to the lower lobe, i.e., apical and basilar segmental bronchi

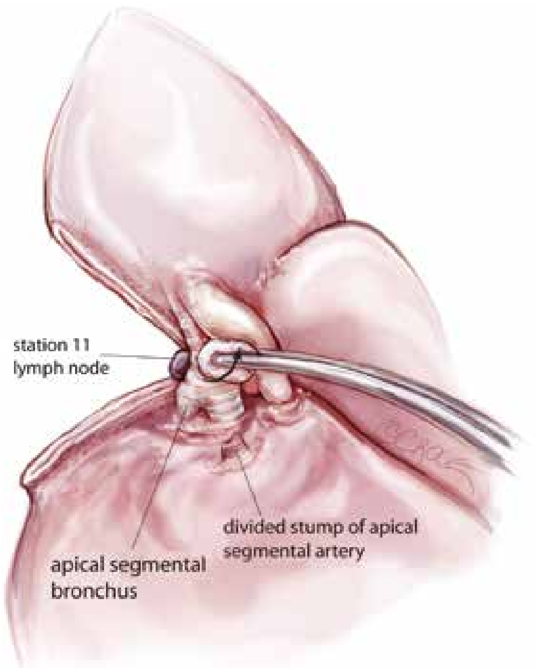

Figure 10 Once the apical artery is divided, the pulmonary artery is pulled forward to reveal the bronchus intermedius posteriorly and its bifurcation to the lower lobe, i.e., apical and basilar segmental bronchi.

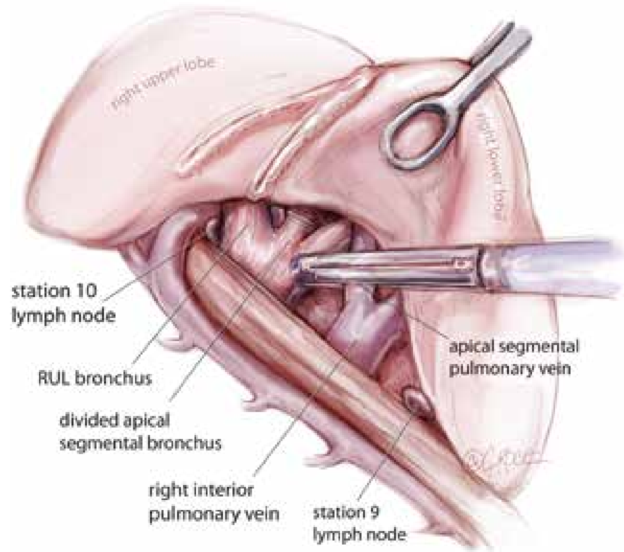

Figure 11 The apical segmental vein is divided using an endoscopic linear stapling device.

(*Figure 10*). The apical segmental bronchus is divided with a stapler, passed through the anterior access port. Lymph nodes are the cleared from the medial and lateral margins of the bronchus. The lower lobe is then retracted forward to exposure the posterior hilum. The lower lobe is further mobilized by dividing the inferior pulmonary ligament. The inferior vein is dissected free from surrounding tissue and the confluence of the apical and basilar segmental veins is developed by 'pushing' the lung tissue distally using a small pledget mounted on the tips of long dissecting forceps. The apical segmental vein is divided using an endoscopic linear stapling device (*Figure 11*).

Finally, the apical segment is separated from the basilar tri-segments using a 'three-directional' stapling technique. It is clear that each lobe is a three-dimensional structure or pyramidal in shape. By simply compressing the lung tissue and dividing it using a heavy stapling device in one plane, not only is it not possible to achieve an anatomical segmentectomy, but also the staples may not be able to hold the thick lung tissues together, resulting in prolonged air-leak. It is important to first orientate the segment to its anatomical position. The 'three-directional' stapling technique requires the first stapler coming from the anterior access incision towards the distal limit of the apical segmental bronchus, compressing the interlobar surface with the anterior surface of the lobe; the second stapler coming from the posterior direction towards the distal limit of the segmental bronchus, compressing the lateral and posterior surfaces of the lobe; and the third stapler dividing the lung parenchyma medial and parallel to the apical segmental bronchus, hence completing the segmentectomy in three directions (*Figure 12A*). The final apical segmentectomy specimen should be pyramidal in shape with individually divided segmental artery, bronchus and vein (*Figure 12B*). All hilar and segmental level nodes relevant to the resected segment are excised. At mediastinal level either extensive sampling or lymphadenectomy is preferred.

Postoperative care

A size 32 Fr apical drain is placed through the mid-axillary line port site and is usually removed on the first postoperative day subject to a satisfactory chest radiograph and aerostasis. Patients are typically nursed on the general thoracic ward after immediate extubation. Analgesia is provided using a patient-controlled analgesia pump and a local anaesthetic paravertebral catheter. Early mobilization is strongly encouraged with the availability of physiotherapy

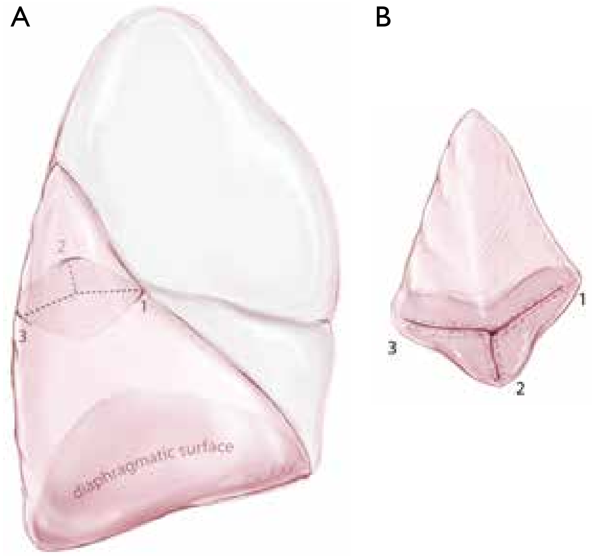

Figure 12 (A) The 'three-directional' stapling technique requires the first stapler coming from the anterior access incision towards the distal limit of the apical segmental bronchus, compressing the interlobar surface with the anterior surface of the lobe; the second stapler coming from the posterior direction towards the distal limit of the segmental bronchus, compressing the lateral and posterior surfaces of the lobe; and the third stapler dividing the lung parenchyma medial and parallel to the apical segmental bronchus, hence completing the segmentectomy in three directions; (B) the final apical segmentectomy specimen should be pyramidal in shape.

seven days per week, and discharge as early as postoperative day 2 or 3 is often possible.

Comments

The posterior approach is a safe, reliable and reproducible approach to VATS lobectomy and segmentectomy. VATS has been shown to compare favorably with open thoractomy in terms of immediate post-operative recovery and is considered to be oncologically equivalent. Our cross-sectional survey on 838 thoracic surgeons worldwide showed that 95% of surgeons who performed VATS agreed with the CALGB definition of 'true' VATS lobectomy; 92% of surgeons who did not perform VATS were prepared to learn this technique, but were hindered by limited resources, exposure and mentoring (5). Majority of thoracic surgeons believed advanced VATS techniques should be incorporated into thoracic surgical training and for more standardized workshops to be made available. A recent consensus from 50 major minimally invasive thoracic surgeons showed that increased use of VATS techniques for lobectomy and segmentectomy would be highly desirable (1).

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None.

Footnote

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

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Lobectomy *vs*. segmentectomy for NSCLC (T<2 cm)

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Abstract: The extent of surgical resection for peripheral clinical T1N0M0 non-small cell lung cancer (NSCLC) ≤2 cm continues to be a matter of debate. Eighteen years ago, a randomized controlled trial (RCT) established lobectomy as the standard of care for peripheral clinical T1N0M0 NSCLC. However, numerous publications since then have reported similar outcomes for patients treated with segmentectomy or lobectomy for peripheral clinical T1N0M0 NSCLC 2 cm or smaller in size. The majority of these publications are retrospective studies. Two ongoing RCTs aim to resolve this debate, one in Japan and the other in the United States. This manuscript is a comprehensive review of the literature that compares lobectomy to segmentectomy for peripheral clinical T1N0M0 NSCLC 2 cm or smaller in size. Until data from the ongoing RCTs become available, this literature review provides the best evidence to guide the thoracic surgeon in the management of these patients.

Keywords: Segmentectomy; lobectomy; lung cancer; 2 cm

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Lobectomy was established in 1995 as the standard of care for optimal oncologic resection of stage I non-small cell lung cancer (NSCLC), after the results of the Lung Cancer Study Group (LCSG) reported a significantly higher rate of recurrence and associated trend toward lower cancer-specific survival in patients undergoing sublobar resections (1). Since then, several investigators have challenged this dogma by demonstrating equivalent oncologic outcomes of segmentectomy and lobectomy for stage IA NSCLC. A large proportion of studies have integrated segmentectomy and wedge resection under the category of limited resection when making comparisons to lobectomy (2). However, recent publications have focused on comparisons between segmentectomy and lobectomy excluding cases of wedge resection (3-6).

Potential advantages of segmentectomy over lobectomy include preservation of lung function and reduced morbidity and disability. Preservation of lung function may be particularly important for elderly patients, those with borderline preoperative cardiopulmonary function, and patients with synchronous or metachronous cancers that would require repetitive resections over the course of their lifespan. The incidence of a second primary lung cancer may be as high as 3% per year (7); thus, patients who survive five or more years after their first resection would face a significant cumulative risk of second cancers. On the other hand, lobectomy may provide a lower recurrence rate that could translate into longer disease free survival, particularly in young patients who are good surgical candidates.

The main objective of this manuscript is to review the literature that compares lobectomy versus segmentectomy for NSCLC less than 2 cm in size. The data provided here is intended to help in the decision-making process about which of these two surgical approaches should be used based on tumor and patient characteristics.

Lung Cancer Study Group (LCSG) trial

This randomized controlled trial (RCT) enrolled patients from February 1982 through November 1988 and compared open lobectomy to sublobar resection for patients with lung cancer ≤3 cm with absence of lymph node involvement (1). There were 247 patients eligible for analysis: 122 received a limited resection and 125 underwent lobectomy. Of the 122 patients who underwent a limited resection, 40 (32.8%) had a wedge resection and 82 (67.2%) had a segmentectomy. There were no significant differences for all stratification variables, selected prognostic factors, perioperative morbidity, mortality, or late pulmonary function. The rate of local recurrence in the limited resection group was 6.3%, which was significantly higher than the 2.1% observed in the lobectomy group (P=0.008), and the 5-year survival rate in the limited resection group was 83.1%, which was slightly poorer than the 89.1% observed in the lobectomy group. In addition, postoperative pulmonary function was not significantly different in the two groups, even at one year after surgery. The authors concluded that, compared with lobectomy, limited pulmonary resection does not confer improved perioperative morbidity, mortality, or late postoperative pulmonary function. Furthermore, due to higher death rates and locoregional recurrence rates associated with limited resection, lobectomy must be considered the surgical procedure of choice for patients with peripheral T1N0 NSCLC.

It must be acknowledged that a considerable number of wedge resections (32.8%) were included in the limited resection group; tumor sizes ranging from 2 to 3 cm were included in the analysis; and routine computed tomographic examination of the lung was not required either preoperatively or for postoperative surveillance. Several publications have demonstrated a lower rate of loco-regional recurrence after segmentectomy compared to wedge resection for stage IA NSCLC (8-10). An adequate body of literature has also demonstrated that T1b tumors (2-3 cm) have lower survival rates than T1a tumors (≤2 cm) (11,12). Moreover, advances in imaging and optimal pre-resection surgical mediastinal staging have improved staging accuracy since the LCSG trial was published (13). This trial was done in an earlier era when tumors were often more central, many were squamous cell cancers, and they were larger stage I tumors (14).

Extended segmentectomy for stage I lung cancer

Since the results of the LCSG were published, several Japanese investigators have studied the role of sublobar resection for stage I NSCLC. The Study Group of Extended Segmentectomy for Small Lung Tumors was created and their final report was published in 2002 (15). This prospective multicenter study enrolled 55 patients with peripheral clinical T1N0M0 (cT1N0M0) NSCLC (≤2 cm) from January 1992 to December 1994. All patients were in physical conditions to tolerate a lobectomy. Extended segmentectomy involves the development of the intersegmental plane, by keeping inflated the segment to be resected after ligation of the segmental bronchus, while the adjacent segments are collapsed. The resection is then performed on the side of the collapsed segments in order to optimize lateral margins, and a complete lymph node dissection including segmental, hilar and mediastinal lymph nodes is undertaken, as is performed during lobectomy (16). The patients were followed up at 1- or 3-month intervals for five years or more. The 5-year disease-free survival (DFS) rate was 91.8%. Postoperative loss of lung function was 11.3% in forced vital capacity (FVC) and 13.4% in forced expiratory volume in one second (FEV1). The authors concluded that extended segmentectomy is viable as a standard operation for patients with small peripheral lung tumors, and causes minimal loss of lung function.

More recently, Nomori *et al.* (17) also examined the outcomes of 179 patients who underwent intentional open radical segmentectomy with systematic lymph node dissection for peripheral cT1N0M0 NSCLC between 2005 and 2009 at a single institution. All analyzed patients had intraoperative frozen section to demonstrate surgical margins of at least 2 cm. Of these 179 patients, 134 (75%) had tumors ≤2 cm, and 45 (25%) had tumors 2.1 to 3 cm. The 5-year DFS was 95% for patients with tumors ≤2 cm and 79% for those who had tumors 2.1 to 3 cm. Postoperative pulmonary function (measured at least six months after surgery) was preserved at 90%±12% of preoperative levels.

The importance of lymph node dissection during segmentectomy has been demonstrated. The frequency of lymph node metastasis in patient with cT1N0M0 NSCLC is approximately 10% (18). A theoretical disadvantage of segmentectomy versus lobectomy is the potential presence of metastatic disease in level 13 lymph nodes in the preserved adjacent segments. Nomori *et al.* (19) investigated the distribution of subsegmental lymph nodes in resected and preserved segments during segmentectomy. Out of 94 patients with cT1N0M0 NSCLC treated with segmentectomy, segmental nodes at both the resected and nonresected segments could be dissected in 42 of the 94 patients. The authors concluded that segmental lymph nodes should be dissected at both the resected and nonresected segments during segmentectomy, especially for tumors in the anteriorly located segment.

Another factor that appears to play an important role in recurrence after segmentectomy is the surgical margin. Schuchert and colleagues (20) performed a retrospective review of 182 consecutive patients undergoing anatomic segmentectomy for stage I NSCLC from 2002 to 2006. The average surgical margin for segmentectomy was 18.2 mm. There were 32 recurrences after segmentectomy (17.6%) at a mean of 14.3 months (14 locoregional, 18 distant), and 89% of recurrences were seen when tumor margins were 2 cm or less. Margin/tumor diameter ratios exceeding 1 were associated with a significant reduction in recurrence rates, compared with ratios of less than 1 (25% versus 6.2%, P=0.0014).

Segmentectomy versus lobectomy for cT1N0M0 NSCLC ≤2 cm

In order to elucidate factors associated with survival, Okumura *et al*. (12) analyzed 144 patients who underwent segmentectomy and 1,241 who underwent lobectomy. The authors concluded that a favorable outcome would be obtained by a segmentectomy in patients with a maximum diameter of the tumor smaller than 2 cm, no nodal involvement, and non-large cell carcinoma. Five- and 10-year overall survival (OS) in patients who met those criteria were both 83%, which was significantly higher than that for those who did not (41%) (P<0.0001). In comparison, 5- and 10-year OS in patients who underwent lobectomy meeting the same criteria (non-large cell carcinoma at stage IA ≤2 cm) was 81% and 64% respectively (P=0.66). There were no 5-year survivors among the six patients with large cell carcinoma who underwent a segmentectomy. In contrast, there was no difference in survival among different histologic types when a lobectomy was performed. The authors concluded that lobectomy, but not a segmentectomy, is recommended for large cell carcinomas, even when the tumor diameter is 2 cm or smaller.

In another retrospective study, Yamato and colleagues (21) reviewed 523 cases of cT1N0M0 peripheral adenocarcinomas ≤2 cm between 1991 and 2004. The surgical procedure was a lobectomy in 277 patients, segmentectomy in 153 patients and wedge resection in 93 patients. The limited resection was intentional in 140 cases, and it was performed for compromised patients in 106 cases. The 5-year survival rate of the patients who underwent a wedge resection was 70.6%, which was significantly worse than the 87.5% after a segmentectomy and the 85.5% after a lobectomy.

A multicenter nonrandomized study comparing lobectomy to sublobar resection was conducted by Okada *et al*. (22) from 1992 to 2001 for patients with a first peripheral cT1N0M0 NSCLC ≤2 cm who were able to tolerate a lobectomy. During the operation, the tumor status was confirmed to be T1N0 on the basis of frozen-section analysis of sampled segmental, lobar, hilar, and mediastinal lymph nodes. For segmentectomy, a margin of at least 2 cm of healthy lung tissue was required. It was specified that when the surgical margin was less than 2 cm or a lymph node was positive, lobectomy had to be performed instead. Of the 567 patients enrolled, 214 patients underwent curative segmentectomy, 30 underwent wedge resection and 236 had lobectomy. DFS and OS were similar in all groups. Five-year DFS was 92.2% after segmentectomy and 91.5% after lobectomy (P=0.64). Five-year OS was 93.9% after segmentectomy and 95.3% after lobectomy (P=0.43).

More recently, Carr and coworkers (11) performed a retrospective review of 429 patients undergoing resection of pathologically confirmed stage IA NSCLC via lobectomy (251 patients) or anatomic segmentectomy (178 patients) from 2002 to 2009. Video-assisted thoracoscopic surgery (VATS) was the approach utilized in 59% of segmentectomies and 39.4% of lobectomies during the study period. The margin:tumor ratio was similar whether performing an anatomic segmentectomy or lobectomy for T1a or T1b tumors. There was no difference in mortality, recurrence rates (14% segmentectomy *vs*. 14.7% lobectomy, P=1.00), or 5-year cancer-specific survival (CSS) for T1a tumors (90% *vs*. 91%, P=0.984) when comparing segmentectomy and lobectomy. The authors concluded that anatomic segmentectomy may achieve equivalent recurrence and survival compared with lobectomy for patients with stage IA NSCLC.

A criticism of the literature comparing the efficacy of segmentectomy and lobectomy since 1995 is that the majority of publications have been limited to single-institution retrospective reviews. However, more recently some investigators have used the Surveillance Epidemiology and End Results (SEER) database to compare survival after lobectomy and limited resection in patients with stage IA NSCLC. Whitson *et al*. (23) analyzed the SEER database for stage I adenocarcinoma or squamous cell carcinoma in patients 40 years and older from 1998 through 2007. The analysis included 13,892 patients who underwent lobectomy and 581 who underwent segmentectomy. Even after stratifying by tumor size, the authors found that lobectomy was associated with more favorable 5-year OS (P=0.0002) and CSS (P=0.0047) rates for tumors ≤2 cm.

Yendamuri and coworkers (13) also used the SEER database to identify surgically treated patients with stage I NSCLC ≤2 cm in size from 1988 to 2008. The cohort included 2,161 patients undergoing sublobar resection and 6,636 patients undergoing lobectomy or greater resection. They grouped these patients into three temporal cohorts:

the first included patients from 1988 to 1997 (early), the second was from 1998 to 2004 (intermediate) and the third was from 2005 to 2008 (late). In the early group, sublobar resection was associated with worse outcome. In the intermediate group, wedge resection but not segmentectomy was associated with a worse outcome compared with lobectomy. The association between extent of resection and OS completely disappeared in the late subgroup, in which neither wedge resection nor segmentectomy had an outcome worse than did lobectomy. The authors concluded that the survival advantage offered by lobectomy over sublobar resection in NSCLC patients with tumor size ≤2 cm has incrementally decreased over the past two decades.

A recent meta-analysis (24) included 24 studies (11,360 patients) published from 1990 to 2010 to compare OS and CSS of stage I NSCLC after sublobectomy or lobectomy. In stage IA patients with tumor ≤2 cm, there were no differences in OS between lobectomy and sublobectomy (HR 0.81; 95% CI, 0.39-1.71; P=0.58). For the comparison between lobectomy and segmentectomy, there was no significant difference on OS (HR 1.09; 95% CI, 0.85-1.40; P=0.45) and CSS (HR 0.99; 95% CI, 0.72-1.38; P=0.97) in stage I NSCLC.

Several studies have specifically limited their objective to compare outcomes between lobectomy and segmentectomy for NSCLC ≤2 cm, excluding larger tumors or wedge resections. Mattioli *et al.* (25) performed a retrospective investigation to compare anatomical segmentectomy and lobectomy for peripheral cT1N0M0 NSCLC ≤2 cm on preoperative CT scan, with regard to the number/station of lymph nodes resected, as well as survival. In this case-matched study, 46 intentional segmentectomy patients were matched with 46 lobectomy patients for age, anatomical segment, and size of the tumor. All patients were able to tolerate a lobectomy as evaluated by cardiopulmonary functional tests. Starting in January 2001, the authors offered anatomical segmentectomy as an alternative to lobectomy to patients affected by a peripheral cT1aN0M0 NSCLC. The cases in which lobectomy was performed within the same time period were retrospectively retrieved from the institutional electronic medical record system database. The approach for the resection was an axillary muscle-sparing thoracotomy. Radical dissection of lymph node stations 4, 5, 6 and 7 was identical in segmentectomies and lobectomies. Node stations 10, 11, 12 and the segmental 13 were also dissected carefully during segmentectomy and in the pathology laboratory after lobectomy. The median number of total dissected lymph nodes was 12 in anatomical segmentectomy compared with 13 in lobectomy (P=0.68), with the number of N1 nodes being 6 and 7, respectively (P=0.43), and N2 nodes 5.5 and 5 (P=0.88). No perioperative mortality was observed. Complications occurred in 13% of segmentectomies and in 15% of lobectomies (P=0.76). The median follow-up was 25 months for the segmentectomy group and 32 months for the lobectomy group. Freedom from recurrence at 36 months was 100% for anatomical segmentectomy and 93.5% for lobectomy (P=0.33)

Thoracoscopic segmentectomy *vs.* lobectomy

The vast majority of the evidence described above involves open procedures. However, a few recent studies have compared the outcomes of thoracoscopic segmentectomy and thoracoscopic lobectomy for small-sized stage IA lung cancer. Shapiro *et al.* (6) analyzed patients between January 2002 and February 2008. Indications for segmentectomy were tumor smaller than 3 cm, limited pulmonary reserve, comorbidities, and peripheral tumor location. Thirty-one patients underwent a segmentectomy and 113 had a lobectomy. Patients undergoing a segmentectomy had worse mean FEV1 than those having a lobectomy (83% *vs.* 92%, P=0.04). There were no differences in mean number of nodes (10) and nodal stations (5) resected. The mean follow-up was 21 months. There were 5 (17.2%) recurrences after segmentectomy and 23 (20.4%) after lobectomy (P=0.71), with locoregional recurrences rates of 3.5% and 3.6%, respectively. OS and DFS were similar between the groups. Zhong and colleagues (26) also compared outcomes between thoracoscopic segmentectomy and thoracoscopic lobectomy. Their inclusion criterion was limited to stage IA NSCLC ≤2 cm. The study period was between March 2006 and August 2011. A total of 39 segmentectomies and 81 lobectomies were analyzed. The two groups had a similar incidence of postoperative complications. The median follow-up was 26.5 months. Local recurrence rates were similar after segmentectomy (5.1%) and lobectomy (4.9%). No significant difference was observed in 5-year OS (79.9% *vs.* 81%) or DFS (59.4% *vs.* 64.2%).

Segmentectomy for clinical T1N0M0 ≤2 cm and ≥50% ground glass opacity component (GGO-dominant)

Tumor characteristics may also play an important role in deciding the extent of surgical resection. Tsutani *et al.* (27)

evaluated 239 patients with GGO-dominant clinical stage IA lung adenocarcinoma from four institutions between August 2005 and June 2010. All patients underwent HRCT and FDG-PET/CT followed by curative R0 resection. The inclusion criteria were absence of >1 cm enlargement in mediastinal or hilar lymph nodes and an absence of >1.5 accumulation for maximum standardized uptake values (SUVmax) in these lymph nodes. Sublobar resection was allowed for a peripheral cT1N0M0 intraoperatively assessed as N0, using frozen section evaluation of enlarged lymph nodes or by ensuring that there was no obvious enlargement of lymph nodes in the thoracic cavity. Systematic lymph node dissection was performed during segmentectomy, but not during wedge resection. Follow-up included a chest CT every six months for the first two years postoperatively, and every year thereafter. Median follow-up period after surgery was 42.2 months. Lobectomy was performed in 90 patients, segmentectomy in 56, and wedge resection in 93. A total of 155 tumors were classified as T1a and 84 as T1b. There was no significant difference in 3-year DFS among patients with GGO-dominant tumors who underwent lobectomy (96.4%), segmentectomy (96.1%), and wedge resection (98.7%; P=0.44). A multivariate Cox proportional hazards model for DFS included variables of age, gender, clinical T descriptor, solid tumor size, SUVmax, and surgical procedure. However, none of these variables were independent prognostic factors.

Pulmonary function tests

With regards to the functional advantage of a limited resection, Harada *et al*. (28) analyzed PFT preoperatively and at two and six months after radical segmentectomy in 38 patients and lobectomy in 45 patients. Both groups were able to tolerate a lobectomy and had cT1N0M0 NSCLC ≤2 cm. The anatomic segmentectomy was made through video-assisted approach with minithoracotomy. They performed segmentectomy if the patient consented to the sublobar resection, and lobectomy if the patient did not. During the postoperative course, statistically significant differences were observed between the two groups in the ratio of postoperative to preoperative FVC (P=0.0006) and FEV1 (P=0.0007), whereas a marginal difference was seen in the ratio of postoperative to preoperative anaerobic threshold (P=0.616). Keenan and colleagues (29) retrospectively analyzed patients undergoing lobectomy (n=147) or segmentectomy (n=54) for stage I NSCLC between March 1996 and June 2001. From the pathologic analysis, there were 126 stage IA and 21 stage IB patients in the lobectomy group, and 47 stage IA and 7 stage IB patients in the segmentectomy group. PFT was obtained preoperatively and at one year. At one year, lobectomy patients experienced significant declines in FVC (85.5% to 81.1%), FEV1 (75.1% to 66.7%), and diffusing capacity (79.3% to 69.6%). In contrast, a decline in diffusing capacity was the only significant change seen after segmental resection. Actuarial survival in both groups was similar (P=0.406), with a 1-year survival of 95% for lobectomy and 92% for segmentectomy. Four-year survivals were 67% and 62%, respectively. Overall, the risk of any recurrence, whether local, regional, or systemic, was identical in the two groups (20.4% segmentectomy, 19% lobectomy). The authors concluded that for patients with stage I NSCLC, segmental resection offers preservation of pulmonary function compared with lobectomy and does not compromise survival.

Ongoing prospective RCTs

The controversy about the optimal extent of surgical resection for peripheral NSCLC ≤2 cm has led to several multicenter prospective RCTs. The JCOG0802/WJOG4607L trial (30) began in August 2009 in Japan to evaluate the non-inferiority in OS of segmentectomy compared with lobectomy in patients with peripheral NSCLC ≤2 cm. A total of 1,100 will be accrued from 71 institutions within three years. The inclusion criteria include age 20-79 years old, sufficient organ function, single tumor, ≤2 cm in maximum diameter, proportion of maximum diameter to consolidation >25%, center of tumor located in the outer third of the lung field, tumor not located at middle lobe, and no lymph node metastasis. The secondary endpoints include postoperative respiratory function, relapse-free survival, and proportion of local recurrence. The distance from the dissection margin to the tumor edge must be evaluated intra-operatively. If the distance is less than 2 cm, the absence of cancer cells in the resection margin must be histologically or cytologically confirmed before finishing surgery. When lymph node metastasis is present or resection margin is not cancer-free, the surgical procedure must be converted to a lobectomy. All randomized patients will be followed for at least five years. Tumor markers, CXR and chest CT is evaluated at least every six months during the first two years and at least every 12 months for the duration of follow-up.

Similarly, the CALGB 140503 study (31) aims to determine whether DFS after sublobar resection (segmentectomy or wedge) is non-inferior to that after lobectomy in patients with NSCLC ≤2 cm. A total of 692 patients will be accrued to the study and randomized intra-operatively to either lobectomy or limited resection. Prior to registration, patients must have a lung nodule measuring ≤2 cm on CT scan, presumed to be lung cancer and located in the outer third of the lung. Intraoperative histological confirmation of NSCLC must be obtained (if not done preoperatively), as well as confirmation of N0 status by frozen examination of levels 4, 7, and 10 on the right side and 5 or 6, 7 and 10 on the left side, either at the time of surgery or pre-operatively by mediastinoscopy within six weeks of the definitive procedure. Patients must also have a performance status of 0-2. Exclusion criteria include prior malignancy within five years, prior chemotherapy or radiation, and age <18 years.

Conclusions

The increasing use of CT scans and improvement in CT resolution has been associated with earlier detection of NSCLC with smaller tumor size. Also, the location and type of lung cancer has evolved over time such that smaller, peripheral adenocarcinomas are now among the most common presentation. An extensive body of literature mainly composed of retrospective studies supports the use of radical anatomical segmentectomy for peripheral cT1N0M0 NSCLC ≤2 cm, certainly for older patients with limited cardiopulmonary function. However, caution should be taken to promote a widespread indication for intentional segmentectomy in young good surgical candidates until the results of the ongoing RCTs become available. When expertise exists, the surgeon should use a minimally invasive approach to realize perioperative and functional patient benefits.

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Footnote

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Open, thoracoscopic and robotic segmentectomy for lung cancer

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Abstract: While lobectomy is the standard procedure for early stage lung cancer, the role of sublobar resection is currently under investigation for selected patients with small tumors. In this review, studies reporting outcomes on open, thoracoscopic and robotic segmentectomy were analyzed. In patients with stage I lung cancer, with tumors <2 cm in diameter and within segmental anatomic boundaries, segmentectomy appears to have equivalent rates of morbidity, recurrence and survival when compared to lobectomy. Segmentectomy also resulted in greater preservation of lung function and exercise capacity than lobectomy. It appears reasonable to consider segmentectomy for patients with stage I lung cancer (particularly in air-containing tumors with ground glass opacities) where tumors are <2 cm in diameter and acceptable segmental margins are obtainable, especially in patients with advanced age, poor performance status, or poor cardiopulmonary reserve. The results of two ongoing randomized controlled trials (CALGB 140503 and JCOG0802/WJOG4607L) and additional well-designed studies on open, thoracoscopic, and robotic segmentectomy will be important for clarifying the role of segmentectomy for lung cancer.

Keywords: Lung cancer surgery; minimally invasive surgery; thoracoscopy/video-assisted thoracoscopic surgery (VATS); segmentectomy

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Introduction

The first segmentectomy, a lingulectomy, was performed by Churchill and Belsey in 1939 for the treatment of bronchiectasis (1). Over the subsequent decades, segmentectomy was increasingly applied to small primary lung cancers (2,3). However in 1995, the Lung Cancer Study Group (LCSG) performed a randomized controlled trial of lobectomy versus limited resection for T1 N0 non-small cell lung cancer (NSCLC) and found that limited pulmonary resection for tumors <3 cm in size resulted in increased locoregional recurrence compared to lobectomy (4). Subsequently in North America, the use of segmentectomy for NSCLC was generally limited to patients with marginal cardiopulmonary function (5).

The LCSG trial is the only randomized controlled trial of lobectomy versus limited resection for lung cancer to date, and is indeed a landmark study. However, it enrolled patients from 1982-1988 (4) and the landscape of thoracic oncology has changed considerably. Since then, there have been new developments leading to renewed interest in segmentectomy for small primary lung cancer tumors (5). Firstly, there is now strong evidence that low-dose computed tomography (LDCT) screening in high-risk patients reduces lung cancer deaths. Importantly, the screening protocols have identified greater numbers of smaller lung tumors (<2 cm), which are more frequently operable and curable (6,7). Of note, the LCSG trial did not specifically assess the effect of lobectomy versus segmentectomy on smaller tumors, as 30% of patients in that study had tumors that were larger than 2 cm (4). Secondly, since 1995, newer staging modalities have emerged which will likely improve patient selection for anatomic lung resection (4). Thirdly, surgeons have advanced the fields of video-assisted thoracoscopic surgery (VATS) and robotic surgery, with increasing experience at applying those approaches to segmentectomy. These new developments have led to a growing number of studies investigating the use of open, minimally invasive and robotic segmentectomy for carefully selected patients with smaller tumors less than 2 cm in size, especially in patients with marginal cardiopulmonary function (5).

A previous review of these studies demonstrated that when compared to thoracoscopic lobectomy, thoracoscopic segmentectomy had equivalent rates of morbidity, recurrence and survival in selected patients (5). When compared to open segmentectomy, thoracoscopic segmentectomy was found to have equivalent oncologic results, with shorter length of stay, reduced rates of morbidity, and lower cost. There have since been additional studies on segmentectomy, including further reports on uniportal and robotic approaches. This review is an update on the current role of segmentectomy and will focus on the most relevant recent studies on open, minimally invasive and robotic segmentectomy for lung cancer.

Open segmentectomy *vs.* open lobectomy

Since the LCSG study, although there have been no new randomized trials, there have emerged several retrospective studies comparing open segmentectomy to open lobectomy (8). In contrast to the LCSG trial, which enrolled patients from 1982-1988 and included 30% of patients with tumors >2 cm, these studies reflected a more current medical and surgical practice, and focused on examining the role of segmentectomy for tumors >2 cm in diameter. These studies reported similar outcomes and have found no significant differences in morbidity, mortality, locoregional recurrence or survival between segmentectomy and the lobectomy (8).

Most of these studies had groups well-matched for pulmonary function, but an important limitation of these studies is that many did not include information on preoperative co-morbidities. Three recent retrospective studies on segmentectomy *vs.* lobectomy did however include preoperative comorbidities and pulmonary function tests in their analysis. In 2011, Schuchert and colleagues compared the results of 107 patients undergoing resection for stage IA NSCLC (≤1 cm) via lobectomy (n=32), segmentectomy (n=40) or wedge resection (n=35) (9). Preoperative forced expiratory volume in 1 second (FEV1) was significantly lower in the sublobar resection (segmentectomy, wedge) groups compared with the lobectomy group; but age, sex distribution, tumor size, histology and preoperative comorbidities were similar between groups. Mean follow-up was 42.5 months and there was no statistically significant difference in overall disease recurrence or estimated 5-year disease-free survival (lobectomy, 87%; segmentectomy, 89%; wedge, 89%; P>0.402). While the authors note that a VATS approach was used more often than an open approach (57% *vs.* 43%) they did not specifically study the effects of open *vs.* VATS approach on outcomes.

Carr and colleagues conducted a retrospective study comparing the outcomes of 429 patients undergoing resection of stage I NSCLC via lobectomy or anatomic segmentectomy (10). The segmentectomy group (n=178) was older and had more co-morbidities—more likely to have coronary artery disease (18.5% *vs.* 12.8%, P=0.036) or chronic obstructive pulmonary disease (26.4% *vs.* 14.4%, P=0.0001)—than the lobectomy group (n=251). The segmentectomy group also had worse pulmonary function than the lobectomy group (FEV1 81.1±17.6 *vs.* 71.8±25.6, P=0.02). The authors found no difference in 30-day mortality (1.1% *vs.* 1.2%), recurrence rates (14.0% *vs.* 14.7%, P=1.00), or 5-year cancer-specific survival (T1a: 90% *vs.* 91%, P=0.984; T1b: 82% *vs.* 78%, P=0.892) when comparing segmentectomy and lobectomy for pathologic stage IA non-small cell lung cancer, when stratified by T stage. Of note, this study included patients who underwent both open and VATS approaches, and an open approach was used less often with segmentectomy than with lobectomy (41% *vs.* 60.6%, P=0.0001). The authors did not specifically evaluate outcomes by type of approach.

With regard to the role of open segmentectomy in the elderly, Kilic and colleagues conducted a retrospective review of 78 patients >75 years of age who underwent segmentectomy *vs.* lobectomy for stage 1 NSCLC. The segmentectomy group included more patients with chronic obstructive pulmonary disease (COPD) and diabetes. The tumors were significantly larger in the lobectomy group (3.5 *vs.* 2.5 cm, P<0.0001). The authors found no significant difference in 5-year disease-free survival between segmentectomy and lobectomy (11). Outcomes associated with an open *vs.* VATS approach were not specifically evaluated.

In addition to the single-institution retrospective studies described above, there has been one population-based study of open segmentectomy and lobectomy for stage I NSCLC. In 2011, Whitson and colleagues analyzed 14,473 patients undergoing anatomic segmentectomy or lobectomy for stage I NSCLC derived from the Surveillance Epidemiology and End Results (SEER) database. The authors were unable to stratify by open or VATS approach, but presumably most of the operations were performed open. Lobectomy was demonstrated to be associated with improved overall (P<0.0001) and cancer-specific (P=0.0053) 5-year survival compared with segmentectomy. After adjusting for tumor size, this improvement in survival remained. However, it is difficult to draw specific conclusions from this study because, in addition to its retrospective nature, the study did not have data on patient preoperative co-morbidities and pulmonary function—important variables which may have significantly affected both procedure selection and postoperative outcomes.

Advantages of open segmentectomy *vs.* open lobectomy

Since the 1995 LCSG randomized trial, there have been numerous retrospective studies that have shown that there are no differences in recurrence and survival between open segmentectomy and open lobectomy, even in patients with greater co-morbidities and worse pulmonary function (10), patients older than 75 years of age (11), and patients with larger tumors between 2 and 3 cm in size (10). Furthermore, in one study, open segmentectomy was found to preserve postoperative pulmonary function at 90%±12% of preoperative levels (12). There is one recent population-based analysis which found that patients undergoing anatomic segmentectomy had a decreased survival rate when compared to those undergoing lobectomy for stage I NSCLC. However, this study did not include information about patient comorbidities or cardiopulmonary function; patients in segmentectomy could have had reduced cardiopulmonary function, greater co-morbidities or other factors that affected survival.

Advantages of segmentectomy *vs.* wedge resection

With regard to the outcomes of patients undergoing an open segmentectomy versus wedge resection for stage I NSCLC, multiple reports show a decreased risk of recurrence and equivalent or improved survival in patients undergoing open segmentectomy compared to those undergoing wedge resections (8). When compared with the wedge resection, segmentectomy has also been shown to be associated with a larger parenchymal margin (13,14), a higher yield of lymph nodes and rate of nodal upstaging (14), and reduced risk of locoregional recurrence (15). Based on these studies, segmentectomy would be the preferred procedure for patients considering sublobar resection.

Predictors for prognosis and recurrence

With regard to predictors for prognosis and recurrence for patients with NSCLC who underwent segmentectomy, Koike and colleagues found age >70 years, gender (male), >75% consolidation/tumor ratio on high-resolution CT, and lymphatic permeation to be independent poor prognostic factors, and lymphatic permeation to be an independent predictor for recurrence (16). Yamashita and colleagues found KI-67 proliferation index to be a predictor of early cancer death (17). Traibi and colleagues have also shown male gender, FEV1 ≤60% and open (as opposed to VATS) surgery to be risk factors for postoperative complications (18).

In 2013, Koike and colleagues reported risk factors for locoregional recurrence and survival in patients undergoing sublobar resection (patients who underwent segmentectomy or wedge resection in the analysis) (15). They found four independent predictors of locoregional recurrence: wedge resection, microscopic positive surgical margin, visceral pleural invasion, and lymphatic permeation. Independent predictors of poor disease-specific survival were smoking status, wedge resection, microscopic positive surgical margin, visceral pleural invasion, and lymphatic permeation.

Thoracoscopic segmentectomy *vs.* open segmentectomy

Since the 1995 LCSG randomized trial, there have been significant advancements in thoracoscopic surgical techniques, including a better understanding of the potential advantages of the thoracoscopic lobectomy and segmentectomy for anatomic pulmonary resection (5). The studies included in the present review will use the definition of thoracoscopic segmentectomy as the completion of sublobar anatomic pulmonary resection, with individual vessel ligation and without the use of a utility thoracotomy, retractors or rib-spreading (5). Studies using a "hybrid" segmentectomy with mini-thoracotomy fall into the category of open surgery and are not included in this section.

The first retrospective study comparing outcomes of thoracoscopic and open segmentectomy was performed by Shiraishi and colleagues in 2004 (19). The authors selected patients with clinical stage IA peripheral tumors (<2 cm) and reviewed the outcomes of 34 patients who underwent VATS segmentectomy versus 25 who underwent open segmentectomy. They found no significant differences in postoperative complications and perioperative deaths. Long-term survival was not evaluated in this study.

In 2007, Atkins and colleagues conducted a retrospective study comparing the results of 48 patients who underwent VATS versus 29 who underwent an open approach (20). The authors found no significant differences in preoperative co-morbidities, pulmonary function, operative time, estimated blood loss, nodal stations sampled and chest tube duration between the two groups. In addition, no significant differences were seen in locoregional recurrences between the open (8.3%) and the VATS (7.7%) approaches (P=1.0). However, there was a significantly decreased length of hospital stay for the VATS group when compared to the thoracotomy group (4.3±3 *vs.* 6.8±6 days; P=0.03). At approximately 30 months postoperatively, it was found that the VATS group had improved long-term survival when compared with the thoracotomy group (P=0.0007), although the groups were not matched oncologically.

Schuchert and colleagues performed a retrospective review of patients who underwent VATS segmentectomy (n=104) versus those who underwent thoracotomy (n=121) (21). There were no significant differences between the two groups in age, gender, histology, and pulmonary function as measured by FEV1 and DLCO. The VATS group had slightly smaller tumor sizes than the thoracotomy group (2.1±1.1 *vs.* 2.4±1.2 cm, P=0.05) and there were fewer lymph nodes harvested during VATS segmentectomy when compared with open segmentectomy (6.4. *vs.* 9.1, P=0.003). The VATS group also had a decreased length of hospital stay compared to the thoracotomy group (5 *vs.* 7 days, P<0.001). There were significantly fewer perioperative pulmonary complications in the VATS group as well (15.4% *vs.* 29.8%; P=0.012) but both groups, VATS and open, had similar rates of postoperative complications. Most importantly, regarding margins, it was demonstrated that a margin: tumor size ratio >1 was associated with a decrease in recurrence (14.7%) when compared to a ratio <1 (28.9%, P=0.037). In addition, the authors performed a propensity analysis that showed no significant difference in recurrence-free or overall survival. Interestingly, there were also no significant differences in locoregional or overall survival between groups with tumors >2 cm and tumors <2 cm.

In another analysis, Leshnower and colleagues conducted a retrospective review of 17 patients who underwent VATS segmentectomy versus 26 who underwent a thoracotomy approach for patients with primary lung cancer and metastatic disease (22). The two groups were similar with regards to age, tumor size, gender, body-mass index, co-morbidities and pulmonary function. An average of 3 lymph node stations were sampled in both groups and there were no significant differences in numbers of lymph nodes sampled (VATS 4.0±3 *vs.* open 6.1±5, P=0.40). There was also no significant difference between the groups in operative time. There were 2 (4.8%) deaths within 30 days after surgery in the thoracotomy group but none in the VATS group. Furthermore, the VATS group had decreased chest tube duration (VATS 2.8±1.3 *vs.* open 5.2±3 days, P=0.001) and reduced hospital length of stay (VATS 3.5±1.4 *vs.* open 8.3±6 days, P=0.01). In addition, the authors found that average hospital costs were approximately $1,700 less for the VATS group, although this finding was not statistically significant.

Advantages of thoracoscopic segmentectomy *vs.* open segmentectomy

In summary, the above studies comparing VATS segmentectomy with open segmentectomy show that VATS segmentectomy for stage I NSCLC is feasible and safe (19-22). VATS segmentectomy appears to be associated with an equivalent survival rate when compared to the open approach: all studies report 0% 30-day mortality for the VATS group, compared to 1.7-7.7% 30-day mortality for open segmentectomy, and there is no apparent difference in long-term survival. The VATS approach was also found to be associated with shorter length of stay, lower costs, reduced rates of overall complications, including fewer cardiopulmonary complications and reduced length of chest tube duration (5). At this time, it appears that there are no significant differences in operative times between the VATS *vs.* open approach: one study has shown a longer operative time (19), and the other three have shown similar operative times (20-22).

Thoracoscopic segmentectomy *vs.* lobectomy *vs.* wedge resection

Evaluation of thoracoscopic segmentectomy *vs.* thoracoscopic lobectomy or wedge resection for NSCLC is also under current investigation. Harada and colleagues conducted an analysis of pulmonary function for patients undergoing VATS segmentectomy (n=38) or VATS lobectomy (n=45) for stage I NSCLC (23). The authors found that 50% fewer segments were resected in the segmentectomy group and that the number of resected segments was associated with reduced forced vital capacity (FVC) and FEV1 at 2-

and 6-month postoperatively (P<0.0001). Consequently, at six months after surgery, the segmentectomy group had regained exercise capacity while the lobectomy group continued to have a 10% loss in exercise capacity.

In 2004, Iwasaki and colleagues performed a retrospective review of patients who underwent VATS lobectomy (n=100) or VATS segmentectomy (n=40) for stage I and II NSCLC (24). The authors found no significant differences in 5-year survival between the segmentectomy and lobectomy groups (77.8% *vs*. 76.7%, P=0.47). Shapiro and colleagues also conducted a retrospective study of VATS segmentectomy (n=31) *vs*. VATS lobectomy (n=113) but solely for stage I NSCLC (25). The segmentectomy group was found to have a longer smoking history and reduced pre-operative pulmonary function when compared to the lobectomy group (FEV1 83% *vs*. 92%, P=0.04). Despite differences in baseline patient fitness between the segmentectomy and lobectomy groups, there were no significant differences in complication rates, perioperative mortality, hospital length of stay, local recurrence (3.5% *vs*. 3.6%) and total recurrence rate (17% *vs*. 20%). In terms of lymph nodes dissected, segmentectomy was equivalent to lobectomy, with both groups having approximately five nodal stations sampled and ten lymph nodes resected. Mean follow-up for the segmentectomy and lobectomy groups were 21 and 22 months respectively, and both groups had similar overall and disease-free survival rates (P>0.5).

In 2010, Sugi and colleagues conducted a retrospective study of 159 patients who underwent VATS wedge resection (n=21), VATS segmentectomy (n=43) or VATS lobectomy (n=95) for stage I NSCLC (26). The lobectomy group had a higher percentage of patients with pathological stage greater than pT1N0 when compared to the segmentectomy group (18% *vs*. 8%, P=0.07). Follow-up was five years and the groups had similar 5-year recurrence-free and overall surviva, although there were differences in tumor size between the groups—the VATS wedge group had tumors <1.5 cm, the segmentectomy group had tumors <2 cm and the lobectomy group had tumors >2 and <3 cm. Yamashita and colleagues compared the results of VATS segmentectomy (n=38) or VATS lobectomy (n=71) with systemic lymphadenectomy (27). Both groups had similar recurrence-free and overall survival, although there were differences in tumor size between the segmentectomy and lobectomy groups (1.5 *vs*. 2.5 cm, P<0.0001).

Nakamura and colleagues performed a retrospective review of patients undergoing VATS lobectomy (n=289), VATS segmentectomy (n=38) or VATS wedge resection (n=84) for stage I NSCLC (28). The authors found differences in the mean tumor size between the lobectomy (2.57 cm), segmentectomy (1.98 cm) and wedge resection groups (1.85 cm). In this study, 5-year survival was lower for the wedge resection group (71.2%), compared to the lobectomy (90%) and segmentectomy (100%) groups. However, compared to the other groups, the wedge resection group comprised sicker patients with more co-morbidities.

Yamashita and colleagues evaluated the results of patients undergoing VATS segmentectomy (n=90) or VATS lobectomy (n=124) for stage IA NSCLC (29). There was a higher percentage of T1a tumors in the segmentectomy group when compared with the lobectomy group (84% *vs*. 58%, P<0.001). The segmentectomy group had a smaller median tumor size (15 *vs*. 20 mm). However, both groups were similar with regards to operative time, intraoperative blood loss, chest tube duration, and hospital stay. There were fewer numbers of dissected lymph nodes in the segmentectomy group when compared to the lobectomy group (12.1 *vs*. 21, P<0.0001) but both groups were also similar with regards to morbidity, 30-day mortality, recurrence, disease-free and overall survival.

Zhong and colleagues conducted a retrospective review of patients undergoing VATS segmentectomy (n=81) or VATS lobectomy (n=120) for stage IA NSCLC (30). There were no significant differences between the groups in pre-operative co-morbidities, pulmonary function, tumor size or histology. Both groups had similar operative times, similar rates of postoperative complications and no perioperative deaths. There were no differences between VATS segmentectomy and lobectomy with regards to lymph nodes resected (11.2±6.5 *vs*. 14.5±8.1, P=0.18). Length of hospital stay was also similar between both groups. There were no significant differences in local recurrence rates and 5-year overall or disease-free survivals. Multivariate Cox regression analyses also showed that tumor size was the only independent prognostic factor for disease-free survival. Another study compared the results of 73 VATS trisegmentectomies for stage IA (n=45) and IB (n=11) lung cancer with 266 VATS left upper lobe lobectomies for stage IA (n=105) and IB (n=73) lung cancer (31). There were no significant differences in overall complication rates or survival between patients undergoing VATS trisegmentectomy and those undergoing lobectomy for either stage IA lung cancer or stage IB lung cancer.

A retrospective review of patients undergoing VATS segmentectomy (n=26) or VATS lobectomy (n=28) for stage

IA NSCLC was also conducted by Zhang and colleagues (32). Again, there were no significant differences in operative time, estimated blood loss, number of lymph nodes resected and postoperative complications. Both groups had similar local recurrence rates and 3-year survival. Of note, the authors did find a significantly decreased length of hospital stay in the VATS segmentectomy group by approximately three days (P=0.03). Postoperative FEV1 was also decreased to a lesser degree in the VATS segmentectomy group. Tumor size, however, was not reported in this study.

Zhao and colleagues compared the results of patients undergoing VATS segmentectomy (n=36) or VATS lobectomy (n=138) for stage I NSCLC (33). There were no significant differences in blood loss, operative time, chest tube duration and length of hospital stay between the two groups. There was also no significant difference in local recurrence and in recurrence-free survival between the two groups, although the study was limited by a relatively short follow-up of less than one year and by not including tumor size data.

Advantage of thoracoscopic segmentectomy over thoracoscopic lobectomy and wedge resection?

These studies demonstrate that although thoracoscopic segmentectomy is a more complex procedure than the thoracoscopic lobectomy (5), the rates of morbidity, recurrence and survival are similar among patients with tumors >2 cm in diameter. Specifically, there were no significant differences in overall complication rates (25,26,29,30,32,33), local recurrence rates (25,26,29,30,32,33), 5-year recurrence-free survival (26,27,29,30) and 5-year survival rates (24,26,27,29,30). The studies also show no difference in operative time between the two groups (29,30,32,33). In addition, the segmentectomy groups had similar (25,29,30,33), or reduced lengths of hospital stay (32) when compared to the lobectomy groups. It appears that thoracoscopic segmentectomy is able to preserve more lung function (23,32) and exercise capacity (23) than thoracoscopic lobectomy, although long-term follow-up data is needed.

There are, however, important limitations to the abovementioned studies. Firstly, some studies did not report the tumor size data (31-33). Of the studies that did, most found that the lobectomy groups had significantly larger tumors than the segmentectomy groups (23-29). This difference in tumor size limits interpretation of results because tumor size is known to be a prognostic factor of survival for NSCLC (30,34). However, in one recent study where both thoracoscopic segmentectomy and lobectomy groups were well-matched in tumor size, histology, preoperative co-morbidities and pulmonary function (30), both groups had similar local recurrence rates, disease-free and overall survival. This is consistent with previous data from the open segmentectomy literature. For example, in 2006, Okada and colleagues conducted a multi-center study of 567 patients with tumor size <2 cm who underwent open segmentectomy or lobectomy (35). Mean tumor size for the segmentectomy and lobectomy groups were 1.57 cm and 1.62 cm (P=0.056), respectively. The segmentectomy was associated with equivalent 5-year survival when compared to the lobectomy (83.4% *vs.* 85.9%, respectively).

Another limitation of the above-referenced studies is that many of them, with the exception of four studies (27,29,30,33), did not report the percentage of patients with bronchoalveolar carcinoma or adenocarcinoma *in situ*. This is an important variable to account for (5), as demonstrated by a study performed by Nakayama and colleagues that examined the results of 63 patients with adenocarcinoma who underwent open sublobar resection of clinical stage IA NSCLC (36). The authors classified the patients' tumors as either "air-containing type" (n=46) or "solid-density type" (n=17) according to the tumor shadow disappearance rate on high-resolution CT. After resection, 38 of the 46 air-containing tumors were identified as bronchoalveolar carcinomas whereas all solid-density type tumors were non-bronchoalveolar carcinomas. Air-containing tumors were associated with better overall 5-year survival than solid-density tumors (95% *vs.* 69%, P<0.0001).

The VATS wedge resection procedure yields a smaller parenchymal margin, reduced number of resected lymph nodes and reduced sampling of nodal stations when compared to segmentectomy (14). There have also been two studies comparing the survival outcomes of this procedure with that of the VATS segmentectomy and lobectomy. However, in the wedge resection group, the tumors were smaller (26,28) or the patient population had greater co-morbidities, which limits interpretation of results (28); further studies with groups that are better matched will be needed prior to making any conclusions regarding the role of VATS wedge resection role in NSCLC.

Further study is also needed regarding selection criteria for the thoracoscopic segmentectomy. Based on the reviewed evidence, it appears reasonable to consider segmentectomy for patients with small, peripheral tumors (in particular air-containing tumors with ground glass opacities suggesting bronchoalveolar histology) that are less than 2 cm in diameter when an acceptable segmental margin is obtainable (margin ≥ tumor diameter), especially in patients with advanced age, poor performance status, or poor cardiopulmonary reserve. Future retrospective studies would benefit from controlling for tumor size, operative co-morbidities, type of cancer, tumor location (including distance from the margin to the edge of the tumor and resection margin) and propensity score matching. There are two ongoing randomized trials (discussed below) that will clarify the role of the thoracoscopic segmentectomy in lung cancer.

Feasibility of mediastinal lymph node dissection (MLND)

Mediastinal lymph node assessment is a critical component of segmentectomy for NSCLC. Mattioli and colleagues reported that open segmentectomy procures an adequate number of N1 and N2 nodes for pathologic examination (37). When comparing the thoracoscopic segmentectomy to the thoracoscopic lobectomy, two studies preliminarily demonstrate no significant differences in lymph nodes harvested or nodal stations sampled (25,30) while one reported fewer lymph nodes harvested with the segmentectomy (29). When comparing open *vs.* thoracoscopic segmentectomy, one study found no difference in lymph nodes harvested (22), while another reported fewer lymph nodes harvested with the VATS approach (21).

In addition, two studies compared the completeness of lymph node evaluation during anatomic resection of primary lung cancer by open and VATS approaches (38,39). Most of the analyses performed in these studies grouped segmentectomies together with lobectomies, thereby limiting the ability to draw any conclusions specifically regarding segmentectomy. However, in one of the studies which reported analyses of nodal upstaging from the Society of Thoracic Surgery national database, the authors did report one subset analysis that showed off the 170 VATS segmentectomies analyzed, upstaging from cN0 to pN1 was seen in 4% of patients compared with 5.3% among 280 open segmentectomies (38). The authors noted that the differences in upstaging between VATS and open approaches may have been the result of approach bias, and that equivalent nodal staging may be possible with increasing experience with VATS (38).

Preliminarily, based on the available evidence, it appears that it is possible to achieve adequate lymph node dissection with segmentectomy, but that surgeon experience does play an important role, particularly in the case of the thoracoscopic segmentectomy. More detailed investigation on lymph node evaluation in VATS versus open segmentectomy and VATS segmentectomy *vs.* VATS lobectomy is therefore needed.

Other types of thoracoscopic segmentectomy

Totally thoracoscopic segmentectomy

There have been a few small case series reported on the “totally thoracoscopic” or “complete VATS” technique for segmentectomy (39-46). In this technique, there is no access incision, and the specimen is retrieved through one of the port sites that is enlarged at the end of the procedure; only video-display and endoscopic instrumentation are used (47). There is no evidence that there are advantages associated with this approach, although it does allow the surgeon to use carbon dioxide insufflation. The largest series reported is from Gossot and colleagues, who performed totally thoracoscopic anatomic segmentectomy on 117 patients (48). The authors reported five conversions to thoracotomy with mean operative time of 181±52 minutes, mean intraoperative blood loss of 77±81 mL, and postoperative complication rate of 11.7%. The mediastinal lymph node harvested and nodal stations sampled were 21±7 and 3.5±1. The average length of hospital stay was 5.5±2.2 days. Preliminarily, it appears that totally thoracoscopic segmentectomy is feasible and safe, although further studies with longer follow-up that compare this technique with traditional open and VATS approaches are needed.

Uniportal segmentectomy

VATS segmentectomies are typically performed via two to three incisions, but Gonzalez-rivas and colleagues presented the first case report demonstrating that the procedure is feasible with one incision and through one port (49). Subsequently, they reported their initial results for 17 uniportal VATS anatomic segmentectomies. Mean operative time was 94.5±35 minutes, 4.1±1 nodal stations were sampled and 9.6±1.8 lymph nodes were resected. There were no conversions. Median tumor size was 2.3±1 cm, chest tube duration was 1.5 days (range, 1-4 days) and the median length of stay was 2 days (range, 1-6 days) (50). Wang and colleagues also demonstrated their experience, performing thoracoscopic lobectomy (n=14) and segmentectomy (n=5) with radical MLND through a single small (3- to 5-cm) incision (51). Mean operative time was 156±46 minutes, median number of lymph nodes harvested was 22.9±9.8, and blood loss was 38.4±25.9 mL. There were no conversions and 30-day mortality was 0%. The authors did not assess for differences by type of operation and there was no long-term follow-up. Preliminarily, it appears that single-incision segmentectomy is feasible and safe, although further studies comparing single-port to traditional open and VATS approaches are needed.

Robotic segmentectomy

A recent review of a national database demonstrated that robotic pulmonary resections have increased from 0.2% in 2008 to 3.4% in 2010 (52). The vast majority of robotic procedures are lobectomies, but there has been a small increase in robotic segmentectomies performed as well.

A retrospective study of 35 patients who underwent robotic thoracoscopic segmentectomy was performed, including 12 patients who had stage IA NSCLC (53). In this series, median age was 66.5 years, tumor size was 1.4 cm, operative time was 146 minutes and number of lymph node stations sampled was 5 (54). Four patients had perioperative complications, and 60-day mortality was 0%, while length of hospital stay was two days. Pardolesi and colleagues reported the initial results of 17 patients who underwent robotic segmentectomy at three institutions (55). The authors used a 3- or 4-incision strategy with a 3-cm utility incision in the anterior fourth or fifth intercostal space. Mean age was 68.2 years and mean duration of surgery was 189 minutes. There were no major intraoperative complications and no conversions were needed. Postoperative morbidity rate was 17.6%, median postoperative stay was five days and postoperative mortality was 0%.

Based on these reports, robotic segmentectomy appears to be a safe and feasible operation although additional studies comparing the outcomes of the robotic segmentectomy with the open and VATS approaches, as well as with the lobectomy, will be needed.

Limitations

There were several key limitations to the studies discussed above. Firstly, because the studies were retrospective in nature, there was the potential for surgeons' bias to affect the type of operation a patient received, which could have affected outcomes. In addition, often, the studies did not compare groups that were well-matched—which could have affected results. For example, in studies where patients in the VATS segmentectomy group were sicker than those in the comparison group (9-11,21,25), the benefits of VATS segmentectomy could have been underestimated. In studies where the VATS group had slightly smaller tumors than those in the comparison group (21,24,26-29), there may have been an overestimation of the benefits of VATS segmentectomy.

To reduce the impact of treatment-selection bias and confounding in estimating the effects of segmentectomy *vs.* lobectomy, randomized controlled trials should continually be performed (described below). Future retrospective studies should also aim to match variables that have confounding effects, use stratification or multivariate regression analysis where appropriate, and incorporate propensity score matching when possible (56,57).

Future research

In the studies reviewed above, there was no data reported on the tolerance of patients for resection of secondary cancers. This would be an important area for future research because up to 11.5% of patients who undergo pulmonary resection for stage I NSCLC develop additional primary lung cancers (25,58). By causing less trauma than open segmentectomy, and preserving more lung function than lobectomy, VATS segmentectomy theoretically would offer patients higher tolerance for resection of secondary cancers when compared to the open segmentectomy or open or VATS lobectomy (5).

In addition, future studies should aim to include data on the number and type of nodal stations sampled or lymph nodes dissected. Only four of the studies in this review (22,25,29,30) reported specific information on lymph node sampling with segmentectomy. The effect of surgeon experience on outcomes in segmentectomy also deserves attention, as there is currently no published data on the topic.

There are two ongoing large-scale randomized controlled trials that will improve our understanding of the outcomes of limited resection for NSCLC: CALGB 140503 and JCOG0802/WJOG4607L (59,60). CALGB 140503, sponsored by the Alliance for Clinical Trials in Oncology, will evaluate the outcomes of patients who are randomly assigned to undergo limited resection (segmentectomy or wedge resection) or lobectomy, with the VATS or thoracotomy approach determined by the surgeon (60). JCOG0802/WJOG4607L, sponsored by the Japan Clinical Oncology Group and the West Japan Oncology Group, will evaluate outcomes of patients who are randomly assigned to undergo segmentectomy (wedge resections are excluded) or lobectomy (59). Both studies will clarify the role of segmentectomy for NSCLC but will have some limitations as well. CALGB 140503 may be limited in its final analysis because the limited resection group includes not only patients undergoing segmentectomy, but also patients undergoing wedge resection. And in both CALGB 140503 and JCOG0802/WJOG4607L, the operative approach—VATS *vs*. open—will not be a primary outcome variable.

Conclusions

Based on the reviewed evidence, it appears reasonable to consider segmentectomy for patients with stage I NSCLC tumors (particularly in air-containing tumors with ground glass opacities) that are <2 cm in diameter when an acceptable segmental margin is obtainable (at least 2 cm), especially in patients with advanced age, poor performance status, or poor cardiopulmonary reserve. The outcomes of CALGB 140503 and JCOG0802/WJOG4607L and additional well-designed studies on open, thoracoscopic, and robotic segmentectomy will be important for further clarifying the role of segmentectomy for NSCLC.

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Footnote

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

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General Introduction

Segmentectomy versus lobectomy for clinical stage IA lung adenocarcinoma

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Background: Despite the increasing prevalence of the early discovery of small-sized non-small cell lung cancers (NSCLCs), particularly adenocarcinoma, sublobar resection has not yet gained acceptance for patients who can tolerate lobectomy.

Methods: We compared the outcomes of segmentectomy (n=155) and lobectomy (n=479) in 634 consecutive patients with clinical stage IA lung adenocarcinoma and in propensity score-matched pairs. Those who had undergone wedge resection were excluded.

Results: The 30-day postoperative mortality rate in this population was zero. Patients with large or right-sided tumors, high maximum standardized uptake value (SUVmax), pathologically invasive tumors (with lymphatic, vascular, or pleural invasion), and lymph node metastasis underwent lobectomy significantly more often. Three-year recurrence-free survival (RFS) was significantly higher after segmentectomy compared to lobectomy (92.7% *vs*. 86.9%, P=0.0394), whereas three-year overall survival (OS) did not significantly differ (95.7% *vs*. 94.1%, P=0.162). Multivariate analyses of RFS and OS revealed age and SUVmax as significant independent prognostic factors, whereas gender, tumor size and procedure (segmentectomy *vs*. lobectomy) were not. In 100 propensity score-matched pairs with variables adjusted for age, gender, tumor size, SUVmax, tumor location, the three-year RFS (90.2% *vs*. 91.5%) and OS (94.8% *vs*. 93.3%) after segmentectomy and lobectomy respectively were comparable.

Conclusions: Segmentectomy with reference to SUVmax should be considered as an alternative for clinical stage IA adenocarcinoma, even for low-risk patients.

Keywords: Adenocarcinoma; segmentectomy; sublobar resection; lung cancer; lobectomy

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Introduction

Sublobar resection for intentionally treating patients with small non-small cell lung cancer (NSCLC) who are able to withstand lobectomy has remained highly controversial, although lobectomy is considered a standard procedure even for sub-centimeter lung cancers. The Lung Cancer Study Group (LCSG) revealed a three-fold increase in local recurrence rates and poorer survival in patients who had undergone sublobar resection rather than lobectomy in a singular randomized phase III study published in 1995 (1). The dogma that lobectomy is the standard of care for stage I NSCLC has been upheld until recently. However, several current investigations have found equivalent outcomes of sublobar resection and lobectomy when NSCLC are ≤2 cm (2-7).

Sublobar resection consists of segmentectomy and wedge resection, which are quite different from each other as curative surgery for lung cancer, since segmentectomy is more likely to provide sufficient margins and allows access to subsegmental and hilar lymph nodes. The present study retrospectively compared the outcomes of segmentectomy, not wedge resection and lobectomy among patients with clinical stage IA lung adenocarcinoma, and adjusted for clinical factors to minimize selection bias of patients. This analysis is an extended and updated version of our previous investigation (8).

Patients and methods

We analyzed data from 634 patients who had undergone lobectomy and segmentectomy for clinical T1N0M0 stage IA lung adenocarcinoma since October 2005. All patients were assessed using high-resolution computed tomography (HRCT) and F-18-fluorodeoxyglucose positron emission tomography/computed tomography (FDG-PET/CT). Patients with incompletely resected (R1 or R2) or multiple tumors were excluded from the prospectively maintained database that was analyzed herein. All patients were staged according to the TNM Classification of Malignant Tumors, 7th edition (9). Platinum-based chemotherapy was administered to patients with pathological lymph node metastasis after surgery. The institutional review boards of the participating institutions approved the study and the requirement for informed consent from individual patients was waived because the study was a retrospective review of a database. Chest images were acquired by multi-detector HRCT independently of subsequent FDG-PET/CT examinations. Tumor sizes and maximum standardized uptake values (SUVmax) were determined by radiologists at each institution. Because of the heterogeneity of PET techniques and performance, we corrected inter-institutional errors in SUVmax resulting from PET/CT scanners of variable quality based on outcomes of a study using an anthropomorphic body phantom (NEMA NU2-2001, Data Spectrum Corp, Hillsborough, NC, USA) that conformed to National Electrical Manufacturers Association standards (10). A calibration factor was analyzed by dividing the actual SUV by the gauged mean SUV in the phantom background to decrease inter-institutional SUV inconsistencies. Postoperative follow-up of all patients from the day of surgery included physical examinations and chest X-rays every three months, as well as chest and abdominal CT and brain MRI assessments every six months for the first two years. Thereafter, the patients were assessed by physical examinations and chest X-rays every six months, and annual CT and MRI imaging.

Statistical analysis

Data were analyzed using the Statistical Package for the Social Sciences software version 10.5 (SPSS Inc., Chicago, IL, USA). Continuous variables were compared using *t*-tests and Mann-Whitney *U* tests in all cohorts and Wilcoxon tests for propensity-matched pairs. Frequencies of categorical variables were compared using the χ^2 test and propensity-matched pairs were analyzed using McNemar tests. Propensity score matching was applied to balance the assignments of the included patients and to correct for the operative procedures (lobectomy or segmentectomy) that confounded survival calculations. The variables of age, sex, tumor size, SUVmax, side and lobe were multiplied by a coefficient that was calculated from logistic regression analysis, and the sum of these values was taken as the propensity score for each patient. Lobectomy and segmentectomy pairs with equivalent propensity scores were selected by a 1-to-1 match.

We defined recurrence-free survival (RFS) as the time from the day of surgery until the first event (relapse or death from any cause) or last follow-up, and overall survival (OS) as the time from the day of surgery until death from any cause or the last follow-up. The durations of RFS and OS were analyzed using the Kaplan-Meier method, and differences in RFS and OS were assessed using the log-rank test. Both RFS and OS were assessed by multivariate analysis using the Cox proportional hazards model.

Results

Of the 634 patients analyzed in this study, 479 and 155 underwent lobectomy and segmentectomy, respectively (*Table 1*). Patients with large tumors, right-sided tumors, pathologically invasive tumors, (presence of lymphatic, vascular, or pleural invasion), high SUVmax, and lymph node involvement were significantly more often treated by lobectomy. However, age and gender did not differ significantly between the two procedures. *Table 2* shows the segments that were removed during segmentectomy.

None of the patients died within 30 days of surgery, and tumors recurred in 54 patients at a median postoperative follow-up period of 34.2 months. Twenty recurrences were local only and 34 were distant (with or without local recurrence). Local recurrence occurred in 17 patients after

Table 1 Patient characteristics

Variables	Lobectomy (n=479)	Segmentectomy (n=155)	P value
Age	66 [30-89]	66 [31-89]	0.37
Gender			
Male	223 (46.6%)	74 (48.1%)	0.78
Tumor size (cm)	2.2 (0.7-3.0)	1.5 (0.6-3.0)	<0.001
SUVmax†	2.1 (0-16.9)	1.1 (0-9.8)	<0.001
Side			
Right	325 (67.8%)	81 (52.3%)	<0.001
Lobe			<0.001
Upper	254 (53.0%)	82 (52.9%)	
Middle	48 (10.0%)	0 (0%)	
Lower	177 (37.0%)	73 (47.1%)	
Lymphatic invasion	97 (20.3%)	10 (6.5%)	<0.001
Vascular invasion	111 (23.3%)	10 (6.5%)	<0.001
Pleural invasion	66 (13.9%)	8 (5.2%)	0.0024
Lymph node metastasis	50 (10.6%)	3 (1.9%)	<0.001

†, maximum standardized uptake value.

lobectomy (hilar lymph node, n=1; mediastinal lymph node, n=11; pleura, n=2; hilar and mediastinal lymph nodes, n=1; bronchial stump and mediastinal lymph node, n=1; mediastinal lymph node and pleura, n=1) and in three patients after segmentectomy (bronchial stump, n=1; pleura, n=1; residual lung and mediastinal lymph node, n=1).

The 3-year OS rates between patients who underwent lobectomy and segmentectomy were similar (94.1% *vs.* 95.7%, P=0.162), whereas three-year RFS rates significantly differed (86.9% *vs.* 92.7%, P=0.0394; *Figure 1*). *Table 3* shows that the multivariate analyses of RFS and OS selected age and SUVmax as significant independent prognostic factors, but not sex, tumor size, or procedure (lobectomy *vs.* segmentectomy).

Propensity score-matching based on clinical variables of age, gender, tumor size, SUVmax, side and lobe, allowed good matches of 100 lobectomy and segmentectomy pairs in terms of clinical and consequently pathological factors, except for more advanced age and higher SUVmax in the segmentectomy group (*Table 4*). Patients who underwent middle lobectomy were excluded from matching for a fair comparison, since tumors located in a middle lobe were never treated by segmentectomy. *Figure 1* shows that the three-year RFS and OS did not significantly differ between propensity score-matched patients after lobectomy or segmentectomy (91.5% *vs.* 90.2% and 93.3% *vs.* 94.8%, respectively).

Table 2 Details of segmentectomy (n=155)

Site	Number
Right (n=81)	
S1	11
S1+2	1
S2	13
S3	7
S6	31
S7	3
S8	8
S9	1
S10	1
S7+8	1
S8+9	2
S9+10	1
S7+8+9+10	1
Left (n=74)	
S1+2	17
S3	9
S1+2+3	10
S1+2+3c	1
S4	5
S5	1
S4+5	7
S6	15
S8	2
S9	5
S10	1
S8+9+10	1

Discussion

The RFS and OS curves of patients with clinical stage IA lung adenocarcinoma seemed better after segmentectomy than lobectomy, although the clinical and pathological backgrounds significantly differed and would obviously affect their survival (11-16). Multivariate analyses of the clinical background for RFS and OS demonstrated that procedure (lobectomy *vs.* segmentectomy) was not a significant prognostic factor. The clinical features or

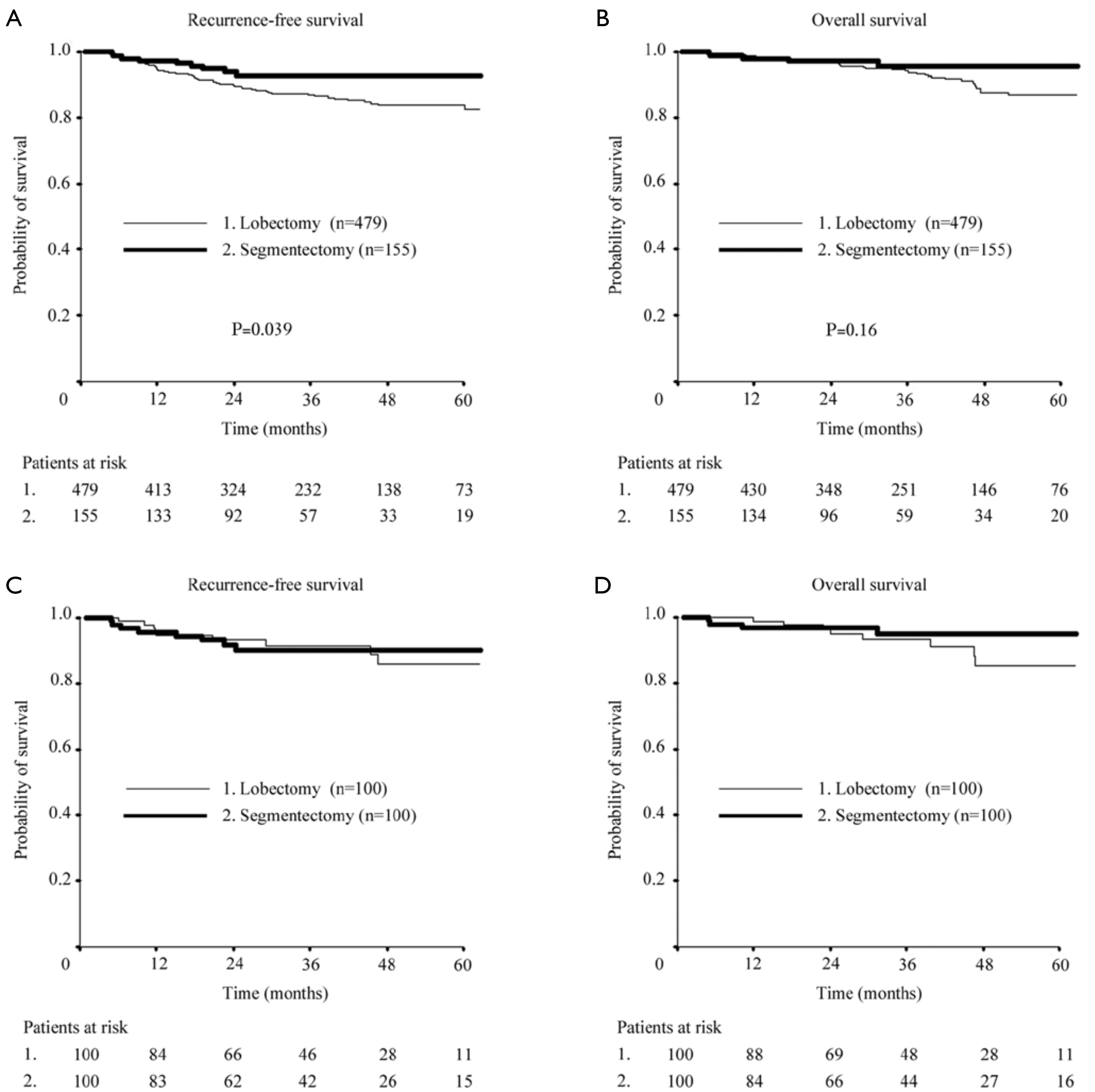

Figure 1 Recurrence-free (RFS) and overall survival (OS) curves of patients after lobectomy and segmentectomy. Three-year RFS (A) and OS (B) after lobectomy and segmentectomy were 86.9% *vs*. 92.7% (P=0.0394) and 94.1% *vs*. 95.7% (P=0.162), respectively, in all cohorts. Three-year RFS (C) and OS (D) in propensity score-matched patients after lobectomy and segmentectomy were 91.5% *vs*. 90.2% and 93.3% *vs*. 94.8%, respectively.

pathological factors of lymphatic, vascular or pleural invasion, or lymph node metastasis were similar in propensity score-matching analyses that matched for potentially confounding variables of age, sex, tumor size, SUVmax, tumor location to minimize selection bias. Only age and SUVmax significantly differed. The three-year RFS and OS rates after segmentectomy and lobectomy group were similar in the matched model, although the former

Table 3 Multivariate analyses for RFS and OS

Variables	HR (95% CI)	P value
Multivariate analysis for RFS†		
Age	1.04 (1.01-1.07)	0.011
Gender		
Male *vs*. female	1.20 (0.74-1.93)	0.46
Tumor size (cm)	1.36 (0.86-2.14)	0.19
SUVmax‡	1.17 (1.09-1.25)	<0.001
Procedure		
Lobectomy *vs*. segmentectomy	0.72 (0.34-1.52)	0.39
Multivariate analysis for OS#		
Age	1.05 (1.01-1.09)	0.0082
Gender		
Male *vs*. female	1.10 (0.49-1.70)	0.78
Tumor size (cm)	1.23 (0.67-2.26)	0.50
SUVmax‡	1.13 (1.04-1.24)	0.0068
Procedure		
Lobectomy *vs*. segmentectomy	0.68 (0.25-1.82)	0.44

RFS, recurrence-free survival; OS, overall survival; HR, hazard ratio; CI, confidence interval. †, recurrence-free survival; ‡, maximum standardized uptake value; #, overall survival.

Table 4 Propensity score-matched comparison of clinical and pathologic factors between patients who underwent lobectomy and segmentectomy

Variables	Lobectomy (n=100)	Segmentectomy (n=100)	P value
Clinical factors			
Age	63 [33-82]	66 [32-89]	0.030
Gender			
Male	46 (46%)	50 (50%)	0.67
Tumor size (cm)	1.6 (0.7-3.0)	1.6 (0.6-3.0)	0.28
SUVmax†	1.2 (0-8.7)	1.2 (0-9.8)	0.047
Side			0.27
Right	62 (62%)	53 (53%)	
Lobe			0.10
Upper	62 (62%)	50 (50%)	
Lower	38 (38%)	50 (50%)	
Pathologic factors			
Lymphatic invasion	11 (11%)	7 (7%)	0.45
Vascular invasion	9 (9%)	9 (9%)	1.0
Pleural invasion	10 (10%)	7 (7%)	0.61
Lymph node metastasis	7 (7%)	3 (3%)	0.34

†, maximum standardized uptake value.

were significantly older and had a higher SUVmax. These data suggest that segmentectomy could be an alternative strategy for treating clinical stage IA lung adenocarcinoma when HRCT and FDG-PET/CT findings are taken into consideration.

This investigation has several limitations and the results should be interpreted with care. Information in the database analyzed herein included surgical procedures; however, further details such as indications for segmentectomy—that is, whether or not patients who were treated with segmentectomy could have tolerated lobectomy—are difficult to obtain. In addition, patients who underwent segmentectomy tended to have less invasive, smaller tumors, with small tumor size or low SUVmax, and thus a lower frequency of pathologically invasive factors such as lymphatic, vascular, pleural or nodal involvement. Therefore, we used propensity score-matched analysis to adjust the patients' backgrounds as much as possible. However, we could not compare the surgical outcomes of patients with a relatively low SUVmax, implying that patients with a high SUVmax require close scrutiny. The database also did not include information about lung function. The key advantage of segmentectomy is the preservation of lung function, and several studies have shown that segmentectomy has functional advantages over lobectomy (5,17,18).

The target tumors of most previous studies that compared the outcomes of segmentectomy and lobectomy were T1 N0 M0 NSCLC of ≤2 cm (4-6). However, the present study included patients with clinical T1b tumors of 2 to 3 cm. Patients with T1b lung adenocarcinomas with a sufficient surgical margin could be candidates for sublobar resection if selected based on HRCT and FDG-PET/CT findings (12).

The ongoing, multicenter phase III clinical trials of propriety of radical segmentectomy in the United States (CALGB-140503) and Japan (JCOG0802/WJOG4607L) should be carefully monitored. The primary end-point of the Japanese study is OS (disease-free survival in the US study), and wedge resection is not permitted as a sublobar resection, as it differs from radical segmentectomy. The Japanese study (19) aims to compare the surgical outcomes of lobectomy and segmentectomy for T1 N0 M0 NSCLC measuring ≤2 cm, excluding radiologically less-invasive tumors such as ground-glass opacity (GGO)-dominant tumors on HRCT (20), and thus can show the true colors of segmentectomy compared with lobectomy. Segmentectomy is more procedurally demanding than either lobectomy or wedge resection, and thus incorrect outcomes of these clinical trials due to technical errors, such as recurrence at resection lines or excessive loss of lung function, might be a concern. Surgeons must carefully avoid local failure at the margin and fully expand adjacent segments to maximize postoperative lung function.

Current understanding of radical segmentectomy can be summarized as follows. Firstly, the indication for segmentectomy should be limited to T1 tumors ≤3 cm in diameter, and HRCT and PET-CT findings must be taken into consideration, particularly for T1b tumors (21-23). Whenever nodal involvement or an insufficient margin is confirmed intraoperatively, segmentectomy should be converted to lobectomy with complete nodal dissection. Secondly, radical (intentional) and compromising indications for segmentectomy must be independently discussed. The former is for low-risk patients who can tolerate lobectomy. Thirdly, segmentectomy is more valuable than wedge resection from an oncological perspective because it allows nodal dissection at the hilum. Thus, the decision of the most suitable procedure, such as whether or not to intraoperatively convert to lobectomy, should consider precise staging and the lower rate of local recurrence resulting from sufficient surgical margins. Therefore, segmentectomy must be clearly separated from wedge resection amongst the categories of sublobar resection for lung cancer. Surgeons must become adept and master segmentectomy as a keynote procedure because small lung cancers are being detected with increasing frequency.

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Footnote

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

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Short-Term Results of Thoracoscopic Lobectomy and Segmentectomy for Lung Cancer in Koo Foundation Sun Yat-Sen Cancer Center

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Background: Thoracoscopic lobectomy and segmentectomy have been demonstrated to be safe and technically feasible for curative resection of lung cancer. This minimally invasive surgery is increasingly popular and adopted by the world all over. We report our short-term results of thoracoscopic lobectomy/segmentectomy operations comparing with previous surgical approach for lung cancer resection by muscle-sparing vertical minithoracotomy in Koo Foundation Sun Yat-Sen Cancer Center.

Methods: We performed a retrospective review of 317 consecutive patients who underwent lobectomy or segmentectomy either by thoracoscopic surgery (n=121) or muscle-sparing vertical mini-thoracotomy (n=195) for lung cancer in Koo Foundation Sun Yat-Sen Cancer center between Jan 2000 and Jun 2009. The operative details, postoperative complication, and length of stay were statistically analyzed.

Results: Thoracoscopic lobectomy and segmentectomy were performed successfully in 121 patients. One patient was converted to open thoracotomy during operation due to uncontrolled bleeding. There is no significant difference in age factors (p=0.763), forced expiratory volume in one second (p=0.480) or comorbidities (p=0.549) between these two groups. Thoracoscopic group had a significantly predominant percentage in women, diabetes mellitus, less smoking index and chronic obstructive pulmonary disease incidence. Patients undergoing a thoracoscopic surgery had a shorter length of stay (6.8±3.4 *vs*. 10.2±9.1 days, p<0.001), longer operative time (3.6±1.0 *vs*. 3.2±1.2 hours, p=0.004), and less blood loss (102.7±95.7 *vs*. 140.1±171.2 ml, p<0.029). There was no significant difference in postoperative complication rate between the two groups (18.2% *vs*. 23.6%, p=0.255). No surgical mortality was found in the thoracoscopic group.

Conclusion: Our findings suggested thoracoscopic surgery for lung cancer would be as safe as muscle-sparing vertical mini-thoracotomy in lobectomy and segmentectomy.

Keywords: Video-assisted thoracoscopic surgery, lobectomy, segmentectomy, lung cancer

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Introduction

Lung cancer is the leading cause of cancer death worldwide. It is also the most common cause of cancer death in women and the second in men in Taiwan (1). Surgical resections are the mainstay treatment for patients with early-stage non-small cell lung cancer (NSCLC). Growing evidences have suggested that video-assisted thoracic surgery (VATS) would be an alternative surgical approach for this group of patients instead of conventional thoracotomy (2-6). Proponents of VATS emphasized the benefits in terms of decreased postoperative pain, less impairment in pulmonary function, shorter chest tube duration, and consequently shorter hospital stay (3-5). However, this technique has not yet gained widespread acceptance in the surgical community, mainly because of the apprehension for its surgical safety and oncologic efficacy.

Relative few reports have demonstrated the results of VATS for lung cancer in Taiwan. Here, we reviewed our experience in management of 317 lung cancer patients who underwent lobectomy or segmentectomy regardless of VATS or muscle-sparing vertical mini-thoracotomy (MSVMT). The aim of our study is the analysis of operative details, postoperative complications and length of hospital stay.

Patients and Methods

Data Collection

We retrospectively reviewed all patients who, from January 2000 to June 2009, underwent lobectomy or segmentectomy for lung cancer in Koo Foundation Sun Yat-Sen Cancer Center. A total of 317 consecutive patients were enrolled in the study. Preoperative staging workup included complete blood count, serum biochemistry tests, chest CT scan, histologic diagnostic procedures, and positron emission tomography-computed tomography (PET-CT). All patients were evaluated with chest computed tomography. 76.7% of patients were staged by PET-CT. Pre-operative tissue diagnostic tools included sputum cytology, transbronchial biopsy, and trans-coetaneous CT or sonography guided biopsy. Clinical data, including age, sex, smoking index, pulmonary function test, preoperative comorbidities, operative time, operative blood loss, postoperative complication, length of hospital stay, and tumor characteristics were all collected. Surgical mortality was defined as death during the same hospitalization or within 30 days after the operation.

The indications for VATS pulmonary resections remained the same as MSVMT approach . The indications of surgical pulmonary resection included clinical T1-3, N0-1, single station N2 and absence of distant organs metastasis. The eligibility of criteria for segmentectomy included cT1N0M0 NSCLC with size diameter smaller than 2 cm and peripheral tumor. We started VATS lobectomy/segmentectomy with radical lymph node dissection for lung cancer in 2005. The initial criteria for VATS approach are described as following: clinical stage I neither extensive pleural adhesion nor endobronchial lesion on preoperative evaluation. After 2007, we extended the indication of VATS approach to be contingent upon the increased experience in performing the procedure. Now, patients considered appropriate for thoracoscopic approach include those with tumor size smaller than 5 cm in diameter without central airway involvement where the local lymph node status is concerned. Incomplete fissure and extensive pleural adhesion were no longer contraindication for VATS approach. Therefore, the numbers of VATS lobectomy/segmentectomy increased eventually over the years.

Surgical Technique

Thoracoscopic surgery was performed via a 4 to 5cm mini-thoracotomy at the anterior axillary line. The utility incision was placed according to the 4th or 5th intercostals space where it provided access for complete hilar and mediastinal dissection. The 30-degree thoracoscope was placed at the 8th or 9th intercostals space in the midaxillary line. Another 10-mm accessory port was not routinely placed at the tip of the scapula. Rib resection or rib spreading was not permitted in the VATS group. All pulmonary vessels and bronchus in the resected lobe were basically sectioned by using endoscopic staplers. All procedures were performed under video screen for guidance. An en-bloc hilar and mediastinal lymph node dissection were completed in the same fashion as done in an open thoracotomy The lung specimen was secured in a plastic bag while it was being withdrawn from the utility minithoracotomy. No epidural pain control was needed in this group.

MSVMT was performed at the 4th or 5th intercostals space. The latissmus dorsi muscle was preserved and the serratus anterior muscle was splitted. In addition, a mental retractor was introduced for opening the intercostals space. All pulmonary vessels and bronchus in the resected lobe were basically divided after triple ligation. Radical lymph node dissection was routinely performed for definitive pathologic staging including both hilar lymph nodes and ipsilateral mediastinal lymph node stations. Epidural pain control was generally used in this group.

Pathology

All resected specimens were examined for pathologic staging. Histological typing was determined according to the World Heath Organization classification (7). The disease stages were determined according to TNM classification of the American Joint Committee for Cancer Staging and Revised International System for Staging Lung Cancer (8).

Statistical Analysis

The continuous data are expressed as the mean ± SD. Comparisons of categorical data between the 2 groups were made by using χ^2 or Fisher exact test. Continuous data were compared by using 2-tailed t test. Statistical analysis was considered to be significant when the probability value was below 0.05. Data analysis was performed using Statistical Package for the Social Science software (version 12.0; SPSS, Chicago, Ill).

Table 1 Number of Cases of Performed Per Year

Year	VATS	MSVMT
2000	–	16
2001	–	23
2002	–	30
2003	–	27
2004	–	27
2005	12	20
2006	15	23
2007	24	12
2008	41	13
2009/6	29	4
Total	121	195

MSVMT, muscle-sparing vertical mini-thoracotomy; VATS, video-assisted thoracoscopic surgery.

Results

In 2005, we began using VATS lobectomy or segmentectomy in NSCLC (*Table 1*). Among the 317 patients studied, 122 patients were planned to undergo VATS. There was one conversion to open thoracotomy during surgery because of uncontrolled bleeding, where the intraoperative blood loss was 500ml; the patient was discharged uneventfully on postoperative 13th day. As a result, 121 patients successfully underwent VATS lobectomy (n=105) or segmentectomy (n=16). 195 patients underwent lobectomy (n=179) or segmentectomy (n=16) via MSVMT. The detailed clinical characteristics of all patients were listed in *Table 2*. The data were categorized according to the type of surgical procedure. There is no significant difference among the factor of age (p=0.763), forced expiratory volume in one second (p=0.480) and comorbidities (p=0.549) between the two groups. VATS group had a significantly predominant percentage in women, diabetes mellitus, less smoking index and chronic obstructive pulmonary disease incidence.

The operative details and postoperative complications were demonst rated in *Table 3*. The pre-operative tissue diagnostic rates were similar. The VATS group demonstrated a significantly longer operation time (p=0.004), less intraoperative blood loss (p=0.029), shorter wound length (p<0.001) and shorter length of hospital stay (p<0.001). No significant difference was found in the location of lung cancer. There was no significant difference between the two

Table 2 Patient Characteristics

	VATS	MSVMT	P value
Numbers of cases	121	195	
Age (years) (mean ± SD)	61.5±10.9	61.9±11.1	0.763
Sex (male/female)	47/74	128/67	<0.001
Smoking index	9.20±20.04	20.2±26.7	<0.001
FEV1 (L)	2.27±0.60	2.32±0.64	0.480
FEV1/FVC (%)	78.26±7.61	76.21±10.78	0.050
Comorbidities	87 (71.9%)	134 (68.7%)	0.549
Dypertension	47 (38.8%)	57 (29.2%)	0.085
Diabetes mellitus	20 (16.5%)	16 (8.2%)	0.029
CAD	4 (3.3%)	8 (4.1%)	0.774
COPD	5 (4.1%)	22 (11.3%)	0.037
Liver disease	13 (10.7%)	16 (8.2%)	0.548
Previous malignancy	23 (19.0%)	26 (13.3%)	0.202

P value less than 0.05 was considered significant. CAD, coronary artery disease; COPD,chronic obstructive pulmonary disease; FEV1, force expiratory volume in one second; FVC, forced volume capacity; MSVMT, muscle-sparing vertical mini-thoracotomy; VATS, video-assisted thoracoscopic surgery.

Table 3 Operative Detail and Postoperative Complication

	VATS	MSVMT	P value
Operation times (hours)	3.6±1.0	3.2±1.2	0.004
Estimated blood loss (ml)	102.7±95.7	140.1±171.2	0.029
Wound length (cm)	4.8±1.1	11.6±4.0	<0.001
Pre-operative diagnostic rate	88.4%	85.6%	
Lesion location			0.394
Right upper lobe	51 (42.1%)	64 (32.8%)	
Right middle lobe	9 (7.4%)	13 (6.7%)	
Right lower lobe	21 (17.4%)	33 (16.9%)	
Left upper lobe	25 (20.7%)	50 (25.6%)	
Left lower lobe	15 (12.4%)	35 (17.9%)	
Complication	22 (18.2%)	46 (23.6%)	0.255
Prolonged air leak >7 days	7 (5.8%)	3 (1.5%)	0.048
Arrythmia	3 (2.5%)	8 (4.1%)	0.541
Chylothorax	4 (3.3%)	6 (3.1%)	1.000
COPD with AE	3 (2.5%)	7(3.6%)	0.747
Pulmonary embolism	0 (0%)	1(0.5%)	1.000
Bleeding	2 (1.7%)	8 (4.1%)	0.328
Pneumonia	2 (1.7%)	3 (1.5%)	1.000
Reoperation	1 (0.8%)	2 (1.0%)	1.000
Empyema	0 (0%)	4 (2.1%)	0.302
Myocardial infarction	0 (0%)	1(0.5%)	1.000
Curative resection	96.7%	95.9%	1.000
Surgical mortality	0 (0%)	1 (0.5%)	1.000
Length of stay (days)	6.8±3.4	10.2±9.1	<0.001

P value less than 0.05 was considered significant. AE, acute exacerbation; COPD, chronic obstructive pulmonary disease; MSVMT, muscle-sparing vertical mini-thoracotomy; VATS, video-assisted thoracoscopic surgery.

groups, but VATS group showed significant prolonged air leak (p=0.048). There was only one surgical mortality on postoperative 23rd day because of pneumonia deteriorated into acute respiratory distress syndrome in the MSVMT group; no surgical death in VATS group.

The pathologic characteristics of tumor were shown in *Table 4*. The VATS group had smaller tumor in size (p<0.001), fewer in total lymph node dissection numbers (p=0.005), fewer in positive lymph node numbers (p=0.006), more adenocarcinoma (p<0.001) and earlier stage (p<0.001) compared with MVST group. The numbers of total lymph nodes dissection and positive lymph nodes removed were fewer in the VATS group.

Discussion

VATS lobectomy for lung cancer was first described in the early 1990s (9-10). The first randomized controlled trial by Kirby concluded that VATS lobectomy was associated with lower postoperative complications, but not with significant decrease in intraoperative blood loss, duration of chest tube drainage, length of stay, or postoperative pain (11). McKenna *et al*. reported the largest single-institutional series on VATS lobectomy to date (12). In their series of 1,100 patients, the mortality rate was only 0.8% and morbidity rate was 15.3%. The mean length of hospital stay was 4.78 days. The shortterm postoperative results suggested that VATS lobectomy is a safe and feasible surgical procedure in the hands of experienced surgeons. The Cancer and Leukemia Group B (CALGB) 39802 prospective (6), multi-institutional study elucidated the technical feasibility and safety of standardized VATS lobectomy for early-stage NSCLC. It was designed to evaluate success rate, morbidity, mortality, cancer recurrence, and failure-free survival. The

Table 4 Tumor characteristics

	VATS	MSVMT	P value
Tumor size	2.7±1.0	4.0±2.3	<0.001
Total LN numbers	21.7±9.9	25.4±12.6	0.005
Positive LN numbers	1.0±2.9	2.3±5.4	0.006
Histology			<0.001
Adenocarcinoma	110 (90.9%)	125 (64.1%)	
SqCC	3 (2.5%)	47(24.1%)	
Others	8 (6.6%)	23 (11.8%)	
Pathologic stage			<0.001
Stage Ia	63 (52.1%)	33 (16.9%)	
Stage Ib	27(22.3%)	55 (28.2)	
Stage IIa	4 (3.3%)	8 (4.1%)	
Stage IIb	4 (3.3%)	36 (18.5%)	
Stage IIIa	17(14.0%)	35 (17.9%)	
Stage IIIb	6 (5.0%)	17 (8.7%)	
Stage IV	0 (0%)	8 (4.1%)	
Uncertain	0 (0%)	3 (1.5%)	

P value less than 0.05 was considered significant. LN, lymph node; MSVMT, muscle-sparing vertical mini-thoracotomy; SqCC, squamous cell carcinoma; VATS, video-assisted thoracoscopic surgery.

study demonstrated technical feasibility and showed low complication and chest tube duration.

Lobectomy remained the standard surgical resection for early lung cancer. However, with the increasing prevalence of computed tomography application, early lung cancer with small size nodule became more easily detectable. There was a resurgence of interest in anatomic segmentectomy for very early lung cancer, especially in patients with compromised cardio-pulmonary function, who might not tolerate lobectomy due to inadequate postoperative reserved pulmonary function (13). Growing data suggested that segmentectomy was an alternative to lobectomy in patients with clinical T1N0M0 status, especially when tumor diameter was less than 2 cm. This anatomic segmental resection could be performed safely without compromising oncologic results (13-15). In some institutions, segmentectomy with radical lymph node dissection was performed not only in high-risk patients but also in low-risk patients with clinical T1N0M0 and tumors ≤2 cm in diameter (16-17). It could offer the benefit of significantly better preservation of pulmonary function compared with lobectomy (18-19). In our institution, segmentectomy was designed as an alternative standard resection for peripheral clinical T1N0M0 lung cancer with diameter 2 cm regardless of the risk level. According to the published data, we considered segmentectomy could preserve more pulmonary function without compromising cancer survival. In our data, a total of 32 patients underwent segmentectomy. There were 16 patients in the VATS group and the other 16 in the MSVMT group. In this study, we focus the analysis of the postoperative complication difference between VATS and MSVMT, not segmentectomy and lobectomy. We merged the data of VATS lobectomy with VATS segmentectomy before comparing the VATS group with MSVMT group on account of both lobectomy and segmentectomy being considered as radical curative anatomic resection for early lung cancer. We compared the data difference on postoperative complications between the two groups and found no significant difference (18.2% *vs.* 23.6%, p=0.255). There was no surgical mortality in the VATS group and only one conversion. We concluded that VATS lobectomy/segmentectomy was a safe and technical feasible surgical approach in our institute based on the present data.

Although the surgical risks of VATS lobectomy/segmentectomy are considered to be acceptable, this new operative approach has been adopted slowly over the past decade. There seems to lack a generally accepted standard procedure for VATS lobectomy/segmentectomy; however, surgical techniques, differently modified, are proposed from all over the world. The obstacles associated with VATS included enigmatic technique skill, steep learning curve, operative safety and oncologic concerns. There are relatively few VATS reports for lung cancer in Taiwan to date. We started VATS lobectomy/segmentectomy with radical lymph node dissection for lung cancer in 2005. The initial criteria for thoracoscopic surgery was limited to small clinical early lung caner. Gradually, we extended the indications of thoracoscopic surgery because of cumulative experiences through time. In our institution to date, patients considered appropriate for thoracoscopic approach include those tumors smaller than 5 cm in diameter without central airway involvement or chest wall invasion. Radical lymph node dissection should be routinely done for definitively pathologic staging of mediastinal lymph node status. Even those patients with single station N2 status by PET-CT scan staging are considered candidates for thoracoscopic surgery.

Many controversies regarding VATS approach face further debates for consensus, which include the length of utility thoracotomy, the application of rib spreader, the usage of endoscopic instruments versus conventional instruments and visualization through the incision or only by the monitor. Even now, the thoracoscopic techniques vary among nations, which may attribute, to some degree, different results in the outcomes. We performed VATS approach, which composed of video-monitor dependent visualization, non-ribs spreading, and shorter-than-six cm working wound length. A total of two to three chest wall incisions were used in our institution.

Better quality of lymphadenectomy may lead to more accurate tumor staging and therefore influence statistical result. Patients with 15 or fewer mediastinal lymph nodes dissected had worse survival outcome than those with more than 15 (20). Generally, we performed a radical mediastinal lymph node dissection for all patients as much as we can. Our data demonstrates the number of dissected nodes is smaller in the VATS group (p=0.005), but the mean numbers of lymph node was larger than 15, which could indicate the accurate tumor staging. We presumed that patients in the VATS group had earlier stage lung cancer, contributing to reduced numbers of lymph node. Of course, it is impossible to discuss the technical impact of lymph node dissection simply based on the numbers. As a matter of fact, the technical quality of node dissection need to be further analyzed according to long-term loco-regional disease-free survival rate.

Adequate postoperative pain control has been known to decrease postoperative pulmonary complications. Diminish pain from chest wall incisions will improve the ability to breathe deep, effectively cough and prevent correlative atelectasis. VATS requires only two small skin incisions for thoracoscopic insertion and utility thoracotomy window without rib spreading, which lessen a lot of postoperative pain (21). The optimal postoperative pain control methods for thoracoscopic surgery have been controversial. Epidural anesthesia may be the most popular and well known means of choice, however several associated complications have been reported in literatures, such as nausea, vomiting, hypotension, pruritus, constipation and technical related complications (22). Epidural analgesia is no longer used in VATS group in our institution the potential risk could be avoided. We prescribed oral non-steroid inflammatory drugs and oral opioids for postoperative pain control. Some patients needed several additional shots of intravenous opioids on postoperative first day. We didn't compare the pain scale between the two groups. In fact, epidural anesthesia was only used in MSVMT group

Thoracoscopic group had a significantly predominant percentage in women, diabetes mellitus, earlier stage, adenocarcinoma, less smoking index and chronic obstructive pulmonary disease incidence in this retrospective study. Limited by the retrospective nature, the patient selection bias contributed to results. Definitive conclusions regarding the VATS cannot be made on account of the nature of this nonrandomized trial. We showed our 10-year surgical experience of lung cancer and the recognized advantages of VATS approach based on our study are shorter hospital stay, less blood loss, less epidural anesthesia necessaries, acceptable postoperative complication and no surgical mortality. In conclusion, our retrospective analysis demonstrated that VATS lobectomy/ segmentectomy is technically feasible, safe and holds more comparative advantages to MSVMT approach.

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Role of segmentectomy for pulmonary metastases

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Abstract: Pulmonary metastasectomy has not been proven by randomized trials to be more effective than non-operative management, but currently has a well-accepted role for certain primary cancers, in particular colorectal cancer and sarcoma. One of the principal tenets for pulmonary metastasectomy is that all lesions are resected. A major technical difference compared to surgical management of primary lung cancer is that management of metastatic disease frequently requires the resection of multiple and possibly bilateral lesions. In addition, surgeons and patients must often consider repeat surgery for management of metachronous lesions that develop some time after a previous resection, given the nature of metastatic cancer. Therefore, surgeons must ensure complete resection of lesions with negative margins but also must be cognizant of minimizing resection of functional lung tissue as much as possible, in order to ensure that both current and future lesions can be resected while leaving patients with adequate pulmonary function. Segmentectomy is generally infrequently utilized for pulmonary metastasectomy, but has a role for lesions for which a wedge resection is technically not possible but a lobectomy is not required. Segmentectomy can be an important tool in achieving the dual goals of complete resection and impacting pulmonary function as little as possible. Using minimally invasive techniques with thoracoscopy to perform segmentectomy is associated with less short-term morbidity than thoracotomy. Although the use of minimally invasive techniques limits manual palpation and therefore potential resection of small lesions not identified by pre-resection imaging, the current literature does not suggest that these procedures should be done via thoracotomy.

Keywords: Metastasectomy; neoplasm metastasis; pulmonary surgical procedures; thoracoscopy; thoracotomy

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Introduction

The lung is one of the most common sites where metastatic disease is found for many malignancies. Some lesions are discovered due to symptoms such as pneumonia, cough, hemoptysis or pain, but most are asymptomatic and are found on routine staging or surveillance imaging (1). A pulmonary metastasis is typically a well-circumscribed nodule, found in the periphery of the lung in two-thirds of cases (2). In contrast to screening for lung cancer, computed tomography (CT) scans performed on patients with a history of a previous cancer do not have a high false-positive rate (3). A new lesion that is larger than 1 cm very likely represents a malignant process if the clinical situation does not suggest infection.

Although many malignancies can metastasize to the lungs, the most common cancers for which pulmonary metastasectomy are considered and performed are epithelial cancers, sarcoma, melanoma and germ cell tumors. The epithelial malignancies for which pulmonary metastasectomy have been reported include gastrointestinal cancers, breast cancers, urothelial cancers, gynecological cancers, head and neck cancers, and thymic cancers. In current practice, pulmonary metastases are most commonly resected in patients with sarcoma and colorectal cancer (4).

Evidence supporting pulmonary metastasectomy

Randomized trials showing that pulmonary metastasectomy improves survival compared to non-resection management have not been performed (4). At present, pulmonary metastasectomy is offered to patients based on the observation that long-term survival can be seen after resection, while long-term survival with systemic therapy alone as treatment for patients with pulmonary metastases appears extremely unlikely (2). The data that supports pulmonary metastasectomy consists of registry data and non-controlled retrospective studies. These studies typically show good survival after pulmonary metastasectomy but have selection bias as an inherent limitation, in that the patients included in these studies by definition were considered potentially resectable and therefore likely had a limited number of metastases. These patients are therefore likely to have a better prognosis than other stage IV patients who have more widespread disease, and may have experienced prolonged survival even if pulmonary metastasectomy had not been performed (5,6).

Despite the lack of randomized data, many studies have documented reasonable survival after pulmonary metastasectomy. In an analysis from the International Registry of Lung Metastases which included 5,206 patients from 18 institutions in North America and Europe who underwent pulmonary metastasectomy from 1991 to 1995, complete resection was achieved in 4,572 (88%) patients (7). The actuarial survival for patients who underwent complete metastasectomy in this cohort was 36% at five years, 26% at ten years and 22% at 15 years. A single institution study of 490 patients who underwent complete metastasectomy at the European Institute of Oncology in Milan, Italy, for a wide distribution of primary cancers from 1998-2008 also showed a very reasonable actuarial five-year survival of 46% (8). Another multi-institution retrospective review of 378 patients who underwent pulmonary resection for colorectal cancer metastases with curative intent from 1998 to 2007, an era of modern chemotherapy, showed a 3-year overall survival of 78% (9). The 5-year survival in a series of 97 patients who underwent pulmonary resection for metastatic sarcoma was 50% (10).

Factors that are associated with improved survival after resection of pulmonary metastases have also been documented. In the analysis of the 5,206 patients in the International Registry of Lung Metastases, survival after pulmonary metastasectomy was best with smaller numbers of pulmonary metastases and longer intervals between diagnosis of the primary and the metastatic diseases (7). Completeness of resection, histology and disease-free interval greater than 36 months all predicted improved survival in the analysis of 490 patients from the European Institute of Oncology in Milan (8). In this cohort, prognosis was best for patients with germ cell tumors, followed by those with epithelial tumors, while patients with sarcoma and melanoma had the worst prognosis. In the analysis of 378 colorectal cancer patients, age younger than 65 years, female gender, a disease-free interval between primary and metastatic disease less than one year, and more than three metastases were all predictors of recurrence (9).

A randomized trial investigating colorectal metastasectomy is currently being performed (4). Until the results of that trial are reported, care will continue to be driven by the data from retrospective series. The decision to proceed with surgical resection of pulmonary metastases should be a multidisciplinary one, made jointly by the thoracic surgeon and the medical oncologist (1). Given that the benefits of resection in this setting have not been definitively established, avoiding both short-term and long-term morbidity for these patients who already have a poor prognosis is critical.

Criteria and goals for pulmonary metastasectomy

Several criteria establishing whether or not pulmonary metastasectomy is reasonable have been developed (1,2). First, the primary site of disease has to be either controlled or appear controllable. In addition, complete resection of pulmonary metastatic disease has to be feasible and anticipated to be tolerated by the patient. Finally, alternative therapies that are better than resection must not be available (2).

In order to achieve complete resection of pulmonary metastatic disease, surgeons often must plan for the resection of multiple and possibly bilateral lesions. Given that a new lesion that is larger than 1 cm on CT scan is very likely to represent a malignant process in a patient with a history of previous cancer if the clinical situation does not suggest infection, surgeons must plan to find and resect all suspicious lesions at the time of metastasectomy (3). The need to plan for the resection of multiple lesions, and the need to consider that a patient may require re-resection in the future if other metachronous lesions occur make the surgical management of metastatic lesions different from the surgical management of primary lung cancer. In addition, surgical management of primary lung cancer generally requires an anatomic resection for both staging purposes and to minimize the chance for local recurrence. In contrast, surgical management of a metastatic lesion only requires complete resection of each lesion with negative margins (11). When performing pulmonary metastasectomy, surgeons therefore must completely resect all lesions with negative margins while minimizing resection of functional lung tissue as much as possible, to ensure that both current and future lesions can be resected while leaving patients with adequate pulmonary function. Ultimately, the volume of disease, the location of the lesions, and the performance status of the patient guide the surgical approach (2).

Segmentectomy for pulmonary metastasectomy

Pulmonary metastasectomy must achieve resection of all lesions both identified on imaging before surgery and found intra-operatively, while preserving as much normal pulmonary parenchyma as possible (1). In contrast to primary lung cancer as described above, an anatomic pulmonary resection for metastatic disease does not improve survival compared to wedge resection (11). Because most pulmonary metastases are located in the lung periphery, resection most often requires wedge resection of the lung parenchyma. An anatomic resection is therefore indicated only when wedge resection would not achieve complete resection (2). More extensive surgical procedures such as lobectomy and pneumonectomy are sometimes technically necessary to allow complete resection of centrally located metastases. These more extensive resections may be appropriately indicated and offer some patients the best chance for long-term survival, but must be considered carefully as patients can subsequently develop metastases in the remaining lung, which could be unresectable depending on the patients' previous resections.

Segmentectomy should be the first resection option carefully considered for all lesions that cannot be removed via wedge resection. As discussed above, pulmonary metastasectomies must accomplish the dual goals of achieving complete resection while preserving as much functional lung tissue as possible. Patients that undergo attempted complete resection of metastatic disease have been shown to have a significant loss of lung function. In 117 patients who underwent a variety of resections, the mean loss at three months after resection of percent-predicted FEV1 and percent-predicted DLCO from preoperative values was 10.8% and 9.7% respectively (12). Factors that predicted worse lung function were post-resection chemotherapy and bilateral procedures. Segmentectomy is associated with significant preservation of pulmonary function compared with lobectomy, and should be considered and explored for all lesions that do not absolutely technically require a lobectomy due to their central location (13,14).

Minimizing the amount of lung resected during metastasectomy is also important for preserving adequate functional lung tissue, as this allows the patient to undergo additional future resections if they develop metachronous lesions for which repeat metastasectomy is indicated. In the International Registry of Lung Metastases report, 20% of 5,206 patients underwent repeat resections; 5% of patients underwent three or more procedures overall (7). In addition, minimizing the extent of resection also likely improves perioperative outcomes. In the International Registry of Lung Metastases report, the operative mortality was 0.6% for sublobar resections, 1.2% for lobectomies and bilobectomies and 3.6% for pneumonectomies (7). The lack of definitive evidence proving a survival benefit to resection and the patients' overall poor prognosis in general makes it even more critical to minimize its morbidity and subsequent impact on pulmonary function.

In general, pulmonary segmentectomies can be performed safely with acceptable morbidity and mortality. The 30-day mortality was 1.1% and the overall morbidity was 34.9% in one series of 785 anatomic segmentectomy patients, 41 of whom had a metastatic lesion resected (15). The major morbidity rate was 9.3%. Of 41 patients who had a segmentectomy for a metastatic lesion, 2 (4.9%) developed a locoregional recurrence. Resection of metastatic disease was the indication for surgery in 30 patients in another series of 77 segmentectomy patients (16). The mortality in this series was 2.6% (2 patients) and the morbidity was 32.5%. The most common complications were atrial arrhythmia (10 patients, 13%), pulmonary complications (9 patients, 12%) and prolonged air leak (7 patients, 9%). In these series, the performance of all common segmentectomies was reported including superior segmentectomy, basilar segmentectomy, lingulectomy and lingular-sparing upper lobectomy. In addition, segmental resections of the individual segments of the right upper and right middle lobe were also reported. *Figure 1* shows some examples of central pulmonary metastases that were resected via segmentectomy.

Anatomic segmentectomies are generally uncommonly used in the treatment of pulmonary metastases, accounting for between 3% and 23% of all resections in several relatively large series (7-9,17-19). *Table 1* summarizes the use of segmentectomy in these series. The use of segmentectomy appears to be increasing over time, which may reflect increasing recognition of the importance of preserving pulmonary parenchyma for this disease process. Surgeons should consider segmentectomy for all cases where wedge

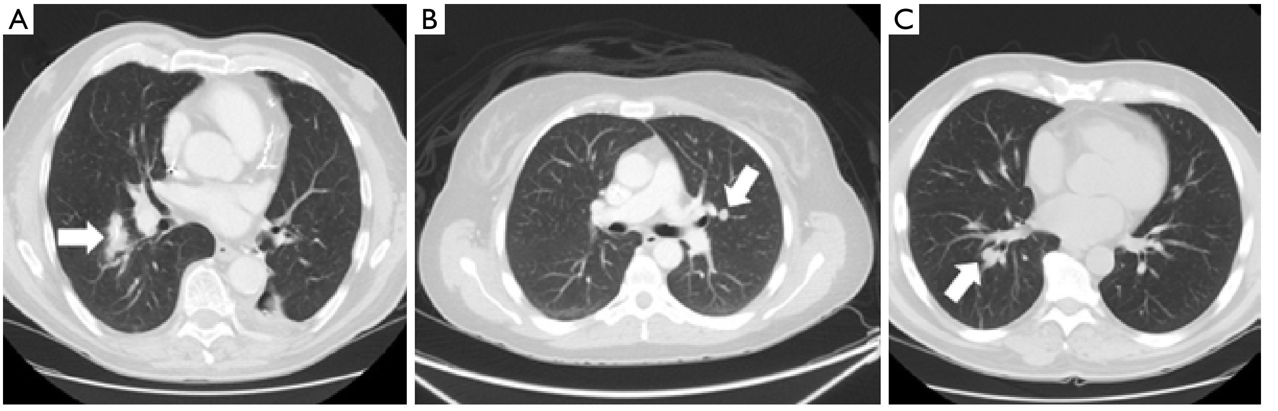

Figure 1 CT scan images of patients with pulmonary metastases that were resected via segmentectomy. (A) Colorectal metastasis (arrow) resected via right superior segmentectomy; (B) Colorectal metastasis (arrow) resected via lingular-sparing left upper lobectomy; (C) Head and neck squamous cell carcinoma metastasis (arrow) resected via right basilar segmentectomy. CT, computed tomography.

Table 1 Summary of segmentectomy use to accomplish resection in several large series of pulmonary metastasectomy

Study	Years of study	Metastatic disease source	Number of procedures	Number of segmentectomies [%]
Welter *et al*. (12)	2008-2010	Multiple	117	27 [23]
Casiraghi *et al*. (8)	1998-2008	Multiple	708	58 [12]
Onaitis *et al*. (9)	1998-2007	Colorectal cancer	378	25 [7]
Rena *et al*. (17)	1980-2000	Colorectal cancer	98	9 [9]
Pastorino *et al*. (7)	1991-1995	Multiple	5,206	449 [9]
Stewart *et al*. (18)	1969-1989	Multiple	69	2 [3]
Venn *et al*. (19)	1980-1987	Multiple	156	4 [3]

resection is not feasible. Surgeons or centers that do not perform segmentectomy should consider referral to a center that does, to ensure that patients receive optimal care when undergoing pulmonary metastasectomy.

Use of minimally invasive approach

An area that is somewhat controversial is whether a minimally invasive technique with video-assisted thoracoscopic surgery (VATS) is appropriate for the resection of pulmonary metastases. Because manual lung palpation is limited with VATS, the identification of pulmonary nodules by VATS relies heavily on the preoperative CT scan and on the ability to visualize lesions in the periphery of the lung. However, pre-resection imaging with CT scans often underestimates the number of pulmonary nodules present (1,20). Metastases that are not detected on CT scan but are found when the lung is explored are noted in 16-46% of patients (3,21-24). Thoracoscopic resection of all lesions seen on CT scan with subsequent open exploration has also revealed missed metastases in 29-56% of patients (25,26). Although improvements with CT scans over time may decrease the number of missed nodules, many surgeons feel that using a thoracotomy so that the lung parenchyma can be fully palpated is essential and a VATS approach without palpation is suboptimal (3). In fact, an investigation of approach for pulmonary metastasectomy in the European Society of Thoracic Surgery (ESTS) practice patterns showed that 65 percent of surgeons thought palpation was necessary for adequate metastasectomy (27).

However, the data supporting the need to perform manual lung palpation via thoracotomy rather than reliance on imaging to guide resection is considered to be weak (3). Although multiple well-designed non-randomized studies have consistently shown that nodules are missed without

Table 2 Results from segmentectomy series that included VATS

	Years of study	Number of patients	VATS approach	Mortality	Morbidity
Atkins *et al*. (16)	2000-2006	77	48	2.6% overall 0% VATS	VATS morbidity: - atrial arrhythmia 15% - pulmonary 10% - air leak 10%
Leshnower *et al*. (32)	2002-2009	41	15	4.8% overall 0% VATS	No morbidity reported after VATS approach
Schuchert *et al*. (15)	2002-2010	785	468	1.1% overall	Overall morbidity: - atrial arrhythmia 6.5% - respiratory failure 5.5% - pneumonia 4.5% - air leak 3.8%

VATS, video-assisted thoracoscopic surgery.

palpation, studies have not shown that missing and not resecting these tiny nodules impacts survival. Several studies have not shown that a thoracotomy approach to pulmonary metastasectomy improves survival compared to VATS, although these studies are all somewhat limited by small sample sizes (28-30). A recent review of current data, which was noted to be limited to non-randomized retrospective studies that did not fully adjust for potential confounding factors, found no difference in survival between thoracoscopic and thoracotomy approaches (31). Thoracoscopic resection of metastases was associated with improved short-term outcomes in two studies, including shorter hospital stays, shorter chest drainage duration and fewer perioperative complications (28,29). Therefore, although the use of minimally invasive techniques limits manual palpation and therefore potential resection of small lesions not identified by pre-resection imaging, an approach of relying on imaging to guide resection via VATS is considered reasonable if careful follow-up is planned so that repeat resection of newly discovered nodules can be performed (3).

A VATS approach should be considered if segmentectomy for a metastasis is planned. Using minimally invasive techniques with thoracoscopy to perform segmentectomy has less short-term morbidity than thoracotomy. VATS segmentectomy has been shown to be a safe procedure that is associated with fewer complications and a reduced hospital stay when compared with an open segmentectomy (16,32). The VATS approach can be used for all potential segmental resections (15,16). The rates of conversion from VATS to open segmentectomy have been reported as 0-6.4%, with the most common reasons for conversion cited as inadequate exposure, hilar fibrosis and bleeding (15,16). The 30-day mortality in a series of 785 segmentectomies, of which a VATS approach was used for 468 patients, was 1.1% (15). There were no peri-operative mortalities in two smaller series of VATS segmentectomies (16,32). *Table 2* summarizes several reports on the use of VATS to perform segmentectomies.

Conclusions

Pulmonary metastasectomy has a well-accepted role for certain primary cancers, in particular colorectal cancer and sarcoma, although this practice has not been proven by randomized trials to be more effective than non-operative management. However, patients have been observed to experience good long-term survival after resection of lung metastases, while long-term survival with systemic therapy alone as treatment for patients with pulmonary metastases is considered to be very unlikely. Because removal of all metastatic lesions has been consistently shown to be of great prognostic significance, surgeons must strive to remove as little lung tissue as possible while still achieving complete resection of each lesion. In this way, the patient will be able to tolerate resection of not only all synchronous disease but also possibly repeat resection if metachronous lesions develop. Segmentectomy has generally been infrequently utilized for pulmonary metastasectomy, but should be the first resection consideration if wedge resection technically cannot be performed for a lesion due to size or location. Avoiding lobectomy or even a more significant resection will allow a patient better preservation of pulmonary function, and likely allow them to tolerate resection of more lesions if necessary. Although the use of minimally invasive techniques limits manual palpation and therefore potential resection of small lesions not identified by pre-resection imaging, the current literature does not suggest that these procedures should be done via thoracotomy. Using VATS to perform segmentectomy is associated with less perioperative morbidity. However, careful follow-up surveillance imaging should be planned when manual palpation is not performed so that repeat resection of any new disease that appears can be considered.

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Footnote

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

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Techniques to define segmental anatomy during segmentectomy

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Abstract: Pulmonary segmentectomy is generally acknowledged to be more technically complex than lobectomy. Three-dimensional computed tomography (3D CT) angiography is useful for understanding the pulmonary arterial and venous branching, as well as planning the surgery to secure adequate surgical margins. Comprehension of the intersegmental and intrasegmental veins makes the parenchymal dissection easier. To visualize the segmental border, creation of an inflation-deflation line by using a method of inflating the affected segment has become the standard in small-sized lung cancer surgery. Various modifications to create the segmental demarcation line have been devised to accurately perform the segmentectomy procedure.

Keywords: Segmentectomy; thoracoscopy; video-assisted thoracic surgery (VATS); three-dimensional computed tomography (3D CT); slip knot; subsegmentectomy

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Introduction

In recent years, the diagnosis of small lung nodules and non-solid lung cancers has been increasing due to developments in computed tomography (CT) technology. It is reported that the prognosis of such malignancies is good even with a sublobar resection (1-3). It is reasonable to perform a less invasive resection of a smaller volume of lung tissue, and the simple procedure of wedge resections may be sufficient if tumors are located in the peripheral sub-pleural parenchyma. However, wedge resection is inadequate for most primary lung cancers and for nodules located deep in the lung. Segmentectomy is preferred in such cases to secure an adequate surgical margin (4). In open thoracotomy surgery, a tumor is dissected bluntly by maintaining a sufficient margin while directly palpating the tumor. However, in thoracoscopic surgery, in which a hand cannot be passed directly into the thoracic cavity, it is important to proceed with the operation with a clear anatomical understanding.

Anatomical segmentectomy

In a lobectomy, demarcation of the lobar anatomy is usually relatively straightforward. In contrast, segmentectomy is more complex. In particular, the recognition of the subsegmental fissures within the pulmonary parenchyma may be difficult, with unclear boundaries between adjacent segments. In addition, when the target disease is a malignant tumor, it is necessary to secure enough surgical margin. In a thoracotomy, the tumor is dissected bluntly from the adjacent segments by maintaining a sufficient margin while directly palpating the tumor, and involved blood vessels are also treated. During thoracoscopic surgery, in which a hand cannot be passed directly into the thoracic cavity, it is important to proceed with the operation with a clear anatomical understanding.

The lung segments extend to the peripheries with the bronchus as the base. There are ten segments in the right lung (upper lobe, three; middle lobe, two; lower lobe, five) and eight segments in the left lung (upper lobe, four; lower lobe, four). Each segment has a different morphology, size and blood vessel branch, which depend on its site, and there are many variations among patients (5-7). The left upper lobe is divided into the upper and lingular divisions, while the bilateral lower lobes are generally divided into the superior and basal segment that is combined with the remaining area. As lobation is occasionally observed between these segments, the anatomy is relatively simple and easily understood. Therefore, video-assisted thoracic surgery

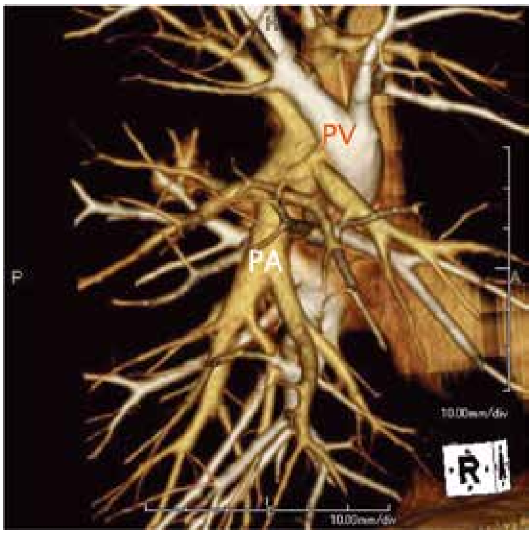

Figure 1 Three-dimensional computed tomography angiography. PA, pulmonary artery; PV, pulmonary vein.

(VATS) segmentectomy has often been performed along this plane (8,9). The problem lies with resections of other segments. It is important to plan and accurately perform the procedure (10-12). A variety of methods have been devised and used clinically, especially in thoracoscopic surgery, to solve the problem of the lack of tactile guidance (13-15).

With non-anatomical segmentectomy, the pulmonary parenchyma is roughly incised after treating the pulmonary artery and bronchus at the pulmonary hilum. However, it is not yet possible to cover resection of all segments with this method alone. The next branch of the segmental bronchus is called a subsegmental bronchus (16). Thoracoscopic resection of this subsegment has recently been performed (17). Thus, we describe herein the methods of understanding the dissection required for anatomical segmentectomy.

Understanding vascular structure

As the segmental artery is located at the pulmonary hilum in the superior segment of the lower lobe, identification and dissection are relatively easy. However, as arterial branches are embedded in the pulmonary parenchyma in some segments, it is sometimes necessary to preserve the proximal branch and divide the peripheral. Also, in many cases, more than one arterial branch is present even in a single segment. In such cases, it is useful to observe in detail and understand the morphology of the branch by employing contrast-enhanced CT, in order to carry out the surgery smoothly. A segmental artery normally accompanies the segmental bronchus. After completing division of the affected artery, the segmental bronchus can be easily traced as it is less flexible in the surrounding tissues.

With rapid advances in multi-detector CT (MDCT) in recent years, it has become possible to easily perform three-dimensional (3D) processing not only in a workstation but also on a personal computer (*Figure 1*). By using MDCT, we understand each patient's individual anatomy and can perform operations mainly by defining the course of arteries and veins (13-15). Usually, radiologists or technicians construct the 3D image using a workstation. The arteries and the veins are separately segmented and color-coded by CT value, and these volume-rendered images are then merged into the 3D-CT angiography. This image is ideal but it takes a long time to create. Thoracic surgeons know the basic anatomy of the lung, and therefore don't need complex images. When we use volume rendering methods, we prepare simple images that meet our needs in as little time as approximately seven minutes (http://www.youtube.com/watch?v=tSO58k9Lja8). By cutting out the area of interest, the image can be magnified, de-magnified or rotated during surgery (*Figure 2*). We previously reported that port-access thoracoscopic segmentectomy could be safely be performed in all segments using this approach, termed Segmentectomy Achieved by MDCT for Use in Respective Anatomical Interpretation (SAMURAI) (15). Since 2004, we have performed thoracoscopic segmentectomy in 160 patients including subsegmentectomy in 20 patients, and our completion rate is 98%. The surgical results for small lung cancer are still insufficient, with a mean follow-up period of only 3.5 years as yet. However, the 5-year survival rate is 100%, which is very favorable.

The venous branches within the segment become intersegmental veins as they converge, and return to the hilum. In segmentectomy, it is very important to understand these intersegmental and intra-segmental veins (*Figure 3*). The pulmonary parenchyma is dissected along the intersegmental vein, and intrasegmental vein thereby is identified. Division of the intrasegmental veins allows identification of the intersegmental border and facilitates the further parenchymal dissection (14,15). It is as if a clam can be opened when the adductor is cut.

Surgical margin

The SAMURAI method not only defines the running of

Figure 2 S1+2a (apical subsegment in left apical posterior segment) resection of the left upper lobe. (A) Three-dimensional computed tomography angiography with a marking of the tumor indicates two subsegmental arterial branches should be divided from the left apical posterior segmental artery. White arrow, first branch of the subsegment; Black arrow, second branch of the subsegment; (B) Operative view of the patient. The white arrow indicates the first arterial branch; (C) Operative view of the patient. The white arrow indicates the stump of the first arterial branch. The black arrow indicates the second arterial branch that was encircled in the deep parenchyma.

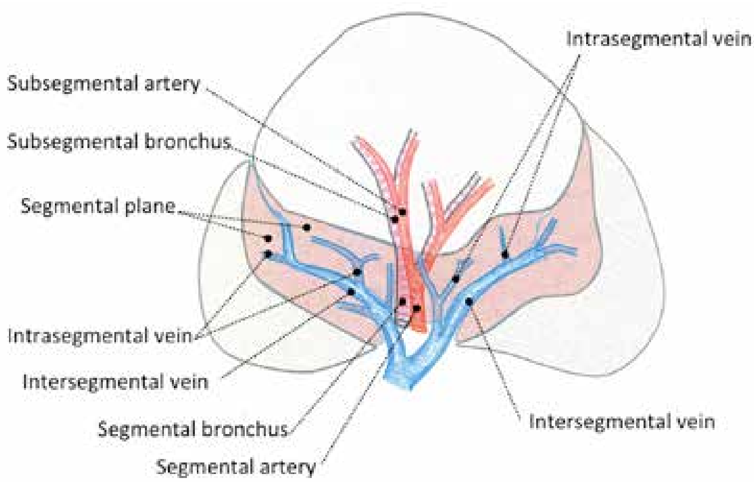

Figure 3 Schema of lung segmentectomy. The intersegmental plane is dissected preserving the intersegmental veins. Intrasegmental veins of the affected segment should be identified and divided.

blood vessels but also determines the extent of resection by virtually defining surgical margins. If it is difficult to preserve the margin in a single segment resection, we perform an extended resection of the parenchyma of adjacent segments.

Iwano and colleagues reported that radiologists propose the extent of resection to surgeons by superimposing a spherical safety margin on 3D images using a workstation for CT (18). While this method is ideal, preparing the images can be complex and time-consuming for surgeons. Although the SAMURAI method cannot create a perfect sphere in images, the surgeons themselves can evaluate resection margins intraoperatively using an appropriate scale in real time (15).

Identification of the intersegmental border

Inflation-deflation line

The basis of segmentectomy is to isolate and divide the bronchus and then dissect its peripheral pulmonary parenchyma. For conventional segmentectomy in open thoracotomy, division at the intersegmental border was generally performed by dissecting the bronchus in the affected lung and collapsing the lung on the peripheral side.

Figure 4 Inflation-deflation line created by slip knot method.

In lung cancer patients, the actual method involved securing a margin by directly palpating the tumor. Meanwhile, Tsubota reported a method of inflating the affected segment to be beneficial (19). Moreover, Okada and colleagues visualized the intersegmental plane by selectively inflating the segment using a jet ventilator and reported this approach to be effective in securing an operative field. Expansion of the affected segment allows not only visualization of intersegmental borders but also maintains the morphology and size of the resected lung in the same state as the actual systemic physiological state, thereby achieving more accurate evaluation of resection margins (11). Therefore, it is considered to be more advantageous oncologically and is becoming a standard method in Japan.

Thus, jet ventilation is useful as an inflation method for the affected segment in thoracoscopic surgery or small thoracotomy. However, this method requires equipment and another doctor to maneuver the bronchoscope. Some institutions experienced such difficulties and various modifications have been devised. Direct inflation into the bronchus using a butterfly needle from the operative field was reported to be useful (20). However, great care is essential as this approach can reportedly cause air embolism (21).

We were not able to effectively insert the bronchoscope into the smaller bronchi during resection at the subsegmental (third order) bronchial branches (16). Therefore, we attempted to block the bronchus by ligation with expansion of the affected segment, especially in segmentectomy of smaller bronchial calibers. We ligated a bronchus conventionally using a knot pusher after ventilation when the bronchus was narrow. However, this method cannot be performed quickly after inflation; therefore, the affected segment will be partly deflated. We found that the monofilament slip-knot, customized from the previously reported modified Roeder knot, was useful since it enabled the surgeon to ligate the bronchus during ventilation of the lung. The bronchus is closed by pulling the thread (http://www.youtube.com/watch?v=XH2jt7kL3mo), and was effective for creating the inflation—deflation line (*Figure 4*) (22). We believe that this method can be generalized because it doesn't need any special equipment and is applicable at any time.

Intersegmental veins

As described earlier, intersegmental pulmonary veins serve as important landmarks (15). The dissection of their branches, the intrasegmental pulmonary veins, facilitates intersegmental dissection. When it is difficult to reach the segmental artery and bronchus located in the deep areas of the pulmonary parenchyma, we can reach the target bronchus by dissecting the parenchyma along the intersegmental pulmonary vein. For example, in segmentectomy of S9+10 or S10 of the lower lobe, the bronchus is located in a very deep area far from the interlobar area. We have devised a posterior approach to dissecting the pulmonary parenchyma along the vein (V6) between the superior and the basal segment, initially, thereby reaching the bronchus posteriorly (http://www.youtube.com/watch?v=V2Rq92JB6vk) (23). Once the bronchus is reached, a line between the inflated and deflated areas is created using the aforementioned method. This facilitates dissection of S9 and S10, formerly classified as the most difficult segments, and reduces the operative time. As such, visualization of the line between the inflated and deflated areas and the intersegmental vein dissection are both important in performing intersegmental dissection.

Other techniques

There is a report describing a fluorescence method, wherein indocyanine green is injected into a blood vessel after treating the target segmental artery (24,25). It is based on the premise that the segmental bronchus is accompanied by the pulmonary artery. As the running vessels do not match in some cases, it is necessary to read CT images in detail to identify the pulmonary artery to ultimately be treated. A method of injecting dyes into the bronchus has also been reported (26). While this direct method is promising, it requires an additional procedure of injecting materials via bronchoscopy. Although both

Figure 5 A solid model of pulmonary arteries and veins of right upper and middle lobe molded from computed tomography data using three-dimensional (3D) printer.

methods require special instruments and procedures, we anticipate that there will be further reports describing their general use in the future.

Future simulation: virtual to real

Computer technology is rapidly advancing. We are now able to visualize the surfaces of pulmonary blood vessels, output the dendritic structure as an STL file, and create a 3-dimensional solid model using a 3D printer. After sterilization, this device can be hand held and observed during surgery (*Figure 5*). As 3D printer equipment and consumable supplies are expensive, there is an issue of cost in creating the model. While it still cannot be regarded as an item for actual use as compared with virtual technology, there is potential for this approach to become a useful tool if the manufacturing cost can be brought down in the future.

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VATS segmentectomy for pulmonary metastasis

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Clinical vignette

We present a case of a 55-year-old man with solitary colorectal pulmonary metastasis (*Video 1*). He is an ex-smoker with near normal lung function, however positron emission tomography (PET) and computed tomography (CT) scans revealed a 2 cm glucose-avid metastasis, located in the lingular segment of the left lung. Informed consent was obtained for video-assisted thoracoscopic surgery (VATS) segmentectomy using the Edinburgh approach. The procedure provides anatomical resection and individual division of the segmental artery, bronchus and vein, as well as superior clearance of local-regional lymph nodes.

Surgical techniques

A 3 cm utility port incision is made in the seventh intercostal space in the anterior axillary line. A 1 cm posterior camera port is inserted in the auscultatory triangle to accommodate the camera. A third 1 cm access incision is made in the eighth intercostal space along the posterior axillary line.

The first step is to identify the pulmonary artery in the oblique fissure. In some patients the artery is immediately visible, but in the majority of cases, it is revealed by separating the overlying lung tissue using a kissing 'Peanut' technique. If the fissure is incomplete, a fissure-last approach should be considered.

The anterior aspect of the oblique fissure is divided by using a purple Covidien Tristapler. With the Edinburgh approach, the tip of the instrument is clearly visualized at all times. This will greatly improve the safety of the procedure. After dividing the fissure, which "opens like a book", the lingular artery is now clearly exposed, which is then skeletonised and divided with a 45 mm Tristapler. The left upper lobe is retracted upwards to expose the station 11 lymph node packet, adherent to the lingular bronchus. The lingular bronchus is delineated both anteriorly and posteriorly using blunt dissection. A purple 45 Tristapler was then used to divide the lingular bronchus.

The left lung is retracted posteriorly to expose the anterior hilum, especially the confluence between the lingular and upper trisegmental veins. A blunt dissector can be used to separate these structures, followed by Tristapler division of the lingular vein. Finally, 3 purple Tristaplers were used to separate the lingular segment from the upper trisegment by passing the staplers through the anterior access incision. The specimen is carefully removed from the thoracic cavity in a retrieval bag to avoid contamination of the wounds with cancer cells.

Comments

VATS is now well established as an alternative to open thoracotomy for major resections of lung cancer and benign disease. Compared to open surgery, the minimally invasive approach has a number of benefits in the immediate post-operative period that include reduced pain, better lung function, shorter hospital stay, improved cosmesis and lower risk of developing chest infection (1). VATS lobectomy is equivalent to open surgery in terms of long-term outcomes, is less invasive and enables more patients to commence and complete postoperative chemotherapy if required. Furthermore, minimally invasive techniques are cost effective and better tolerated by our patients.

We have adopted the Edinburgh posterior approach to minimally invasive lung resection (VATS) as the surgical strategy of choice for all cases of peripheral lung cancer of 7 cm or less in diameter and for suitable benign disease. This criterion is decided according to the 'VATS Lobectomy Consensus Statement' by 50 minimally invasive thoracic surgeons worldwide (2). VATS techniques may also be used in patients with advanced disease such as moderate or central chest wall involvement and pneumonectomy for low bulk central involvement. However given the trend towards lung conservation strategies, pneumonectomy is now only considered for cases where bronchovascular reconstruction is not feasible.

In our experience, the main advantage of the Edinburgh approach is the excellent visualization of the posterior hilum, which facilitates dissection of the airways and branches of the major pulmonary artery. In the Edinburgh approach, the tips of the instruments come towards the operating surgeon and are therefore easily seen whilst in use, increasing the safety of dissection (3). More importantly, the lymph node packets are clearly seen, allowing thorough lymphadenectomy.

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Port-access thoracoscopic anatomical right anterior segmentectomy

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Contributions: (I) Conception and design: H Oizumi; (II) Administrative support: H Kato, M Sadahiro; (III) Provision of study materials or patients: H Oizumi, H Kato, M Endoh, J Suzuki, H Watarai, K Suzuki; (IV) Collection and assembly of data: H Oizumi, H Kato, M Endoh; (V) Data analysis and interpretation: H Oizumi; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

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Background: Thoracoscopic lung segmentectomy is a complicated and thus controversial procedure. The term "segment" comprises several genres. Each segment or subsegment is defined anatomically as the lung area for ventilation of the bronchial branches. Human lungs consist of 18 segments as well as block segments such as lingular or basal segments. Therefore, thoracoscopic lung segmentectomy includes various types of procedures.

Methods: We developed pulmonary segmentectomy method under three-dimensional multidetector computed tomography simulation and so far performed 248 port access thoracoscopic anatomic lung segmentectomies. Also we developed a slip-knot technique for creating the inflation-deflation line to delineate the intersegmental plane and used this method as standard since 2010. The intersegmental plane was identified using the intersegmental veins as landmarks and the demarcation between the resected (inflated) and preserved (collapsed) lungs.

Results: The success rate of segmentectomy performed under complete thoracoscopy was 99%. Minithoracotomy was required for two patients because of arterial bleeding. The chest tubes were left in place for 1-8 d (median duration, 1 d). There were no recurrences of the primary tumor in the curative-intent resection group patients for lung cancer treatment.

Conclusions: Thoracoscopic lung segmentectomy achieved by multidetector computed tomography for use in respective anatomical interpretation enabled precise parenchymal dissection. Our slip-knot technique facilitated the creation of inflation-deflation line under thoracoscopic surgery and shortened the surgical time consequently. Herein, we present the representative case of an 84-year-old man who underwent port-access anatomical resection of the anterior segment of right upper lobe (S3). In this patient, we used a vessel sealing system for cutting the vessels and dissecting the parenchyma.

Keywords: Thoracoscopy; segmentectomy; sublobar resection; lung

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Introduction

Segmentectomy is increasingly being used for the treatment of small-sized lung cancers. However, segmentectomy using a thoracoscopic approach is controversial as this procedure is complicated and it is difficult to secure adequate working space (1). Using intraoperative three-dimensional contrast-enhanced computed tomography simulation (2), slip knot method for creating the inflation-deflation line (3), and a vessel sealing system to cut the vessels and dissect the parenchyma can make this complicated surgery easier

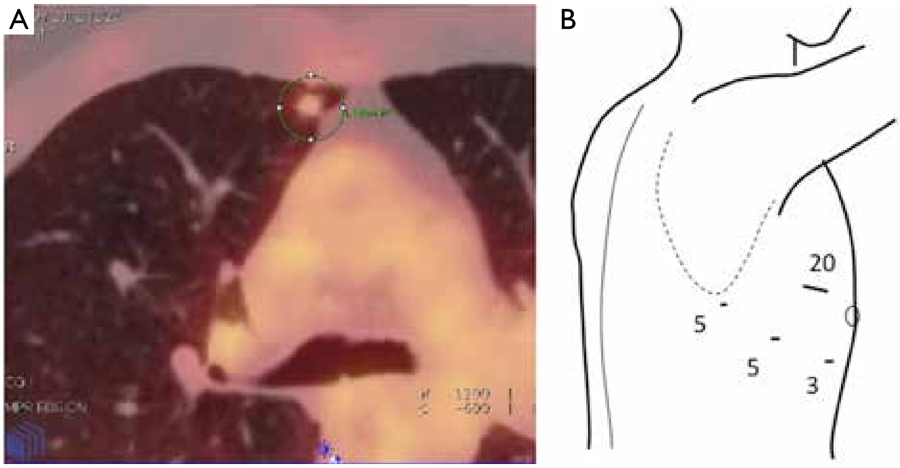

Figure 1 (A) Finding of FDG-PET scan; (B) schema of trocar placement. Custom-made soft trocar is used at the 20-mm port. Other trocars are less than 5-mm to avoid the excessive burden of intercostal nerves. FDG-PET, fluorodeoxyglucose positron emission tomography.

to perform and practically applicable. Herein we report the use of this method for thoracoscopic segment 3 (S3) segmentectomy in a patient with stage IA non-small cell lung cancer (NSCLC).

Case presentation

An 84-year-old woman who was diagnosed with a lung tumor was admitted to our hospital. Chest computed tomography showed a 7-mm-diameter pulmonary nodule in S3 of the right upper lobe; which showed accumulation of fluorodeoxyglucose (FDG) in the positron emission tomography (PET) scan (*Figure 1A*).

Generally, the procedure is performed under general anesthesia with differential ventilation. Patients are positioned in left lateral decubitus. After single lung ventilation has been initiated, four trocars are inserted. The surgeon stands facing the patient as the video perspective is more natural from the front and the intercostal space is wider than the posterior intercostal space. In our patient, two 5-mm trocars were placed in the 5th intercostal space at the posterior and middle axillary line; a 3-mm trocar was placed in the 5th intercostal space at the anterior axillary line; and a 20-mm soft trocar was placed in the 3rd intercostal space at the anterior axillary line. A 5-mm 30-degree scope was used (*Figure 1B*).

Using three-dimensional volume rendering, a solid image was constructed from 1-mm data slices of the contrast-enhanced computed tomographic images. The three-dimensional rendered image angiography was focused just within the upper lobe and was magnified, rotated, and set as the surgeon's view in the operation room (*Figures 2,3*).

First, the root of the upper pulmonary vein was exposed and the intersegmental vein (V3b) was isolated. The intersegmental vein (V1b) between S1 and S3 was identified and the parenchyma was dissected along the intersubsegmental vein. The key to this procedure is to release the vascular sheath using forceps and dissect the parenchyma using a sealing device. The anterior pulmonary artery (PA) (A3) was identified and dissected beside the V1b. After opening the fissure, the posterior vein (V2) was exposed and the intersegmental vein (V3b) was encircled. The anterior PA (A3) was ligated using 2-0 silk. The key to this procedure is to divide this artery proximal to the V1b that enables the adequate dissection of the bronchus. The V3b was clipped and divided using a sealing device. The parenchyma was again dissected along the intersegmental vein (V1b) and the subsegmental arterial branches (A3a, A3b) of the A3 were divided using the vessel-sealing device. The lymph nodes of the hilum (#12u) were dissected and the frozen section revealed no signs of metastasis.

The branch of the posterior vein (V2) was exposed and the intersegmental vein between S2 and S3 (V2c) was identified. The parenchyma was dissected along the proximal V2c. Such dissection and isolation of the veins as well as the arteries facilitates the best anatomical exposure of the bronchus.

The anterior bronchus (B3) was then encircled using a monofilament polypropylene thread, and a modified Roeder knot was created extracorporeally. Both lungs were inflated

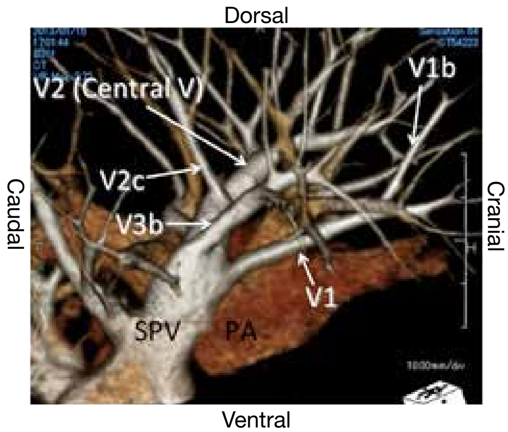

Figure 2 Three-dimensional computed tomographic angiography image of the right upper lobe of the lung. The complicated anatomy of the pulmonary vessels is precisely depicted. In this image, the intersegmental veins between can be easily seen. V#, indicates the corresponding segmental/subsegmental vein. PA, pulmonary artery; SPV, superior pulmonary vein.

Figure 3 Set up of three-dimensional computed tomography angiography image (4). The three-dimensional rendered image angiography of the upper lobe was rotated, and set as the surgeon's view. Available online: http://www.asvide.com/articles/710

and the slip knot was pulled to ligate the bronchus with full expansion of the lung. The right lung was again collapsed and the B3 was stapled and divided using an endoscopic stapler (3). Thereafter, the S3 remained inflated while the other segments collapsed. The intersegmental plane of the parenchyma was divided by electrocautery or by using sealing device as described previously. After parenchymal dissection in the hilum, even the main branch of V2 (so called central vein) besides V1b or V2c became apparent. Finally, the peripheral lung parenchyma was divided using

Figure 4 Port-access thoracoscopic anatomical segmentectomy procedure (S3) (5).
Available online: http://www.asvide.com/articles/711

staplers and the S3 was removed using a retrieval bag. Fibrin glue was sprayed to the intersegmental plane (*Figure 4*).

The operative time was 145 min, and blood loss was 80 mL. The chest drainage tube was removed on postoperative day 1.

Discussion

The number of reports of anatomical segmentectomy or subsegmentectomy is increasing owing to the growing number of patients diagnosed with peripheral smaller NSCLCs, such as ground glass opacity nodules (1,6). However, reports of these procedures performed using a thoracoscopic approach are limited (1,2,7). Majority of the resected segments are related to the easier and larger segments such as lingular segment, superior segments of bilateral lower lobe, left upper division, or bilateral basilar segments.

We introduced three-dimensional computed tomography simulation to comprehend the precise anatomy of the complicated vessels and the bronchi. This enabled us to resect even the most difficult segments such as the posterior basal segment of the lower lobe by using electrical devices and staplers (2). Moreover, the slip knot method made it possible to resect the smaller subsegments with sufficient surgical margin (3). S3 is classified as a fairly difficult to resection via the total thoracoscopic approach. A considerable number of knacks or tips exist that may help perform anatomical thoracoscopic segmentectomies precisely.

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Uniportal video-assisted thoracoscopic anatomic segmentectomy

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Introduction

Anatomic segmentectomy was first described in 1939 for the treatment of benign lung conditions (1). The usual indications also include metastatic disease to the lung when ta parenchyma-sparing procedure is anticipated Nevertheless, anatomic pulmonary segmentectomy has been demonstrated to be effective in the resection of small primary lung cancers (2,3). Recently there has been a renewed interest in the use of anatomic segmentectomy, especially for patients unable to tolerate lobectomy because of poor cardiopulmonary function or severe comorbidities. Several recently published studies have shown that segmentectomy can be performed safely without compromising oncologic results (3-6).

Surgical technique

Single port VATS segmentectomy follows the principles of major pulmonary resections by VATS: individual dissection of segmental veins, segmental arteries and lobar segmental bronchus with a no rib spreading, video-assisted thoracoscopic approach. Radical mediastinal lymphadenectomy should complete the procedure (7).

The size of the utility incision is comparable to those commonly used for double-or triple-port approaches (8) and it is usually smaller than for a lobectomy, about 3-cm long. The incision is usually placed at the level of the 5th intercostal space (*Figure 1*) to get good access to upper hilar structures and lymph node stations. Adequate exposure of the lung is mandatory for successfully completion of the segmentectomy. The surgeon and the assistant must be positioned in front of the patient in order to have the some thoracoscopic vision during all these steps of the procedure and be more coordinated with the movements (*Figure 2*). Instruments must preferably be long and curved to allow the insertion of 3-4 instruments simultaneously (*Figure 3*). Optimal exposure of the lung is key to facilitate the dissection of the segmental structures and to avoid instrument interference. The HD 30° thoracoscope (the videolaparoscope with the distally mounted CCD design helps the instrumentation) is usually inserted in the posterior part of the incision and the instruments are placed below the camera. Bimanual instrumentation is crucial to achieve a successful segmental resection through a single incision VATS (*Video 1*). A single chest tube is inserted through the same incision at the end of the procedure (*Figure 4*).

Different types of segmentectomies can be performed according the segment to be resected:

- ❖ RUL
  - Posterior segment
  - Apical segment
  - Anterior segment
  - Apico-posterior segmentectomy
- ❖ LUL
  - Lingulectomy
  - Apical trisegmentectomy (Lingula sparing)
- ❖ LLL/RLL
  - Superior segmentectomy
  - Composite basilar segmentectomy
  - Individual segments (7-8-9-10)
- ❖ RML
  - Medial
  - Lateral

Figure 1 Incision for uniportal VATS segmentectomy.

Figure 2 Surgeons positioned in front of the patient watching the same monitor. The scrub nurse is located on the opposite side.

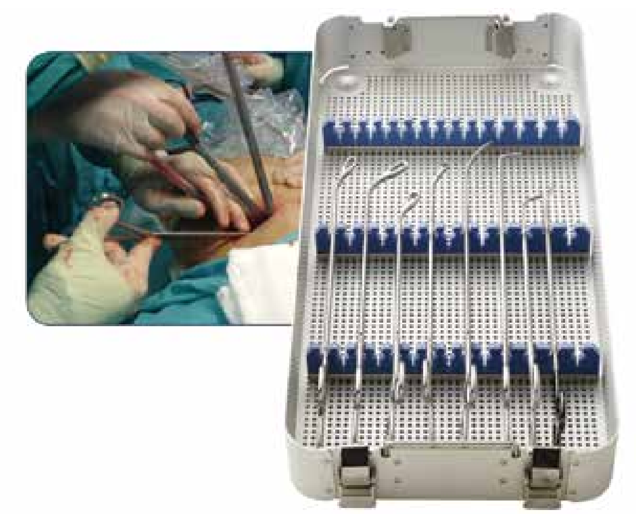

Figure 3 Uniportal of specific adapted instruments (proximal and distal articulation).

Video 1 Bimanual Instrumentation during uniportal VATS segmentectomy.

Available online: http://www.asvide.com/articles/543

Figure 4 Single-chest tube placed in the posterior part of the incision.

The most frequent anatomic segmental resection is the superior lingulectomy and the superior segment of lower lobe (S6).

Left upper lobe (LUL)

A-lingulectomy (Video 2-using staplers. Video 3-using vascular clips)

The lingula is retracted laterally and posteriorly and the pleura overlying lingular vein (LV) is incised. The identification of LV and lower lobe vein (LLV) indicates the location to place the stapler to divide the anterior portion of major fissure (the anvil of the stapler is placed

Video 2 Lingulectomy by using endostaplers.
Available online: http://www.asvide.com/articles/544

Video 3 Lingulectomy by using vascular clips (Click aV).
Available online: http://www.asvide.com/articles/545

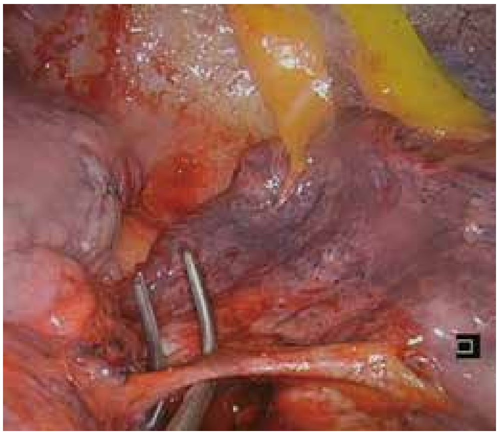

Figure 5 Dissection of lingular artery exposed in the fissure.

Video 4 Lef upper anatomic trisegmentectomy.
Available online: http://www.asvide.com/articles/546

between the LLV and LV, and we pull the parenchyma into the jaws of the stapler). This maneuver facilitates the dissection and insertion of stapler to transect the vein (*Video 2*). In some cases there is no angle for stapler insertion, then we use vascular clips, like click aV (Grena®) (*Video 3*). Other option is to tie off the LV (the short distance from the incision facilitates this maneuver). Once the vein is divided, the lingular bronchus is exposed, dissected and stapled. When there is no angle for stapler we can transect bronchus by using scissors and close the stump at the end of the procedure by using a stapler (*Video 3*).

A ring forceps is then placed holding the lingula for traction, exposing the lingular artery which is then divided. Finally the intersegmental plane is divided (*Videos 2,3*). When the fissure is open, and the artery is visualized in the fissure, the dissection of the lingular artery can be performed from the fissure making easy the procedure (*Figure 5*).

B-apical trisegmentectomy (Lingula-sparing left upper lobectomy)-Video 4

The anterior and apical arterial segmental branches are approached anteriorly, dissected and ligated by using stapler or vascular clips. The upper division of pulmonary vein is dissected and divided (anterior, apical and posterior veins) (*Video 5*). The posterior artery is usually visualized after vein division and is divided by using vascular clips (we can use clips for proximal control and energy sealant devices for distal division) (*Figure 6*). The trisegmental bronchus

Video 5 Dissection of upper lobe vein for anterior, apical and posterior segment.
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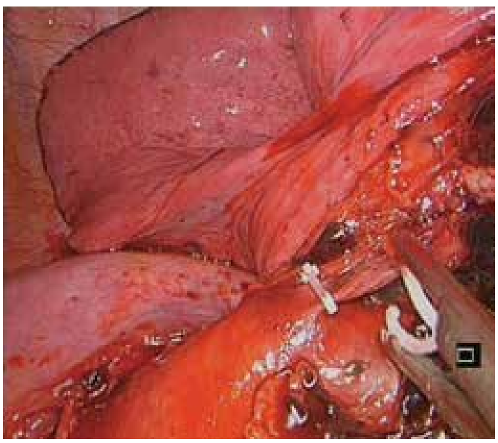

Figure 6 Division of posterior ascending artery during left upper lobe trisegmentectomy by using vascular clips.

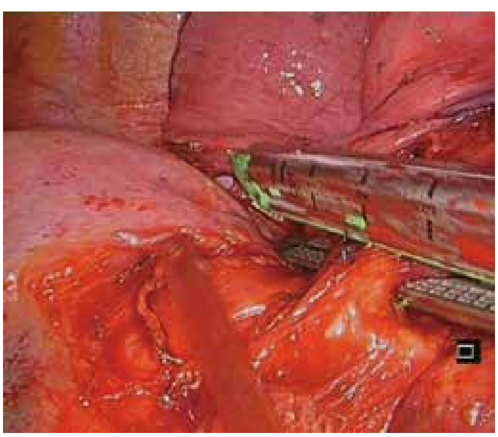

Figure 7 Division of segmental bronchus during left upper trisegmentectomy.

Figure 8 Division of segmental artery during right lower lobe superior segmentectomy.

is easily visualized after ligation of the segmental vein and arteries. Care must be taken during this dissection to avoid injury of lingular artery. After the bronchus is stapled (*Figure 7*) and divided the parenchymal resection is then completed through the segmental plane by using staplers (*Video 4*).

Lower lobe (LLL-RLL)

A-superior segment lower lobe-Video 6

The resection of the superior segment (S6) of lower lobe is easy because of the constant anatomical landmarks. The segmentectomy is done differently depending whether the fissure is complete or not. If fissure is complete we try to expose the superior segment artery in the fissure. To staple the artery we use a vascular clip (click aV, Grena®) or an endostapler (*Figure 8*) (7).

With a long ring forceps we retract the lower lobe and cut the pulmonary ligament to find the segmental vein (V6) for dissection and division by using a clip or a stapler. We dissect and expose the superior segmental bronchus and we staple it in the same way as mentioned for the vein (*Figure 9*). The last step is to divide the intersegmental plane (*Figure 10*) and remove the segment in to a protective bag (*Video 6*).

Regarding segmentectomies with incomplete fissure or with no visible artery the procedure must be different. The preferred method does not involve dissection within the fissure in order to minimize postoperative air leaks. The resection must be performed from bottom to top, leaving the fissure stapling as the last step (fissureless technique). After cranial retraction of the lobe, the sequence of the dissection should be: inferior pulmonary ligament;

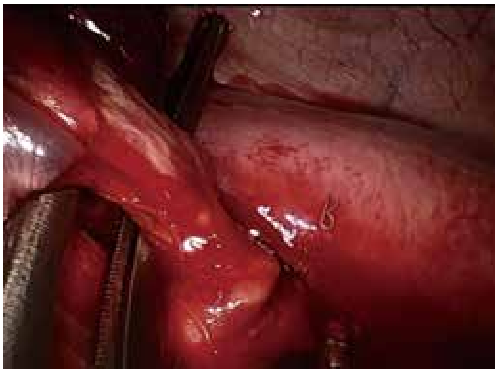

Figure 9 Division of segmental bronchus during left lower lobe superior segmentectomy.

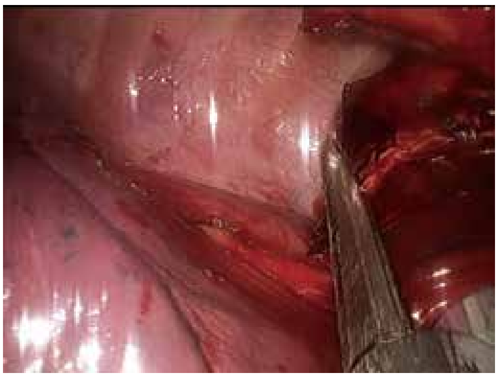

Figure 10 Intersegmental plane stapler division during left lower lobe superior segmentectomy.

Video 6 Superior segmentectomy left lower lobe (S6).
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Figure 11 Division of basilar artery during right lower lobe basilar segmentectomy (artery exposed in the fissure).

segmental vein; segmental bronchus, segmental artery and intersegmental plane. Once the segmental bronchus is stapled, the inflation of the lobe delimits the intersegmental plane.

B-basilar segmentectomy

Removal of 4 segments in the right lower lobe (S7-S8-S9-S10) or 3 segments in the left lower lobe (S7-S8-S9) sparing the apical segment (S6) is called basilar segmentectomy. These segments are usually removed together since they depend from a single bronchus.

When the fissure is open the procedure is easy, and the basilar artery can be easily dissected in the fissure (*Figure 11*), and divided. After division of the basilar segmental vein (*Video* 7), the basilar segmental bronchus (the most difficult part of the operation) is dissected and stapled. The intersegmental plane is completed last.

When performed stepwise in a caudo-cranial fashion, extra care must be taken to correctly identify the segmental structures. Once the inferior segmental vein has been divided, the lower lobe basilar segmental bronchus is exposed, dissected and divided from its inferior aspect to its bifurcation with the middle lobe bronchus on the right side or the upper lobe bronchus on the left side. Dissection of the bronchus with development of the plane between the bronchus and artery is performed with visualization of the artery. We recommend the removal of the interbronchial lymph nodes to better define the landmarks. The basilar

Video 7 Division of segmental vein and basilar artery during right lower lobe basilar segmentectomy.
Available online: http://www.asvide.com/articles/549

Video 8 Right upper lobe apical antomic segmentectomy.
Available online: http://www.asvide.com/articles/550

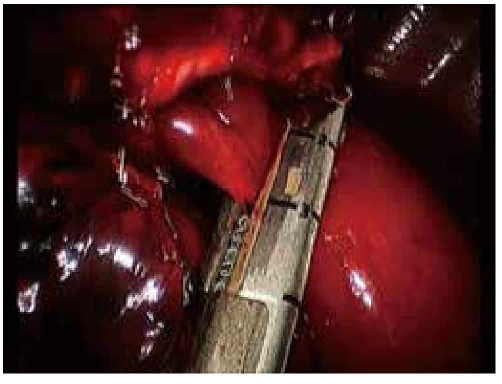

Figure 12 Division of basilar artery during left lower lobe basilar segmentectomy from down to up (fissureless technique).

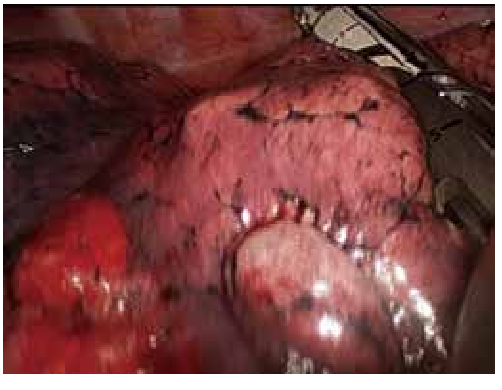

Figure 13 Division of intersegmental plane during left lower lobe basilar segmentectomy.

segmental arterial branch to the lower lobe is identified (*Figure 12*) and divided and the intersegmental plane is stapled (*Figure 13*).

Other more complex segmentectomies

The anatomic resection of a single segment like the anterior, posterior or apical segment of RUL (*Video 8*) (*Figure 14*), medial or lateral segment of RML and 7, 8 or 9 segment of lower lobe (*Figure 15*) is a complex procedure. The difficulty of thoracoscopic anatomic resection of a single segment is mainly based on the division of the segmental plane and the individual dissection of single segmental structures.

While the bronchial anatomy is very consistent, the arterial anatomy is variable. We always have to keep in mind that venous anatomy can drain multiple segments. It is very important to define the intersegmental plane. The ventilation of the lung delimitate the segmental plane once the segmental bronchus has been divided. To avoid collateral ventilation some authors have suggested following a reverse inflation-deflation technique, stapling the segmental bronchus once the whole lung is ventilated in order for the inflated segment to remain readily visible after deflation (6).

Discussion

Uniportal VATS segmentectomies are usually more difficult

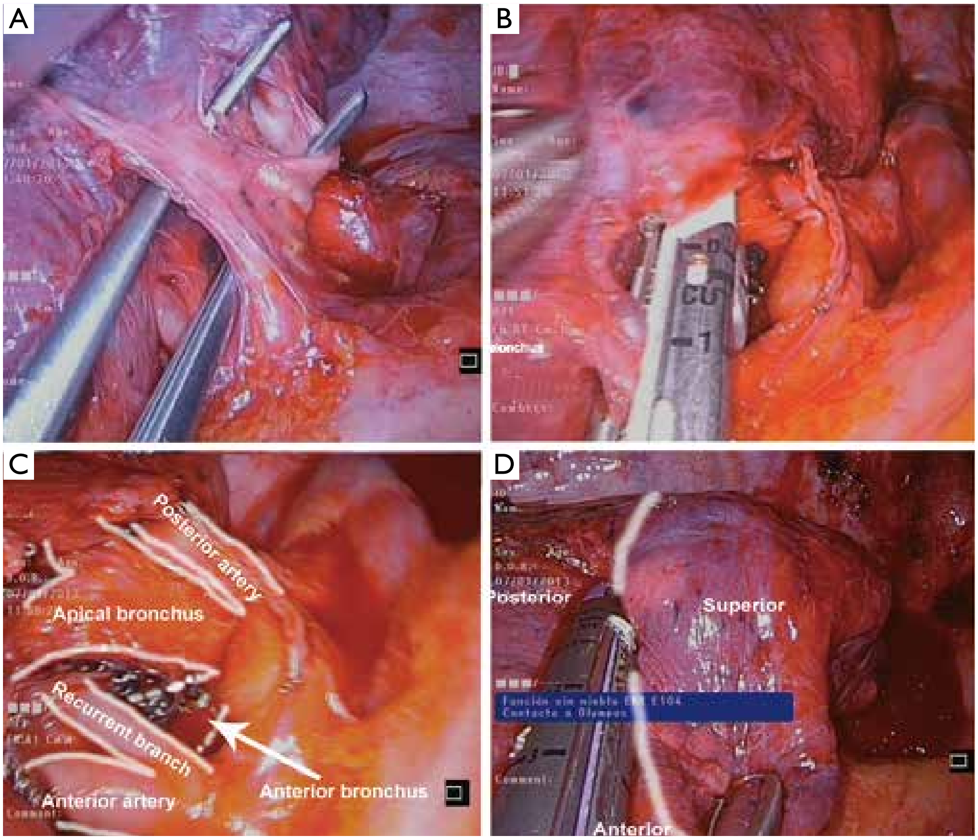

Figure 14 Right upper lobe apical segmentectomy. A. Apical artery; B. Apical vein; C. Apical bronchus; D. Intersegmental plane.

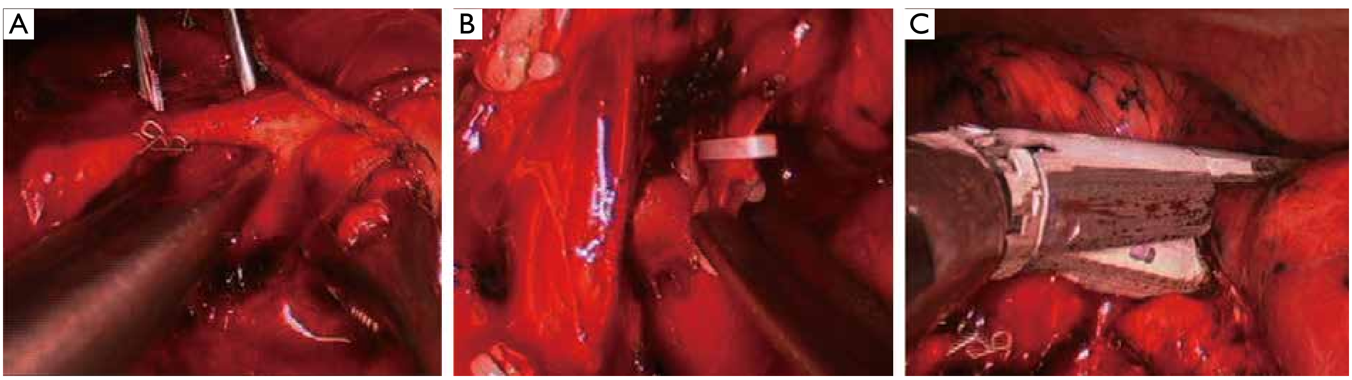

Figure 15 Segmentectomy of 7, 8 basal segments left lower lobe. A. Segmental artery; B. Segmental vein; C. Intersegmental plane.

than lobectomies. Most of reported segmentectomies are related to segments that can be easily excised, such as the lingular, superior, and basilar segments (1-3). In these segments the parenchyma can be separated by using staplers. To remove other segments via uniportal VATS, the procedure is more difficult but feasible. The preoperative evaluation of branches of pulmonary veins (8) or trans-bronchial indocyanine green injection and the use of infrared thoracoscope helps the intersegmental plane identification of complex segmentectomies (7). Since June 2010 we have performed 17 uniportal VATS anatomic segmentectomies. Lingulectomy for lung metastasis was the most frequent operation. The mean surgical time was 94.5±35 minutes (40-150 minutes). The mean number of nodal stations explored was 4.1±1 (range, 0-5) with a mean of 9.6±1.8 (range, 7-12) lymph node resections. The median tumor size was 2.3±1 cm (range, 1-4 cm).The median chest tube duration was 1.5 days (range, 1-4 days) and the median length of stay was 2 days (range, 1-6 days).

In our experience, there was no conversion of uniportal segmentectomy to conventional VATS or open and this outcome is a direct consequence of greater skills acquired with experience (9).

Compared to segmentectomy by thoracotomy, uniportal thoracoscopic segmentectomy was associated with a shorter length of stay and with equivalent morbidity and mortality (10). The procedure has some difficulties: it is technically demanding and more challenging than lobectomy, requiring a perfect knowledge of the bronchial and arterial relationships and possible anomalies of arterial branches. Once bronchovascular structures have been divided, the division of the intersegmental plane is the most difficult step.

The advantage of using the camera in coordination with the instruments is that the vision is directed to the target tissue, bringing the instruments to address the target lesion from a sagital perspective, thus we can obtain similar angle of view as for open surgery (11). Instruments inserted parallel to videothoracoscope mimic inside the chest maneuvers performed during open surgery.

Another potential advantage of this approach could be a reduction in post-operative pain. There could be several explanations for this issue: only one intercostal space is involved and avoiding the use of a trocar could minimize the risk of intercostal nerve injury (during instrumentation, we try to apply the force over the superior aspect of the inferior rib through the utility incision). We have observed that patients operated by conventional VATS sometimes refer their pain towards the posterior and inferior incision, and only a few times refer pain in the utility incision. We strongly believe that this pain could be explained by trocar compression over the intercostal nerve during camera movement. Some authors have reported less postoperative pain in patients operated on for pneumothorax through a single-incision, in comparison to the classical triple-port approach (12). Further studies will be required to demonstrate that there is less pain with single incision techniques, compared to conventional VATS for segmentectomy.

Conclusions

Single-port VATS segmentectomy is a feasible and safe procedure in experienced VATS centers. The uniportal thoracoscopic segmental resection should be performed by skilled VATS surgeons and is a good option for small primary tumors, metastasic lesions or benign conditions not suitable to be performed by wedge resection.

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None.

Footnote

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

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Single incision video-assisted thoracoscopic anatomic segmentectomy

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Introduction

Anatomic segmentectomy was first described in 1939 by Churchill and Belsey (1). Although segmentectomy is usually indicated for benign lesions or for metastasis when the goal is resecting the lesion while sparing parenchyma, anatomic segmentectomy has also been demonstrated to be effective in the resection of small lung cancers (2). Recently, due to the increasing incidence of small lung tumors, there has been renewed interest in the use of anatomic segmentectomy, especially for patients unable to tolerate lobectomy. Several recently published studies have shown that segmentectomy can be performed safely without compromising oncologic results (3,4). Video-assisted thoracoscopic surgery (VATS) is currently a better choice than thoracotomy for segmentectomy. Although most surgeons use three to four incisions, the surgery can also be performed using only one (5).

Surgical technique

Single-incision VATS segmentectomy follows the principles of major pulmonary resections by VATS: individual dissection of segmental veins, segmental arteries and the segmental bronchus, as well as complete mediastinal lymphadenectomy with a video-assisted thoracoscopic approach and no rib spreading.

The size of the incision is comparable to the utility incision commonly used in a double- or triple-port approach and is usually smaller than that for a lobectomy, approximately 3 cm long (6). The incision is usually made at the level of the 5th intercostal space to provide access to upper hilar structures and lymph node stations. Both the surgeon and assistant are positioned anteriorly to the patient in order to have the same thoracoscopic vision during all the steps of the procedure and be more coordinated with the movements. Instruments with a proximal and distal articulation are preferable as they reproduce the same experience as a conventional instrument but also allow the insertion and manipulation of three to four instruments simultaneously (Scanlan International, Inc., MN, United States).

Optimal exposure of the lung is crucial for facilitating the dissection of the segmental structures and to avoid instrument malposition. The 30° high-definition thoracoscope is usually placed in the posterior part of the incision and the instruments are placed below the camera. Bimanual instrumentation is crucial to achieve a successful segmental resection through a single port VATS. A single chest tube is placed at the end of the procedure through the same working incision.

In this video we show seven different anatomic segmentectomies performed through a single incision thoracoscopic approach, including: (I) Right upper lobe apico-posterior segmentectomy (S1-S2); (II) Right upper lobe apical segmentectomy (S1); (III) Left upper lobe trisegmentectomy (S1-S2-S3); (IV) Left lower lobe superior segmentectomy (S6); (V) Right lower lobe basilar segmentectomy (S7-S8-S9-S10); (VI) Anatomic lingulectomy using vascular clips (S4-S5); and (VII) Anatomic lingulectomy using endostaplers (S4-S5).

Right upper lobe apico-posterior segmentectomy (S1-S2)

Exposure of the vein is achieved by retracting the upper lobe posteriorly. The common apico-posterior segmental vein is dissected as distal as possible and divided with an endostapler.

The upper lobe is then retracted upward and forward in order to expose the apical artery which is dissected and divided using a stapler.

When the fissure is complete, the posterior ascending artery can be easily dissected and divided from the fissure. When the fissure is incomplete, a fissureless technique is performed in order to expose the posterior artery. The anterior portion of the intersegmental plane is divided using a stapler to expose the posterior ascending artery and the bronchus. A posterior segmental artery is then discovered. A vascular clip for proximal transection and ultrasonic energy device to do the distal division. Now the trifurcation of the upper lobe bronchus is exposed. The apical and posterior lobar bronchus are dissected separately and freed from its attachments to the upper lobe. A loop is passed around the two segmental branches and both bronchus are cut with an endostapler.

Finally, the parenchyma is divided by placing the stapler in the border between the apico-posterior and the anterior segment plane. The specimen is inserted into a protective bag and retrieved through the single incision.

Right upper lobe apical segmentectomy (S1)

The second video shows an apical segmentectomy of a 2.5 hilar tumor not possible to remove with a wedge resection. The first step is to identify the mediastinal trunk of the artery. Once the segmental vein for segment 1 is dissected we use a vascular stapler to divide it. We usually insert the staplers through the inferior part of the incision and the camera is normally placed above.

By using scissors we release the adherences of the anterior branch of the artery from the inferior portion of the tumor.

We divide the apical artery using vascular clips. The anterior portion of the intersegmental plane is divided by a 60 mm stapler. After identification of the branches for the anterior and posterior segment, we continue with the division of the parenchyma by placing the staplers above the stumps. In this particular case, the apical bronchus is divided through the intersegmental plane due to the benign nature of the tumor.

Left upper lobe trisegmentectomy (S1-S2-S3)

The third case shows a trisegmental resection of left upper lobe (also known as lingular-sparing lobectomy). The view of the apico-anterior arterial trunk is direct, and this branch is approached anteriorly, dissected and ligated by a stapler. The upper division of the pulmonary vein is dissected and divided [anterior, apical and posterior veins, preserving the lingular vein (LV)]. The trisegmental bronchus is easily visualized after ligation of the segmental vein and arteries, with care taken during this dissection to avoid injury of the lingular artery. After the bronchus is stapled, the posterior artery is usually visualized and is then divided by using vascular clips. The last step is to divide the parenchyma through the segmental plane by using staplers.

Left lower lobe superior segmentectomy (S6)

The resection of the superior segment (S6) of the lower lobe is straightforward as there are consistent anatomical landmarks. The conduct of segmentectomy will vary slightly depending on whether the fissure is complete or not. In this case, the fissure is complete so the superior segment artery is exposed through the fissure. The artery is easily divided by using an endostapler.

With a long lung grasper, the lower lobe was held and the pulmonary ligament was cut to find the segmental vein for dissection, followed by division by using a vascular stapler. We dissect and expose the superior segmental bronchus and it was stapled in the same way as mentioned for the vein. The last step is to divide the intersegmental plane and remove the segment using a protective bag.

Right lower lobe basilar segmentectomy (S7-S8-S9-S10)

Removal of four segments in the right lower lobe (S7-S8-S9-S10) while sparing the apical segment (S6) is called basal segmentectomy. These segments are usually removed together since they are dependent on a single bronchus.

After identification of the artery in the fissure, a stapler was placed above to better expose the artery. The anterior portion of the fissure is stapled, which allowed division of the basilar artery using a stapler.

The next step is dissection of the basilar segmental vein. The direct view provided by the single incision approach allows excellent visualization of the plane between the superior segmental vein and basilar vein. The basal vein was divided with a stapler. Once the inferior segmental vein has been divided, the lower lobe basilar segmental bronchus is exposed, dissected and divided from its inferior aspect to its bifurcation with the middle lobe bronchus on the right side or the upper lobe bronchus on the left side. Dissection of the bronchus with development of the plane between the bronchus and artery is performed with visualization of the artery. We recommend the removal of the interbronchial lymph nodes to better define the anatomy. The intersegmental plane is completed last. The lung is inflated to confirm an adequate ventilation of the superior segment of the lower lobe.

Anatomic lingulectomy using vascular clips (S4-S5)

The next video shows two different ways to perform an anatomic lingulectomy. In the first video we used vascular clips for vessels. The lingula is retracted laterally and posteriorly and the pleura overlying the LV is incised. In this particular case, the tumor was involving part of the lower lobe in the fissure, so the first step was to divide the anterior portion of the fissure from an anterior view.

The identification of the LV, lower lobe vein (LLV) and the artery indicates the location to place the stapler to divide the anterior portion of major fissure. The anvil of the stapler is placed between the LLV and LV, and above the upper part of the artery, and the parenchyma is retracted into the jaws of the stapler.

This maneuver facilitates the dissection of the LV. A ring forceps is then placed while holding the lingula for traction, exposing the small recurrent lingular artery which is then divided with clips. Once this small vessel is divided, the lingular bronchus is exposed. In this particular case there was no angle for the stapler, so the bronchus was transected using scissors and the stump was closed using a stapler at the end of the procedure. Subsequently the main lingular artery is exposed and divided by using vascular clips.

Finally the intersegmental plane is divided and the stump of the bronchus with is closed with an endostapler at the end of the procedure.

Anatomic lingulectomy using staplers (S4-S5)

The last segment of this video shows a non-edited lingulectomy using endostaplers. The fissure is complete so the lingular artery is easily exposed, dissected and divided in the fissure by using a vascular stapler. The LV is dissected and divided by using a 30 mm vascular stapler. Once the vein is divided, the lingular bronchus is exposed and transected using endostaplers. The last step is to divide the intersegmental plane.

Comments

Uniportal VATS segmentectomies are usually more difficult than lobectomies. From June 2010 to February 2014, we have performed 28 uniportal VATS anatomic segmentectomies. The mean surgical time was 89.5±3 minutes (range, 40-150 minutes). The mean number of nodal stations explored was 4.1±1 (range, 0-5) with a mean of 11.5±1.8 (range, 7-25) lymph node resections. The mean tumor size was 2.24±1 cm (range, 1-4 cm). The median chest tube duration was 2 days (range, 1-6 days) and the median length of stay was 2 days (range, 1-6 days).

None of these segmentectomy cases required conversion, which may be attributed to experience in uniportal lobectomy, including vascular dissection, the management of fissures, as well as experience in more complex cases (lobectomy after induction therapy, hilar calcification, and pneumonectomy) (7).

Comparing segmentectomies by thoracotomy with uniportal thoracoscopic segmentectomies, the latter was associated with a shorter length of stay and with equivalent morbidity and mortality (8).

The advantage of using the camera in coordination with the instruments is that the vision is directed to the target tissue, addressing the target lesion from a straight perspective and thus obtaining a similar angle of view as with open surgery. In standard three-ports VATS, the geometric configuration of a parallelogram generates interference with the optical source, creating a plane with a torsion angle not favorable on the flat two-dimensional vision of currently available monitors (9).

Another potential advantage of this approach could be a reduction in postoperative pain, although this has not yet been demonstrated. There could be several explanations for this issue: only one intercostal space is involved and avoiding the use of a trocar could minimize the risk of intercostal nerve injury. During instrumentation, force is applied only over the superior aspect of the inferior rib through the utility incision.

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Footnote

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Comparing the postoperative outcomes of video-assisted thoracoscopic surgery (VATS) segmentectomy using a multi-port technique versus a single-port technique for primary lung cancer

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Background: Single-port video-assisted thoracoscopic surgery (VATS) has attracted much attention recently; however, it is still very challenging to perform especially on more technically demanding sublobar anatomic resection procedures such as segmentectomy. Therefore we conducted a retrospective study on the perioperative results of single-port segmentectomy using a propensity-matched method for comparison with multi-port segmentectomy in patients with primary lung cancer.

Methods: For procedures of anatomic segmentectomy performed between May 2006 and March 2014, we retrieved data on patients' demographic information, medical history, cancer information, and postoperative outcomes from our surgical database of thoracoscopic lung cancer surgery. Outcome variables included the number of lymph nodes retrieved during the surgery, the amount of blood loss, the duration of hospitalization, the length of the wound, the operation duration in minutes, and incidence and types of complication. The *t*-test and Chi-squared test were used to compare demographic and clinical variables between single- and multi-port approaches.

Results: A total of 98 consecutive patients who underwent VATS segmentectomy for lung cancer treatment were identified in our database: 52 (53.1%) underwent a single-port segmentectomy and 46 (46.9%) had a multi-port segmentectomy. After propensity score matching, the differences in patients' age, pulmonary function tests, tumor size, and operating surgeons were no longer significant between the two sample groups. The length of the wound was the only surgical outcome for which single-port segmentectomy had a significantly better outcome than multi-port segmentectomy (P value <0.001).

Conclusions: This study showed that single-port VATS segmentectomy yielded comparable surgical outcomes to multi-port segmentectomy despite technique difficulties and smaller wound in our setting.

Keywords: Single-port; video-assisted thoracoscopic surgery (VATS); segmentectomy

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Introduction

Thoracoscopic surgery for lung cancer was first described in the early 1990s, and it is now accepted as a technically feasible (even standard) option for many kinds of lung surgery after two decades of development. The many recognized advantages of the procedure include decreased postoperative pain, reduced impairment of pulmonary function, shorter duration of chest tube insertion, and consequently shorter hospital stays (1). Single-port video-assisted thoracoscopic surgery (VATS) was first described by Rocco *et al.*, who reported wedge resection of the lung with a single-port approach in 2004 (2). In addition, Gonzalez *et al.* reported performing lobectomy and segmentectomy through a single incision (3). Recently, single-port VATS has become an increasingly popular approach for managing thoracic diseases. This popularity can be attributed to the continuous innovations in endoscopic systems, energy devices, and surgical instruments as well as, most importantly, the obligation and desire of surgeons to reduce surgical trauma and ameliorate patients' discomfort (4).

Not only the technique of VATS has been evolving towards less invasiveness, but a lesser extent of surgical resection also has been suggested over the years. In 1995, a milestone study by the Lung Cancer Study Group (LCSG) concluded that lobectomy was the standard procedure for lung cancer treatment because of the higher rate of local recurrence following segmentectomy (5). However, the landscape of thoracic oncology has changed remarkably in subsequent decades and new developments have led to an era of minimally invasive thoracoscopic approaches, which include segmentectomy for carefully selected patients. Recent articles pointed out that there was no significant difference in disease-free survival following lobectomy and segmentectomy among stage IA lung cancer patients (6,7). Studies also suggest that segmentectomy has comparable oncologic outcomes with lobectomy for early non-small cell lung cancer (8). Literatures often recommend thoracoscopic segmentectomy over thoracoscopic lobectomy on account of results demonstrating reduced postoperative complications and hospital stay, equivalent oncologic results, rate of recurrence, and survival in selected lung cancer patients (9).

We started using the thoracoscopic approach for lobectomy and segmentectomy with radical lymph node dissection to treat lung cancer patients in 2005, and we adapted to using the two-port thoracoscopic approach in 2007. In November 2010, we omitted the thoracoscopic port and began using a single-port approach for lung cancer surgery to simplify the surgical wound and reduce postoperative discomfort. The positive feedback from patients' clinical outcomes constantly encourages us to modify existing procedures and invent new ones to solve technical problems. We have also developed several simple and effective methods to facilitate the dissection of mediastinal lymph nodes (10). With the single-port approach, there is no need for additional grasping of lung tissues; furthermore, instrument fencing can be avoided. The anterior-to-posterior order of dissection described by Pham *et al.* (11), which we adopted in 2007, was particularly helpful when we were developing our method of single-port surgery.

Single-port VATS is now as widely used as multi-port VATS in lung cancer segmentectomy in our hospital. However, there remains a lack of comparative information on the postoperative outcomes between these two techniques. Hence, we conducted a retrospective cohort analysis to compare single- and multi-port segmentectomies using a propensity score matching method to verify the clinical application of single-port thoracoscopic surgery in patients who received segmentectomy.

Materials and methods

Surgical technique

Our previous study had described the details of single-port segmentectomy surgical techniques (12). In brief, the surgery was performed under general anesthesia with a single lung ventilation in the lateral decubitus position. Both the surgeon and the assistant stood at the anterior side of the patient. A single incision of approximately 4 cm was made in the fifth or sixth intercostal space along the anterior axillary line and a wound protector (Alexis wound protector/retractor, Applied Medical Technology Inc., Brecksville, OH, USA) was routinely used without rib spreading. All procedures were performed with thoracoscopic assistance, in which a 10-mm, 30-degree thoracoscopic video camera and several thoracoscopic instruments were simultaneously inserted into a single incision. The surgical field was visualized primarily on the screen via the thoracoscopic view. The majority of the dissection was performed with endoscopic hook electrocautery and energy devices such as a Harmonic scalpel (Ethicon Endo-Surgery Inc., Cincinnati, OH, USA). The pulmonary vessels and bronchi were sectioned with the use of endoscopic staplers or vascular clips (Hemo-lock vascular clips, Weck Closure Systems, Research Triangle Park, NC, USA). Energy devices were used to aid lymphadenectomy (systemic lymph node sampling: 2R, 4R, 7, 8, and 9 for right-sided cancers; 4L, 5, 6, 7, 8, and 9 for left-sided cancers). After the divisions of segmental vessels and bronchi, the parenchymal excision was completed either by staplers or electrocautery along the inflated-deflated zone. At the end of surgery, a protective specimen bag was always used to retrieve the specimen and

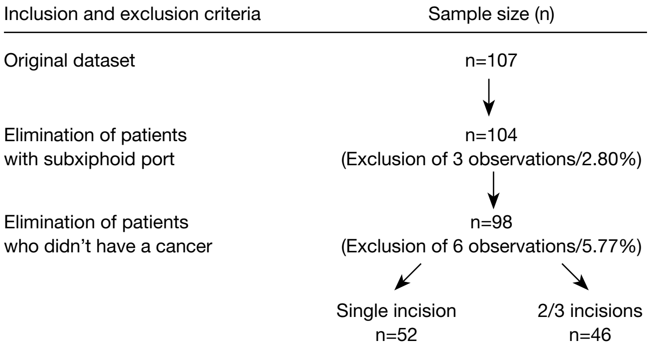

Figure 1 Flow chart showing patient selection process.

a single chest drain (14 Fr Pigtail, 16 or 20 Fr chest tube) was placed at the edge of the incision.

Data sources and patient selection

We retrieved data from our prospective database, which was established in 2000 at the Department of Thoracic Surgery, Koo-Foundation Sun Yat-Sen Cancer Center, Taipei, China. The study was approved by the institutional review board of the hospital.

For each individual, demographic information (age and gender), medical history (chronic obstructive pulmonary disease, diabetic mellitus, and tuberculosis), and cancer information (stage, year of intervention, location, histologic type of cancer, TNM classification, and FEV_1/FVC ratio) were collected prospectively. Histological typing was established according to the World Health Organization classification. TNM stage was determined according to the American Joint Committee on Cancer staging system, 7th Edition.

Outcome variables included the number of lymph nodes retrieved during the surgery, the amount of blood loss, the duration of hospitalization, the length of the wound, the operation duration in minutes, and incidence and types of complication.

Most data were collected at the time of diagnosis; however, some data (e.g., cancer information and hospital outcomes) were collected during the course of surgery.

In total, 107 adult patients who had a segmentectomy from May 2006 to March 2014 were identified. We excluded patients with a subxiphoid port placement and patients not diagnosed with lung cancer. Nine patients were excluded. For the remaining 98 patients included in the study, 52 (53.1%) underwent single-port surgery and 46 (46.9%) had multi-port surgery (*Figure 1*). The multi-port surgery group included the two-port approach and three-port approach procedures.

Statistical analysis

To control for potential selection bias, we used a propensity score matching method. The cohort of patients who had single-port surgery was matched with patients who had multi-port surgery using the nearest neighbor-matching algorithm with a "greedy" heuristic. Matching occurred if the difference in the logits of the propensity scores was less than 0.2 times the standard deviation of the scores. To generate the propensity score, we applied a 1:1 ratio and used the following covariates in the logistic regression: age, tumor size, FEV_1/FVC ratio, and the identifier of the surgeon. A total of 29 pairs of patients were selected after the propensity score matching.

Differences between the baseline characteristics of patients and parameters after propensity score matching were tested using *t*-test for continuous variables and Chi-squared test for categorical data. We also compared outcome parameters at baseline and after propensity score matching between patients who underwent single-port surgery and those who received multi-port. Finally, we cross-tabulated the demographic variables and clinical variables with the outcome variables in the single-port group to look for potential predictors of the surgical outcomes.

P values less than 0.05 were considered statistically significant. All statistical analyses were conducted using SAS software version 9.3 (SAS Institute Inc., Cary, NC, USA).

Results

Among the single-port group (*Table 1*), 34 traditional segmentectomies were performed, including trisegmentectomy, lingulectomy, common basal segmentectomy, and superior segmentectomy of lower lobe; the other 18 atypical segmentectomies included apicoposterior segmentectomy of left upper lobe, right apical segmentectomy, posterior segmentectomy of right upper lobe, apical segmentectomy of right upper lobe, right segment 8+9 bisegmentectomy right segment 7+8 bisegmentectomy, and right segment 9+10 bisegmentectomy.

The clinical and demographic characteristics of the patients before and after the propensity matching are presented in *Table 2*. All variables included in the logistic regression model for the propensity score matching (i.e.,

Table 1 Type of surgical procedure among the single-port approach group (n=52)

Type of surgical procedure	No. of patients
Traditional segmentectomies (n=34)	
Trisegmentectomy	17
Lingulectomy	7
Superior segmentectomy of lower lobe	8
Common basal segmentectomy	2
Atypical segmentectomies (n=18)	
Apicoposterior segmentectomy of left upper lobe	4
Right apical segmentectomy	2
Posterior segmentectomy of right upper lobe	5
Apical segmentectomy of right upper lobe	2
Right segment 8+9 bi-segmentectomy	1
Right segment 7+8 bi-segmentectomy	2
Right segment 9+10 bisegmentectomy	2

age, FEV_1/FVC ratio, tumor size, and surgeon) were initially statistically significant and became non-significant after matching. Gender and pathological stage group were significantly different between patients that underwent the single-port surgery and those that underwent multi-port surgery. Even though they were not specifically matched in the process, these two factors were not significantly different after the propensity score matching.

Table 3 lists the details of the outcome variables in each cohort analyzed before and after propensity score matching. After propensity score matching, the number of lymph nodes retrieved, blood loss, length of hospital stay, operation time, and complication rate did not differ significantly between the groups. Only the length of the wound remained significantly different after matching; specifically, the average length of wounds was 3.71 and 4.36 cm in the single- and multi-port groups, respectively.

Table 4 describes the cross tabulation of some demographic and clinical variables with the outcome variables for the single-port group (29 patients). In this cohort, females lost an average of 73.40 mL of blood during the intervention, which contrasted with an average of 22.50 mL blood loss among male patients (P value =0.028). We also noted that patients who had diabetes mellitus before surgery had significantly longer wounds than patients without diabetes (average length of 4.00 *vs.* 3.69 cm; P value=0.041). The other associations tested between outcomes and clinical variables were not statistically significant.

Discussion

In our sample, patients receiving single-port segmentectomy, as compared to those receiving multi-port segmentectomy, were more likely to be female, younger, with better lung functioning, having smaller tumor, and in stage I. Using propensity score matching, we were able to control for most of the confounding factors. The differences in gender, age, FEV_1/FVC ratio, tumor size, operating surgeon, and pathological stage were not statistically significant after matching between the two groups in our dataset.

This study has shown that single-port thoracic segmentectomy can yield comparable surgical outcomes to multi-port segmentectomy in most of the tested parameters. The length of the wound was the only surgical outcome for which single-port segmentectomy had a better outcome than multi-port segmentectomy. There is a growing body of literature that compares the oncologic efficacy of thoracoscopic segmentectomy with that of lobectomy (6,13-16). These studies propose technical modifications for anatomic resection, and present the feasibility of single-port segmentectomy. However, comparisons of postoperative outcomes between multi-port and single-port segmentectomy have rarely been reported. This study helps fill the gap of information.

We started using single-port VATS segmentectomy in December 2010 for the removal of a centrally located carcinoid tumor. We then used it for lung cancers with tumors of less than 2 cm in diameter and for elderly patients with compromised cardio-pulmonary function. Our preliminary results of single port VATS, including 14 lobectomies and five segmentectomies, were performed successfully without the need for conversion to conventional open surgery (17). We also reported that 233 lung cancer patients underwent thoracoscopic lobectomy or segmentectomy via a single-port or multi-port technique without surgical mortality, and showed that these two techniques produced comparable lengths of hospitalization and postoperative complication rates. Furthermore, patients in single-port approach group had shorter operative times, more lymph nodes removed, and less intraoperative blood loss (18). In recent years, our team has addressed single-port thoracoscopic surgery in several published articles (10,12,17,19,20).

After gaining experience of the procedure and advancing

Table 2 Clinical characteristics of segmentectomy patients before and after propensity-score matching

Characteristics	All patients (n=98)			Propensity-matched patients (n=58)		
	Single-port (n=52)	Multi-port (n=46)	P value	Single-port (n=29)	Multi-port (n=29)	P value
Sex						
Female	43 (82.69)	26 (56.52)	0.005*	25 (86.21)	18 (62.07)	0.070
Male	9 (17.31)	20 (43.48)		4 (13.79)	11 (37.93)	
Age, y#	59.00±11.63	66.8±9.95	<0.001*	61.72±12.24	67.24±9.57	0.061
FEV_1/FVC, L#	80.15±7.42	71.93±8.75	<0.001*	77.14±7.79	74.39±6.23	0.222
Tumor size, cm#	2.15±1.03	2.92±1.87	0.016*	2.24±0.96	2.38±1.11	0.623
Surgeon#						
A	45 (86.54)	30 (65.22)	0.013*	22 (75.86)	21 (72.41)	0.764
B	7 (13.46)	16 (34.78)		7 (24.14)	8 (27.59)	
Pathologic stage (AJCC 7th)						
1	38 (80.85)	22 (66.67)	0.486	21 (80.77)	16 (72.73)	0.854
2	6 (12.77)	7 (21.21)		4 (15.38)	5 (22.73)	
3	2 (4.26)	3 (9.09)		1 (3.85)	1 (4.55)	
4	1 (2.13)	1 (3.03)		0 (0)	0 (0)	

*, statistically significant; #, represented as matched variables.

Table 3 Surgical outcomes among single-port and multi-port patients

Outcome variables	All patients (n=98)			Propensity-matched patients (n=58)		
	Single-port (n=52)	Multi-port (n=46)	P value	Single-port (n=29)	Multi-port (n=29)	P value
No. of lymph nodes retrieved	19.20±10.73	17.70±10.50	0.489	19.46±10.96	18.79±11.97	0.826
Blood loss, mL	63.27±78.38	60.22±50.44	0.817	66.38±93.43	55.52±49.40	0.583
Hospital stay, day	5.77±1.98	6.93±2.17	0.007*	6.17±2.28	6.66±2.38	0.434
Length of wound, cm	3.62±0.74	4.58±1.02	<0.001*	3.71±0.74	4.36±0.61	<0.001*
Operation time, min	3.31±0.97	3.46±0.93	0.425	3.48±1.00	3.26±0.83	0.358
Complication rate, %	44 (89.80)	37 (80.43)	0.198	22 (84.62)	23 (79.31)	0.733

*, statistically significant.

the technique and instrument, we introduced precise resection of the so-called subsegment, or combination of subsegments, according to the approach of *Illustrated Anatomical Segmentectomy for Lung Cancer* for deep-seated small lung nodules proposed by Hiroaki and Morihito (21). Cases of complicated subsegmental resection have increased in the last 2 years and may have required more operative time and possibly longer hospital stays due to prolonged air leaks. The effect of different single-port approach procedures has been analyzed (not shown here), but no significant differences between simple and complicated segmentectomy were identified regarding demographic parameters or postoperative outcomes. It showed that, after years of experience and instrumental refinement, single-port VATS has been a routine procedure and treatment of choice for dealing with general thoracic malignancies in our hospital.

Segmentectomy was once regarded as an inadequate procedure for lung cancer treatment and was reserved only for poorly functioning elderly patients. Thanks to the development of low-dose chest CT scans, early detection of lung cancer has become more common in recent years. Segmentectomy could be the treatment of choice for this group of patients who have a low chance of lymph node metastases, and it was advocated to cope with the rapidly increasing numbers of small early lung cancer identified by

Table 4 Comparison of clinical variables and outcome variables for the single-incision group after propensity-score matching (n=29)

Characteristics	Outcome variables (mean ± σ)												Total, n (%)
	Lymph node retrieved, no.	P value	Blood loss, mL	P value	Hospital stay, day	P value	Length of wound, cm	P value	Operation time, min	P value	Complication	P value	
Sex		0.843		0.028*		0.874		0.229		0.410		0.580	
Female	19.29±11.22		73.40±98.83		6.20±2.36		3.64±0.74		3.42±1.05		0.14±0.35		25 (86.21)
Male	20.50±10.66		22.50±18.93		6.00±2.00		4.12±0.63		3.87±0.63		0.25±0.50		4 (13.79)
Age, y		0.096		0.315		0.286		0.469		0.952		0.930	
<65	21.84±10.33		49.00±41.66		5.75±1.41		3.77±0.82		3.47±1.01		0.15±0.37		20 (68.97)
≥65	14.44±11.10		105.00±154.90		7.11±3.48		3.56±0.53		3.50±1.06		0.17±0.41		9 (31.03)
Stage I cancer		0.233		0.212		0.277		0.711		0.657		0.376	
Yes	17.13±8.34		84.69±121.40		5.75±2.11		3.66±0.47		3.41±1.17		0.21±0.43		16 (55.17)
No	22.15±13.21		43.85±30.97		6.69±2.46		3.77±0.99		3.58±0.79		0.08±0.29		13 (44.83)
Antecedent of DM		0.605		0.354		0.674		0.041*		0.741		0.171	
Yes	15.50±13.43		50.00±0.00		5.50±2.12		4.00±0.00		3.25±1.06		0.50±0.71		2 (6.90)
No	19.77±11.01		67.59±96.85		6.22±2.33		3.69±0.76		3.50±1.02		0.12±0.34		27 (93.10)
Antecedent of TB*													
Yes	–		–		–		–		–		–		0 (0.00)
No	–		–		–		–		–		–		29 (100.00)

Standard deviations are reported in parentheses. *, the data was not applicable for analysis due to no patient with antecedent TB infection.

CT screening programs. For small lung malignancies, both the single-port thoracoscopic approach and segmentectomy can minimize injury and provide benefits such as reducing wound trauma, preserving lung parenchymal function, and improving respiratory recovery, which can lead to shorter lengths of hospitalization and early return to work.

This study shows that single-port thoracoscopic segmentectomy with radical lymph node dissection can be performed safely and feasibly with perioperative outcomes that are comparable to conventional VATS segmentectomy as well as improved surgical wound trauma. In further research, the oncologic validity of segmentectal resection in relation to lung cancer should be investigated, possibly with prospective study conducted for scientific comparison.

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Footnote

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Comparison of single port versus multiport thoracoscopic segmentectomy

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Backgrounds: Single-port thoracoscopic segmentectomy is a challenging option in the early stages of lung cancer. The purpose of this study was to determine the feasibility of single-port video-assisted thoracoscopic surgery (VATS) segmentectomy compared to conventional multi-port VATS.

Methods: A total of 45 patients underwent pulmonary segmentectomy by video-assisted thoracoscopic surgery between March 2006 and October 2015. We analyzed the operative outcomes of segmentectomy by surgical approach (34 single-port versus 11 multi-port).

Results: Twenty-three primary lung cancers (51.1%), 16 benign lung diseases (35.6%), and 6 secondary lung cancers (13.3%) were diagnosed and included in our study. In 29 malignancy cases (64.4%), the mean tumor size was 1.8±0.7 (range, 1–3.5) cm. Twenty patients (44.4%) underwent preoperative localization with hook-wire and radiocontrast. The most frequent operated segment was the left upper divisional segment (n=9, 30%). There was no significant difference in operation time (P=0.073), the number of dissected lymph nodes (P=0.310), intraoperative events (P=0.412), and the development of prolonged air leak (>5 days) (P=0.610) between the single-port and multi-port VATS segmentectomy groups. There was a reduction in postoperative morbidity (P<0.001) and hospital stay (P=0.029) in the single-port VATS group.

Conclusions: Single-port VATS segmentectomy for early lung cancer and benign lung disease, is a safe and feasible option for patients undergoing pulmonary segmentectomy.

Keywords: Segmentectomy; sublobar resection; single-port thoracoscopic surgery; video-assisted thoracoscopic surgery (VATS)

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Introduction

Video-assisted thoracoscopic surgery (VATS) is becoming more popular for the treatment or diagnosis of lung disease. The wide acceptance of VATS is partly due to the reduction in postoperative pain and to a shorter recovery time compared to conventional thoracotomy (1). Recently, the treatment of choice for lung cancer has been changed to VATS for the early treatment of lung cancer in most centers (2). Anatomic lung resection, lobectomy or pneumonectomy, with the removal of the mediastinal lymph nodes are considered the treatment of choice and provide the best chance of survival in early lung cancer. Sublobar resection, segmentectomy or wedge resection, is considered alternative modalities for the treatment of clinical T1N0 lung cancer in high-risk patients with poor cardiopulmonary reserve who could not tolerate radical anatomic resection (3,4). VATS pulmonary segmentectomy became more popular and achieved through various additional techniques including preoperative localization (5) and the identification of the intersegmental plane (6,7).

More recently, the single-port VATS approach has advanced to perform many types of thoracic surgeries (8), including diagnostic procedures, minor and major lung anatomic resections (9), and the excision of mediastinal tumors. While it is not mandatory to use specialized instruments during single-port surgery, the handling of conventional endoscopic instruments through such limited port requires considerable surgical skills and operating time at an early learning period. Thus, this approach is currently limited as there are some negative perceptions regarding the need for specialized devices, the potential risk for complications, and the increased operating time and medical expenses associated with this procedure. Also, many thoracic surgeons believe that this approach has its limitation in oncologic clearance and outcome. There is still some controversy regarding adopting the single-port VATS approach in the thoracic surgical field.

VATS thoracic surgery, through a single-port, allows the direct vision to target structures and parallels the handling of instruments similar to open surgery (10), potentially with less intercostal pain (11) and comparable surgical outcomes (12) with an experienced operator providing more than just cosmetic results. Evidence continues to support single-port VATS as a feasible surgical option (13).

Single-port VATS pulmonary segmentectomy is considered a potentially advanced technique (12,14). Even with open thoracotomy or conventional VATS, pulmonary segmentectomy is still a technically demanding procedure compared to anatomic lobectomy. In addition to this, due to the location of the target lung segment, there is limited access to the segmental vessels and bronchus. Thus, a great concern for patient safety remains.

The authors report the surgical outcomes of single-port VATS segmentectomy in various lung diseases (15). We launched the single-port VATS major lung resection (lobectomy, bilobectomy, and pneumonectomy) in patients with lung malignancy from 2010 and single-port VATS segmentectomy from 2012 after a learning period from two port VATS (16). More recently, we adopted a 2-cm incision port in single-port VATS major lung resection for lung malignancy.

There has been relatively little information in the literature regarding the technical details and surgical outcomes of single-port VATS segmentectomy. The current study attempts to determine whether single-port VATS segmentectomy can play the alternative role in current minimal invasive thoracic surgery.

Materials and methods

Patients

We retrospectively collected data on 45 patients who underwent a single-port (n=34) or multi-port (n=11) VATS pulmonary segmentectomy. The indication of pulmonary segmentectomy in our series included the peripherally located clinical T1N0M0 lung cancer with a lesion less than 2 cm in diameter with ground glass lesion showing a solid portion less than 50%, Inflammatory lung diseases which were resectable through segmentectomy instead of lobectomy to preserve normal lung parenchyma in patients with poor pulmonary reserve, or metastatic cancers or benign tumors were not available for wedge resection. VATS pulmonary segmentectomy was performed by multi-port approach (n=11, from 2006) before launching our single port VATS surgery from 2012. We compared the operating time, intraoperative event (conversion), mediastinal lymph node dissection, and postoperative outcome between single-port and multi-port VATS segmentectomy.

Operative procedure

Twenty patients underwent preoperative dual localization with hook-wire and radiocontrast or radioisotope under CT fluoroscopic guidance to identify the correct location of the lesion and achieve adequate intersegmental resection margins from the lesion (*Figure 1*). All localization procedures were performed 1–2 h before the operation. We used the intraoperative C-arm fluoroscopy to detect the radiocontrast injected around the target lesion before the division of the intersegmental plane.

Anesthetic and surgical techniques for single-port VATS segmentectomy were not significantly different from those of single-port VATS lobectomy. The operator was always on the right side of the patient and positioned to the lateral decubitus, and made a 2 to 4 cm single-port incision at the 5^{th} intercostal space on the anterior or posterior axillary line according to the location of the lesion. We always applied wound protector on the port to achieve better instrumental performance. We used a 5-mm thoracoscope in most of the cases. We used a 5-mm diameter articulating endoscopic device, a conventional endoscopic device with the shaft shortened, curved tip electrocautery, flexible curved-tip endostaplers, and interlocking vascular clips for branches of pulmonary segmental vessels if staplers were not adequate during single-port VATS segmentectomy. We used a 35-mm vascular stapler for the division of segmental vessels,

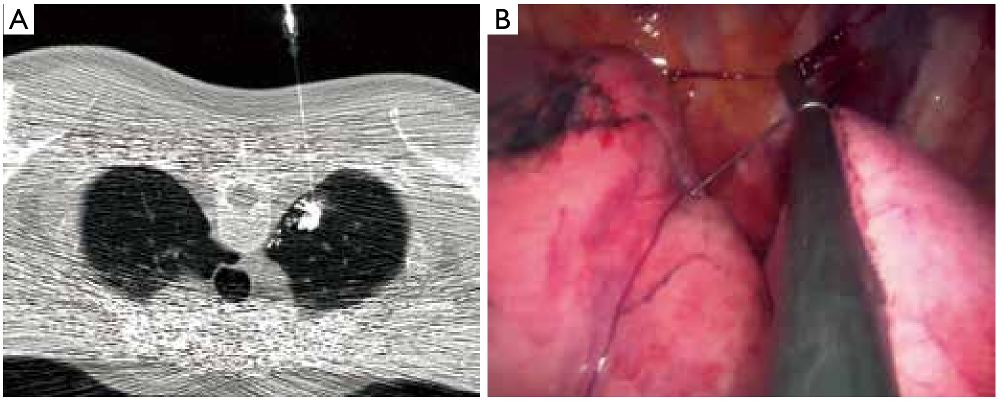

Figure 1 Preoperative dual localization technique (A) CT guided dual localization with hook wire and radiocontrast. (B) Intraoperative finding.

sometimes by the guidance of a soft drain.

Detailed procedures and sequences of single-port VATS segmentectomy by pulmonary segment were as follows. During segmentectomy for the upper lobar segment, we started the dissection of the interlobar fissure to expose the pulmonary segmental artery. After exposure of the pulmonary segmental artery for target pulmonary segment, segmental artery branches were divided with a flexible curved tip vascular stapler or by double clipping the interlocking vascular clips (*Figure 2A*). After traction of the lung to posteriorly, the pulmonary vein could be dissected, and segmental branches of the pulmonary vein exposed by further dissection of the mediastinal pleura. Isolated segmental pulmonary veins could be divided after careful dissection of the posterior vein wall to avoid injury to the apical branches of the pulmonary artery to the upper lobe (*Figure 2B*). We divided the apical segmental artery before the vein division to facilitate the passing of the stapler if there was tension or difficulty in stapling the segmental vein. After releasing the perivascular and peribronchial tissues and lymph nodes, the segmental bronchus was isolated and divided by the stapler (*Figure 2C*). Before the division of the segmental bronchus, we performed intraoperative fiberoptic bronchoscopy for the correct identification of the target segment (*Figure 2D*). We used inflation and deflation techniques before stapling the segmental bronchus for the delineation of the intersegmental plane. The anesthesiologist administered a 2 kg/cm^2 pressure of jet ventilation (*Figure 2E,F*). After stapling the segmental bronchus, we divided the intersegmental plane with the guidance of the C-arm fluoroscope to achieve adequate intersegmental resection margins from the target lesion (*Figure 2G*).

For single-port VATS segmentectomy of the lower lobe segment and superior or basal segmentectomy of the lower lobe, the procedure started with the release of the inferior pulmonary ligament to expose the inferior pulmonary segmental vein. We dissected the interlobar segmental pulmonary artery by fissure exposure. The vein dissection was the next step to expose the segmental bronchus to the lower lobe. Ideally, the perivascular and peribronchial between the segmental artery and bronchus should be removed to isolate the target segmental bronchus. Finally, we divided the segmental bronchus and intersegmental plane using the same technique we used to divide the upper lobe segment. We removed the segmentectomy specimen by a protective endo-bag through the single-port.

We performed complete lymph node dissection including upper and lower mediastinal, subcarinal, and lobe-specific lymph nodes for occult metastasis. In some cases, we performed dissection around specific lobes with sampling in non-specific lobes. In our surgeries on left thorax, para-aortic and subaortic lymph nodes were dissected routinely with the endoscopic node grasper (*Figure 2H*). We placed a 20- or 24-French chest tube and intrapleural catheter for continuous analgesic injection pump through the single-port. The apico-posterior segmentectomy procedure is available in the *Figure 3*.

Postoperative courses

We removed the chest drains according to our criteria; drain amount less than one-third of the patient's body weight per day, no air leak, and no pneumothorax on chest image. The patient was discharged the day after the removal of the chest drain if there were no postoperative complications.

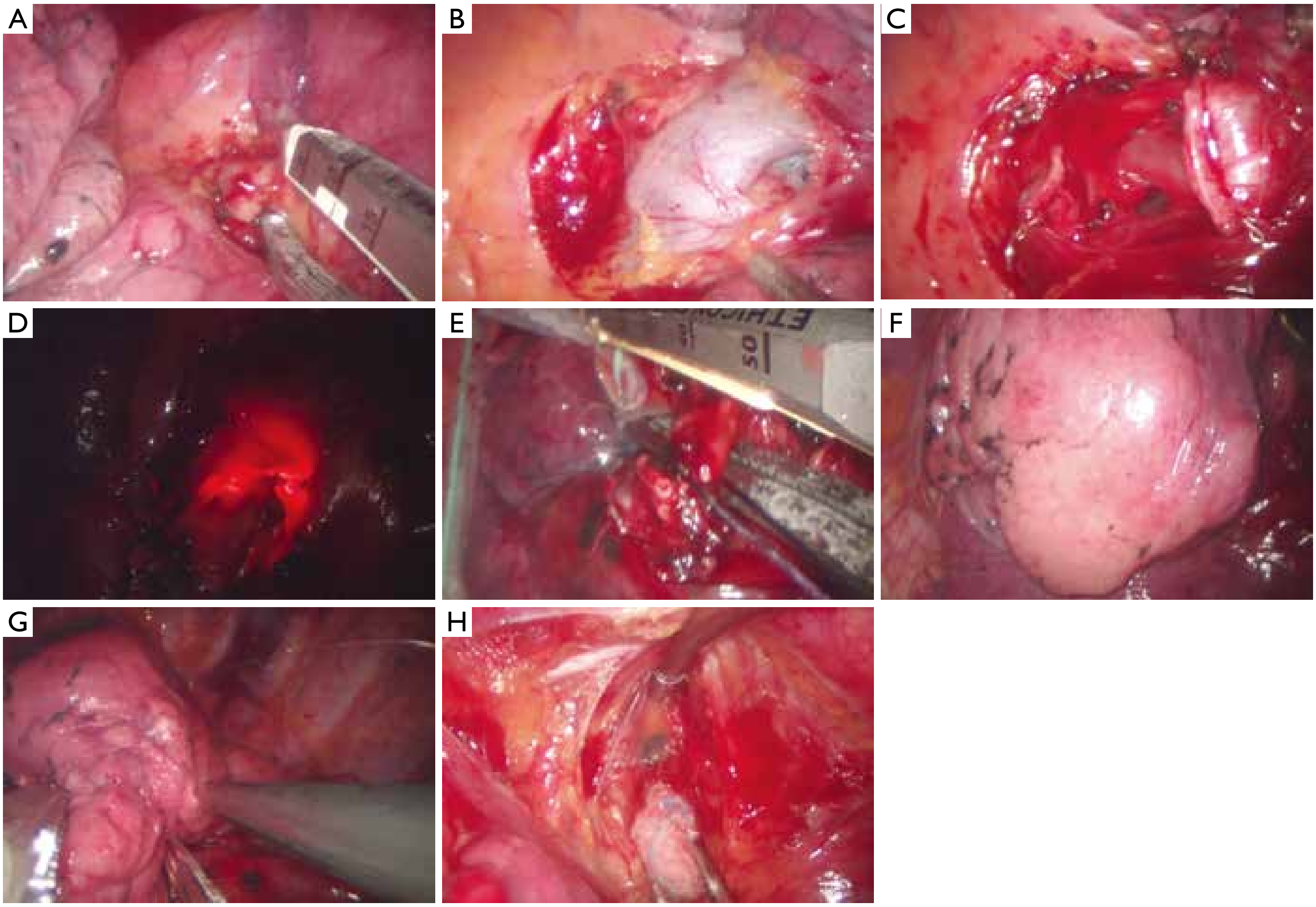

Figure 2 Photos from left upper lobe apico-posterior segmentectomy by single-port thoracoscopic surgery. (A) Apico-posterior segmental pulmonary artery; (B) apico-posterior pulmonary vein; (C) divided apico-posterior pulmonary vein; (D) intraoperative bronchoscopy; (E) division of apico-posterior segmental bronchus; (F) inflated lung for delineation of the intersegmental plane; (G) division of intersegmental plane away from the lesion (hook wire); and (H) subcarinal lymph node dissection.

Figure 3 Single-port VATS segmentectomy: left upper lobe apico-posterior segmentectomy (17). VATS, video-assisted thoracoscopic surgery. Available online: http://www.asvide.com/articles/827

Results

From March 2006 through October 2015, 45 patients underwent VATS segmentectomy in our institution for lung malignancy or benign lung disease. Among these patients, 34 (76.5%) underwent a segmentectomy performed by single-port VATS from 2012. Twenty-four (51.1%) had primary lung malignancies; indications for pulmonary segmentectomy included peripherally located clinical T1N0 lung cancer less than 2 cm in diameter showing less than 50% solid portion. In addition to these patients, we included six secondary lung cancer (13.3%) patients and 16 benign lung diseases (35.6%) confined to specific pulmonary segment resectable through segmentectomy in our study. The mean tumor size was 1.8±0.7 cm (*Table 1*). The age of

Table 1 Patient characteristics

Patients characteristics	Values
Age, mean ± SD [range]	60±13 [30–86]
Sex, n (%)	
Male	33 (73.3)
Female	12 (26.7)
Diagnosis, n (%)	
Primary lung cancer	23 (51.1)
Adenocarcinoma	14 (31.1)
Squamous cell carcinoma	8 (17.8)
Sarcoma	1 (2.2)
Benign lung disease	16 (35.6)
Infectious lung disease	13 (28.9)
Benign tumor	3 (6.7)
Secondary lung cancer	6 (13.3)
Tumor size*, mean ± SD (range)	1.8±0.7 (1–3.5)
No. of thoracoscopic port, n (%)	
Single-port VATS	34 (75.6)
Multi-port VATS	11 (24.4)
Preoperative localization, n (%)	20 (44.4)

*, measured only in tumor case; VATS, video-assisted thoracoscopic surgery.

Table 2 Lung segmentectomy performed by thoracoscopic surgery

Segment	Single-port (n=34)	Multi-port (n=11)
Right upper lobe		
Apical segmentectomy	0	1
Apico-posterior segmentectomy	3	0
Right middle lobe		
Medial segmentectomy	3	0
Right lower lobe		
Basal segmentectomy	3	0
Superior segmentectomy	3	1
Left upper lobe		
Apico-posterior segmentectomy	2	2
Lingular segmentectomy	3	0
Posterior segmentectomy	0	1
Upper divisional segmentectomy	9	1
Left lower lobe		
Superior segmentectomy	4	3
Basal segmentectomy	4	2

patients ranged from 30 to 86 years (mean 60±13 years), our study population was primarily male 73.3% (n=33). Segmentectomy for the upper divisional segment of the upper lobe, the superior segment of the lower lobe, the lingular segment, and the basal segment were the most common procedures (*Table 2*).

The operation time in single-port VATS segmentectomy (148±65 min) was longer compared to multi-port VATS segmentectomy (107±68 min). However, this difference was not significant (P=0.073). The number of resected lymph nodes during VATS segmentectomy (n=24) was higher (P=0.031) in the multi-port VATS group compared to the single-port VATS group; these occurred in a relatively small population (n=3). In the single-port VATS group, dissection of lymph nodes around a specific lobe was performed in 13 patients and complete systemic dissection was performed in five patients. Bleeding was the most common event reported during VATS segmentectomy (three in single-port and two in multi-port) which we controlled without conversion in most cases. Conversion to mini-thoracotomy occurred in two patients in the single-port VATS segmentectomy group. There was one conversion to lobectomy as we failed to find the lung lesion in the segmentectomy specimen. There was no lymph node metastasis in patients with malignancy at pathologic results. Prolonged air leak (>5 days) was the most common minor postoperative event in our study population. However, there were no significant differences between groups (P=0.610). Three patients developed postoperative pneumonia (one in single-port and two in multi-port) which resolved in all patients with antibiotic treatment. Two patients developed postoperative empyema in the single-port VATS segmentectomy group. There was no postoperative mortality within 30 days. Indwelling time of the chest drain was unchanged in the single-port VATS segmentectomy group. However, the hospital stay was decreased in the single-port VATS segmentectomy group (5.5±4.1 days, P=0.029) (*Table 3*).

Discussion

Our results indicate that single-port VATS is a feasible option and should be a VATS alternative for pulmonary segmentectomy in early lung cancer. In our study, there were a small number of multi-port VATS segmentectomies because sublobar resection has not been favorable in the surgical treatment of lung cancer; it has a higher rate of local recurrence and poor survival compared to those undergoing a lobectomy. However, recently, it has been reported that VATS segmentectomy achieves excellent

Table 3 Operative outcome of thoracoscopic segmentectomy

Variables	Single-port (n=34)	Multi-port (n=11)	P value
Operation time, min, mean ± SD	148±65	107±68	0.073
No. of dissected lymph node, n, mean ± SD	14±6	16±3	0.310
Systemic dissection	5	2	
Lobe specific dissection	13	1	
Lobe specific sampling	5	0	
Intraoperative event, n	4	2	0.412
Bleeding	3	2	
Conversion to lobectomy	1	0	
Conversion to open thoracotomy, n	2	0	0.567
Prolonged air leak (>5 days), n	12	4	0.610
Major morbidity, n	3	2	0.001
Pneumonia	1	2	
Empyema	2	0	
Mortality, n	0	0	–
Chest drain indwelling time, days, mean ± SD	4.3±3.7	6.3±1.9	0.187
Hospital stay, days, mean ± SD	5.5±4.1	8.9±5.3	0.029

oncologic results compared with thoracotomy in early lung cancer (<2 cm in size, typically adenocarcinoma) with low morbidity (~10%) and mortality (18). Also, in our institution, we have been changing our surgical strategy to minimal lung resection with a minimal incision in early stage non-small lung cancers and other lung malignancies for better lung function. With our single-port VATS experiences, the authors report the possibility of performing single-port VATS segmentectomy with proper localization techniques in patients with various lung diseases without expensive special devices. However, there remains little information on the surgical outcomes of single-port VATS compared with multi-port VATS. Future prospective cohort studies are needed to address the surgical outcomes of single-port VATS.

Nonetheless, our study reported better postoperative outcomes (morbidity and hospital stay) associated with single-port VATS. It is also evident that more operating time in the early period is needed when operating a single-port VATS compared to multi-port VATS. Operation time decreases as surgeons gain more experience; thus, this shouldn't be an issue with experienced surgeons for single port segmentectomy. In our study, the results of mediastinal lymph node dissection in lung malignancy were no worse than patients undergoing single-port VATS. The need for complete lymph node dissection is not clear in sublobar resection and should be studied in VATS (19). An advantage of the single-port VATS approach is the direct endoscopic view that allows the surgeon a target similar to that of open thoracotomy that may be helpful in the dissection of the segmental vessel. The disadvantages of the single-port VATS are that this procedure is still technically difficult to conduct in the early learning period and might not be safe if performed by an unexperienced surgeon.

Technically, the steps performed in single-port VATS segmentectomy are no different from those of the multi-port VATS. The surgeon should consider the operative plan with preoperative CT and PET scan before launching the single-port VATS segmentectomy. The most common and easiest lung segment is the superior segment and lingular segment on both lower lobes. The upper division (trisegment) of the left upper lobe and the composite basilar segment of either lower lobe are difficult segments to access for segmentectomy. Apical and/or posterior segmentectomy of the right upper lobe is not indicated in the presence of emphysema in the upper lobes (20). Adequate port placement is considered based on the target lung segments. We favor the 5^{th} intercostal space at the anterior or posterior axillary line according to the tumor location. Comprehensive understanding of lung segmental anatomy should be carried out to dissect and divide the correct segmental vessels. Technically, there are no limits of single-port VATS segmentectomy according to the lung segments. After the division of the segmental vessels, the segmental bronchus can be identified, and the peribronchial tissue released for safe stapling. Before the division of the segmental bronchus, the surgeon should confirm the correct bronchus by lung inflation after clamping the bronchus or inspecting it via intraoperative bronchoscopy. To divide the intersegmental plane with adequate resection margins (more than 2 cm from the lesion or more than the tumor size), a preoperative localization or a jet inflation technique, or intravenous injection of isocyanine green could help to delineate the intersegmental imaginary fissure.

In summary, currently, the single-port VATS approach may not be popular in the thoracic surgical field as there are many technical limitations to performing advanced VATS procedures. Future studies are needed to ascertain the acceptable long-term outcomes and patient safety of the VATS. The single-port VATS approach applies to most thoracic surgeries if indicated for pulmonary segmentectomy. It appears that this surgical approach might play an important role in updating minimal resection with minimal incision.

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Footnote

Conflicts of Interest: This paper is an invited article for ASPVS 2016. Speaker is Prof. Hyun Koo Kim as 4th ASPVS faculty member. The other authors have no conflicts of interest to declare.

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Robotic lobectomy and segmentectomy for lung cancer: results and operating technique

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Abstract: Video-assisted thoracic surgery (VATS) is a minimally invasive approach with several advantages over open thoracotomy for the surgery of lung cancer but also some limitations like rigid instruments and suboptimal vision. Robot technology is an evolution of manual videothoracoscopy introduced to overcome these limitations maintaining the advantages related to low invasiveness. More intuitive movements, greater flexibility and high definition three-dimensional vision are advantages of the robotic approach. Different studies demonstrate that robotic lobectomy and segmentectomy are feasible and safe with long term outcome similar to that of open/VATS approaches, however no randomised comparison are available and benefits in terms of quality of life (QOL) and pain need to be demonstrated yet. Several different robotic techniques are currently employed and differ for number of robotic arms (three versus four), the use of CO_2 insufflation, timing of utility incision and the port positioning. The four arms robotic approach with anterior utility incision is the technique described by the authors. Indications to perform robotic lung resections may be more extensive than those of traditional videothoracoscpic approach and includes patients with locally advanced disease after chemotherapy or those requiring anatomical segmentectomy. Learning curve of vats and robotic lung resection is similar. High capital and running costs are the most important disadvantages. Entry of competitor companies should drive down costs.

Keywords: Lung cancer; surgery; robotics; segmentectomy; lobectomy

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Introduction

The paradigm shift—encapsulated by the phrase 'from maximum tolerated treatment to minimum effective treatment'—that has involved many areas of surgical oncology, has scarcely touched thoracic surgery. Although minimally invasive techniques like video-assisted thoracic surgery (VATS) and robot-assisted surgery, that avoid division of major thoracic muscles and rib-spreading, are available for resecting lung tumours, they are not widely used. A survey conducted by the European Society of Thoracic Surgeons in 2007 found that only around 5% of responding European surgeons were using VATS for pulmonary resections (1). This, notwithstanding the fact that a systematic review of VATS in comparison to thoracotomy for early-stage non-small cell lung cancer (NSCLC)—which included randomized controlled trials—found that VATS was associated with shorter chest tube duration, shorter length of hospital stay, and better survival (at 4 years) than open surgery, all differences being statistically significant (2). Other data show that VATS is associated with reduced postoperative pain, reduced need for blood transfusions and reduced postoperative complications, as well as improved aesthetic and functional outcomes leading to better quality of life (QOL) (3).

The most frequent reason given by surgeons for not using VATS for lobectomy was that it was a difficult technique with a steep learning curve (1).

It would appear that VATS has drawbacks that made its widespread adoption by thoracic surgeons slow. These include counter-intuitive hand movements to manipulate the instruments, an instrument fulcrum effect, and tremor amplification. The surgeon stands over the patient to operate the instruments, while the virtual operating field is displayed on a monitor some distance away, disrupting eye-hand coordination. Furthermore most VATS endoscopes provide low-definition 2-dimensional images with limited magnification possibilities. VATS systems are therefore characterized overall by poor ergonomics, making delicate manoeuvres difficult.

Robotic surgery was introduced at the end of 1990s in part to overcome the limitations of minimally invasive surgery. Probably the first series using a robotic system to perform lung lobectomy was published in 2002 (4). The only currently available robotic systems for performing thoracic surgery are da Vinci Systems produced by Intuitive Surgical, Sunnyvale, California.

The main advantages of robotic technology over VATS are that natural movements of the surgeon's hands and wrists are translated by the computer-assisted robotic arms into precise movements of the surgical instruments inside the patient, with tremor filtration. The surgeon works at a console some distance from the patient and views the operating field in the console monitor, so that the eye-hand-operating field axis is maintained. The endoscope, directly manipulated by the surgeon at the console, feeds variable magnification, high-definition stereoscopic images to the monitor, which may compensate for the absence of haptic feedback (5).

However these are theoretical advantages, and if the trend to less aggressive oncological surgery is also to involve the thorax, then robotic surgery must be shown to be easier than VATS, and produce equivalent or better surgical and oncological outcomes. Furthermore the high capital and running costs of robot systems (6) will need to be reduced, and opportunities for training or retraining thoracic surgeons will need to be expanded.

Robotic lobectomy—published experience

Lobectomy with lymph node dissection is standard of care for stage I and II NSCLC (7). Following the initial reports (4), the feasibility and safety of robotic lung lobectomy was investigated in a series of studies published over in the subsequent 10 years. Park *et al.* (8) reported on 34 cancer lobectomies using a three robotic-arm technique (two thoracoscopic ports and a 4-cm utility incision without rib spreading) in which patient and port positions were similar to those used in VATS, and the surgical steps reproduced those of VATS lobectomy, with anterior-to-posterior hilum isolation. Four patients were converted to thoracotomy. A median of 4 (range, 2-7) lymph node stations was removed. There were no perioperative deaths. Median chest tube duration was 3.0 days (range, 2-12 days), median length of stay was 4.5 days (range, 2-14 days) and median operating time was 218 minutes (range, 155-350 minutes). Gharagozloo *et al.* 2009 (9) reported on 100 consecutive cases operated on with a hybrid two-phase procedure: robotic vascular, hilar and mediastinal dissection, followed by VATS lobectomy. The complication rate was 21% and three patients died postoperatively, considered due to the inclusion of high risk cases. There were no deaths among the last 80 cases, and the first 20 patients were considered to represent the learning phase. The authors considered that the robotic system was best for fine dissection (lymphadenectomy) while the established VATS procedure was superior for the lobectomy phase.

Veronesi *et al.* (5) 2010 presented the first comparison of open muscle-sparing thoracotomy with robotic lobectomy using a four-arm technique and 3-4 cm access port. Propensity scores for preoperative variables were used to match the 54 robotic cases with 54 patients who received open surgery. Hospital stay was shorter in the robotic group, but operating times were longer; however after the first tertile of cases, the duration of surgery reduced significantly. The authors concluded that robotic lobectomy with lymph node dissection was practicable and safe. The mean duration of the robotic lobectomy was around 220 minutes for the initial cases and around 170 minutes during the last phase of the experience (data not presented).

Dylewski *et al.* 2011 (10) reported on 200 lung robotic resections using an approach in which pulmonary resection was performed through the ports only, and pneumothorax was induced by CO_2 insufflation. At the end of the procedure the specimen was extracted via a subcostal trans-diaphragmatic approach, and the diaphragm subsequently repaired. Median duration of surgery was short at 100 minutes (range, 30-279 minutes) and median hospital stay was three days. However, the readmission rate was high (10%) usually for effusion, requiring drainage, or postoperative pneumothorax.

Like Veronesi *et al.* (5) 2010, Cerfolio *et al.* 2011 (11) used a propensity score to match 106 consecutive patients who received robotic lobectomy to 318 patients who received open rib and nerve-sparing lobectomy. The robotic group had numerically lower morbidity and mortality (0%

vs. 3.1%), significantly better mental QOL and significantly shorter hospital stay (2.0 *vs.* 4.0 days). However operating time was significantly longer with the robotic approach (2.2 *vs.* 1.5 hours). During their experience, the authors modified their technique to add a fourth robotic arm, a vessel loop to guide the stapler, CO_2 insufflation, and specimen removal though a supra-diaphragmatic 15 mm access port—changes which reduced operating times and conversions. Cases with larger tumours, hilar node involvement, or previous chemoradiation for nodal involvement were not excluded, amounting to enlarged indications for minimally invasive lung cancer resection. The authors commented that the robot made it possible to perform an "outstanding" node dissection.

Schmid's group in Innsbruck (12) in 2011 compared posterior (first five patients) and anterior robotic techniques in a learning series of 26 patients. Median hospital stay was 11 days (range, 7-53 days), median operating time was 228 min (range, 162-375 min), and one death occurred within 30 days. The group initially favoured the robotic technique, but in a review stated (13) that they had returned to VATS for major lung resection as the clinical advantages of the robotic approach were insufficient to justify the greater expense and longer operating times.

In 2012 Louie *et al.* (14) published a case-control evaluation of 53 consecutive robotic lobectomies or segmentectomies and 35 anatomic VATS resections, with nodal stations sampled in both groups. Although surgical and postoperative outcomes were similar in the two groups, robotic cases had significantly shorter duration of narcotic use and earlier return to normal activities. The authors reported that the two approaches afforded similar possibilities for performing mediastinal lymph node dissection; however robotics gave greater confidence in dissecting hilar lymph nodes.

The publication of Park *et al.* (15) is the only one so far to evaluate long-term oncological outcomes after robotic lobectomy. This study examined 325 consecutive patients who underwent robotic lobectomy for NSCLC at three centres (two in Italy, one in the USA) between 2002 and 2010. Most (76%) cancers were stage I, 18% were stage II, and 6% were stage III. Median follow-up was 27 months. Overall 5-year survival was estimated at 80% [95% confidence interval (CI): 73-88%]: 91% (95% CI: 83-99%) for stage IA, 88% (95% CI: 77-98%) for stage IB, and 49% (95% CI: 24-74%) for stage II. For stage IIIA patients, 3-year survival was 43% (95% CI: 16-69%). These findings suggest that robotic lobectomy for NSCLC affords long-term stage-specific survival consistent with historical results for VATS and thoracotomy.

The number of lymph nodes removed was used as an indirect indicator of oncological radicality in the comparative studies of Veronesi *et al.* (5) and Cerfolio *et al.* (11). Median numbers of lymph nodes removed were indistinguishable in the robotic and open procedures, suggesting that the robotic approach achieves similar oncological radicality to that achieved by thoracotomy. Two other studies (14,16) found no differences in numbers of lymph nodes removed by VATS and robotic lobectomy for lung cancer.

The frequency of nodal metastases identified in clinically node-negative cases is another indirect indicator of oncological radically. The paper by Park *et al.* (15) on 325 robotic lobectomies found that 13% of stage I cases were upstaged to N1. This is similar to upstaging rates reported after open surgery by Boffa *et al.* 2012 (17) and higher than VATS (18) suggesting that robotic surgery may offer better radicality than VATS. Wilson *et al.* (19) retrospectively reviewed patients with clinical stage I NSCLC after robotic lobectomy or segmentectomy at three centres. They found the overall rate of pathologic nodal upstaging of 10.9%, 6.6% for hilar (pN1) upstaging and 4.3% for mediastinal (pN2) upstaging. After comparing their findings to those for VATS and open thoracotomy as reported in recent publications (2,17,18,20) and adjusting for clinical T stage according to the AJCC, 7^{th} edition, the authors concluded that rate of robotic pathologic nodal upstaging for clinical stage I NSCLC was superior to that for VATS and similar to that for thoracotomy.

Park *et al.* (21) reported that the initial capital cost of the da Vinci robot system was about a million USD in 2008, annual maintenance was 100,000 USD, and cost of disposables 730 USD per operation. They estimated that it was about 3,981 USD more expensive to use per operation than VATS. Nevertheless the robotic operation was cheaper than open thoracotomy (by about 4,000 USD), mainly because thoracotomy patients remained in hospital longer.

The costs of using a robotic system for lobectomy and wedge resection were evaluated in a recent study by Swanson *et al.* (22) in which records of 15,502 lung surgery cases from the Premier hospital database were analysed. Only 4% of surgeries were robot assisted and a propensity score was used to create well matched groups for analysis. Using robotic assistance was associated with higher average hospital costs per patient: lobectomy, USD 25,040.70 for robotic *vs.* USD 20,476.60 for VATS (P=0.0001); wedge resection USD 19,592.40 *vs.* USD 16,600.10 (P=0.0001). The study also found that operating times were longer for both lobectomy (robotic 4.49 *vs.* VATS 4.23 hours; P=0.0969) and wedge resection (robotic 3.26 *vs.* VATS 2.86 hours; P=0.0003). Length of stay was similar with no differences in adverse events. Another recent study Nasir *et al.* (23) analysed "approximate financial data" for robotic lung operations performed by one North American surgeon (282 lobectomies, 71 segmentectomies, 41 conversions to open). Median hospital charges were USD 32,000 per patient with hospital profit of USD 4,750 profit per patient. Major morbidity occurred in 9.6%, 30-day operative mortality was 0.25%, and 90-day mortality was 0.5%. And median patient reported pain score was 2/10 at examination 3 weeks after discharge. The authors commented that although these costs were high they were still profitable for the hospital.

Cost analysis of the author experience showed a mean total cost for a robotic lobectomy of around 12.000 euros which is covered by the Italian health reimbursement with no net profit or loss for the hospital.

Robotic lobectomy—technique

Techniques for robotic lobectomy vary. The Milan group uses a four-arm system—three robot arm ports and a utility incision (5). Other authors (4,8) in New York and Pisa started out using three arms, but later adopted a four-arm technique. Dilewski *et al.* (10) and Cerfolio *et al.* (11) use a four-arm technique but making a utility incision only at the end of the procedure because they insufflate the chest cavity with CO_2 to facilitate access. The position of the utility incision (mainly to remove the surgical specimen) varies with surgeon preference. Veronesi and Park use a fourth intercostal space incision, Dylewski *et al.* 2011 (10) use a subcostal 2-4 cm trans-diaphragmatic incision, and Cerfolio *et al.* (11) an incision between ribs 9 and 10 that can be used to extract large tumours. Gharagozloo *et al.* (9) use a hybrid robotic-VATS technique.

Preoperative assessment and indications

Indications for robotic lobectomy do not differ from those for VATS lobectomy. Patients must have adequate cardiopulmonary reserve, and lesions that are resectable by lobectomy or segmentectomy. Some surgeons (10,11) are using robotic lobectomy on patients with advanced lung cancer after induction treatment, lymph node involvement,

Figure 1 Positions of entry ports for right lobectomy with a utility incision in IV or V intercostals space a camera port in VII or VIII i.c. space and two posterior ports for robotic arms. The arrow indicates the direction of entry of the robot cart. The two blue cycles indicate the incisions used for the anterior videothoracoscopic approach with two ports.

and centrally located lesions that require bronchial sleeve resection, which apparently satisfactory results. Standard staging is performed and includes CT with contrast (chest, brain upper, abdomen), and CT/PET (positron emission tomography). For centrally-located lesions bronchoscopy is performed. CT-guided biopsy is performed when a preoperative diagnosis is necessary, for example in patients with co-morbidities, for lesions not highly suspiciousness for cancer, and for centrally located lesions that cannot be removed by (VATS) wedge resection.

Patient positioning and port placement

The patient is positioned in lateral decubitus and single-lung anaesthesia induced via a double lumen endotracheal tube. The robot is positioned slightly behind the patient's head (*Figure 1*).

Using the four-arm technique, three port incisions and a utility incision are made. First entry (if VATS wedge resection not performed, see below) is via a 1 cm incision through the eighth intercostal space at the level of the mid-axillary line, A 30-degree stereoscopic camera is inserted to explore the thoracic cavity and provide visual guidance for

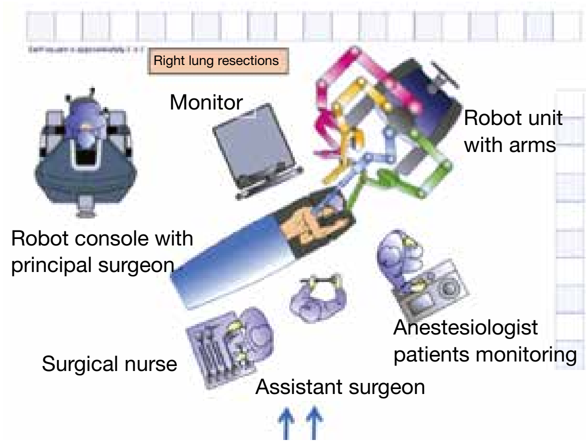

Figure 2 Operating room set-ups for right lung resections.

the successive 3 cm utility incision, which is made through the fourth or fifth intercostal space anteriorly (*Figure 2*). This is followed by an 8-mm incision at the eighth intercostal space in the posterior axillary line for the right robotic arm (on the right side), and another incision in the auscultatory triangle posterior, for the final robotic arm. This fourth incision makes it possible to retract the lung and better expose the operating field.

The ports are standard for all lobectomies except that, on the right side, the camera port through the seventh intercostal space is in the mid axillary line, whereas on the left side this port is moved 2 cm posteriorly (compared to the right) to avoid the heart obscuring vision of hilar structures.

Lesions without a preoperative diagnosis are first excised by standard VATS wedge resection followed by intraoperative frozen section examination.

Small or deep undiagnosed lesions can be located by injecting a solution containing ^{99}Tc-labeled colloid and radio-opaque (iodinated) tracer into the nodule under CT control not more than 24 hours before surgery (24). During surgery a gamma ray-detecting probe is introduced through a port to precisely locate the ‘hot’ nodule and guide the wedge resection.

The lobectomy commences by isolating hilar elements using a hook or spatula and two Cadière graspers. The hook is manipulated by the right arm of the robot introduced through the utility thoracotomy for right side dissections or through the posterior trocar in the eighth intercostal space for left side lobectomies. One of the Cadière graspers (fourth robotic arm) is used to retract the lung and expose structures. The other grasper is manipulated by the left arm of the robot and used to grip structures during dissection. When a hilar vessel or bronchus is ready to be surrounded with a vessel loop for stapler introduction, a third grasper is introduced (substituting the hook). Vessels and the bronchus are sectioned using mechanical staplers introduced through a thoracoscopic port by the assistant surgeon after removal of a robotic arm. The pulmonary vein is usually the first structure to be isolated and divided. If the lesion is in the right upper lobe, vein resection is followed by isolation of the branches of the pulmonary artery and sectioning, followed by isolation of the bronchus and bronchus sectioning. If the lesion is in the right lower lobe or left lung, after pulmonary vein sectioning, the bronchus is usually isolated and stapled before the artery. When performing middle lobectomy, the most favourable sequence is vein, bronchus and artery.

The incomplete fissure is usually prepared with an Endo GIA Autosuture stapler (Coviden) introduced by the assistant surgeon through one of the ports. The lobe is extracted through the anterior utility thoracotomy in an Endo Catch (Covidien) pouch.

Lymph node dissection

While suspicious lymph nodes are usually removed before lobectomy, radical lymph node dissection is performed after lobectomy using the same technique as in open surgery. Para-tracheal lymph node dissection is performed on the right side without azygos vein division. The mediastinal pleura between the superior vena cava and the azygos vein are incised. The lymph nodes, together with the fatty soft tissue of the region of the Barety space, are removed en bloc using a hook and Cadière grasper. In patients with large quantities of mediastinal fat or very large lymph nodes an UltraCision harmonic scalpel (Ethicon) may be used.

The nodes of the subcarinal station are removed after resection of the pulmonary ligament and retraction of the lung towards the anterior mediastinum to expose the posterior mediastinum. Bronchial arteries can usually be avoided thanks to good visibility, if not they are simply coagulated; a clip is not usually required. Tachoseal is sometimes applied to the fissure surface to reduce air leakage. A single 28 Ch (Tyco Healthcare) pleural drain is positioned at the end of the operation.

Segmentectomy

Anatomic segmentectomy is excision of one or more bronchopulmonary segments, with ligation and division of the bronchi and vessels serving those segments. Usually bronchial, hilar, and mediastinal vascular lymph nodes are examined intraoperatively and only patients with N0 disease receive segmentectomy; others receive lobectomy (25). Segmentectomy and also wedge resection—removal of a small wedge-shaped portion of the lung without intraoperative examination of sampled nodes—have been viewed as mainly suitable for elderly patients or those with impaired lung function, who cannot tolerate lobectomy (26), particularly since the publication of a randomized trial comparing sublobar resection (segmentectomy or wedge resection) with lobectomy in patients with T1-2N0 NSCLC, able to tolerate lobectomy (26,27). After a minimum follow-up of 4.5 years, the trial survival was non-significantly worse, and there were more recurrences (significant) in the sublobar resection arm; however failure seemed to mainly occur in patients who received wedge resection (26,27). By contrast non-randomized studies have reported similar survival rates for segmentectomy and lobectomy (28-30). Furthermore a 2014 meta-analysis (31) which examined overall survival and disease-free survival in patients who underwent sublobar resection and were eligible for lobectomy, found that long-term survival was similar for sublobar resection and lobectomy patients.

Interest in performing segmentectomy has grown since the results of the randomized National Lung Screening Trial (NLST) were published in 2011. This trial, which enrolled 53,000 high-risk North American smokers over 55 years of age, found that mortality was reduced by 20% in the low dose CT-screened arm compared to the arm screened by chest radiography (32).

As result of this study lung cancer screening is becoming more widely adopted (33) and small early-stage lesions cancers will constitute an increasing proportion of lung cancers diagnosed. It is likely that many of these small cancers will be adequately treated by segmentectomy or wedge resection which could ideally be performed using minimally invasive robot-assisted surgery. A number of ongoing trials are now re-examining the role of sub-lobar resection for small early-stage lung cancer.

The Cancer and Lymphoma Group B (CALGB 140503) is conducting a prospective, randomized multi-institutional phase III trial to determine whether sublobar resection is non-inferior, in terms of survival and recurrence, to lobectomy in patients with a small (≤2 cm) single peripheral lesion, confirmed as stage IA NSCLC (34). The trial aims to recruit about 1,300 patients.

Another randomized phase III non-inferiority trial is being conducted in Japan (35). Patients with a single peripheral stage IA NSCLC lesion ≤2 cm are randomized to segmentectomy/wedge resection *vs.* lobectomy. The trial aims to recruit 1,100 patients from 71 institutions over 3 years.

A Milan is co-coordinating an Italian multicentric phase III randomized trial comparing sublobar resection to standard lobectomy. The aim is to recruit 810 patients over 3 years. Eligibility criteria are similar to those of the trials cited above. However there will also be preoperative stratification with CT-PET to identify a subgroup who are PET-negative, have a lesion ≤1 cm, or both. Eligibility criteria are checked intraoperatively and if satisfied patients are randomized. For patients in the PET-negative/≤1 cm subgroup, lymph node sampling is not performed before randomization and if randomized to segmentectomy/wedge resection, receive only lung resection. Patients randomized to lobectomy receive both lobectomy and lymphadenectomy. Patients with nodule >1 cm and positive at PET receive lymph node sampling with preoperative frozen section: only those with a negative frozen section at three lymph node levels and negative margin at resection line are randomized.

Robotic segmentectomy—published experience

Few papers on robotic pulmonary segmentectomy have been published. The first appears to be a multicentric study involving groups in Milan, the Memorial Sloan Kettering Cancer Center, New York, and Hackensack University Medical Center, New Jersey (36,37). The study reported on 17 patients (7 men, 10 women), mean age 68.2 years (range, 32-82 years) who underwent robotic pulmonary segmentectomy from 2008 to 2010. Mean operating time was 189 minutes (range, 138-240 minutes). Median postoperative stay was 5 days (range, 2-14 days). There were no conversions to VATS or thoracotomy and no postoperative deaths. Early postoperative complications consisted of one (5.9%) case of pneumonia and two (11.9%) cases—both with emphysema—of prolonged air leak. Most cancers (64.7%) were in a lower lobe. Median tumour size was 1.11 cm (range, 0.6-2.8 cm) with NSCLC in 8, typical carcinoid in 2, and lung metastases in 7. In three patients the metastases appeared to be from colon cancer, and in one case each were compatible with breast cancer, adenoid carcinoma, gastrointestinal trophoblastic tumour, and osteogenic sarcoma. Six of the primary lung cancers were pN0, and two were pN1. This initial experience was considered encouraging because it offered all the advantages of minimally invasive surgery plus those inherent in the robotic system. In particular, it proved easy to perform radical dissection of the mediastinal and hilar lymph nodes, with no major bleeding, chylothorax or recurrent laryngeal nerve injury. By contrast, lymphadenectomy with VATS can be challenging (38).

The 2014 paper of Toker *et al.* (39) reported on 21 patients (15 with malignant disease) who underwent robotic pulmonary segmentectomy using the da Vinci System. There were no conversions. Four patents had postoperative complications. Mean operating time (at the robotic console) was 84 minutes [standard deviation (SD) 26, range, 40-150 minutes]. Mean duration of chest tube drainage was 3 days (SD 2.1, range, 1-10 days) and mean postoperative hospital stay was 4 days (SD 1.4, range, 2-7 days). The authors removed a mean of 14.3 (range, 2-21) nodes from mediastinal stations, and 8.1 (range, 2-19) nodes from hilar and interlobar stations. They concluded, with the previously cited study, that that robot-assisted thoracoscopic segmentectomy for malignant and benign lesions was practical, safe, and associated with few complications and short postoperative hospitalization. They noted that the number of lymph nodes removed appeared "oncologically acceptable" for early lung cancer patients, and that to evaluate postoperative pain, respiratory function and QOL, a prospective comparison with VATS was necessary.

During robotic segmentectomy, it can be challenging to identify intersegmental planes. A new technique to identify these planes has been recently described (40). After division, within the hilum, of the bronchus, vein, and artery of the target segment, the non-toxic fluorescent dye indocyanine green (ICG) is introduced through the peripheral vein catheter, and the robot visual system is changed to fluorescence mode. Mediastinal and parenchymal tissue appears green 30-40 seconds after infusion. The coloration reaches maximum intensity after about a minute and fades slowly. Thus, perfused lung parenchyma becomes green, while the isolated segment (to be removed) remains un-coloured, affording excellent demarcation of the segment and facilitating transection along intersegmental planes with endoscopic staplers. Since lung palpation is not possible with the robotic technique, the clear view of intersegmental planes that ICG affords makes it easier to ensure adequate distance between the lesion and the resection margin. This procedure has so far been used on few patients but appears promising.

Robotic segmentectomy—technique

Principle of anesthesia, patient position and room set up are similar to those or lobectomy.

The position and number of ports is the same as robotic lobectomy described above, and port placement does not vary with side or type of segmentectomy. The isolation of segmental elements is usually performed using a Cadiere and a hook cautery. The ligation of the vascular branches is either performed with an endovascular stapler or between Hem-o-Lok clips (Teleflex Medical, Research Triangle Park, NC). The parenchima is divided with multiple firings of the endoscopic stapler. Lymph node dissection and postoperative care follow the principles of lobectomy.

Conclusions

Randomised studies comparing vats versus robotic approach are not available so far and few papers describe a long term results after robotic resection for lung cancer. The experiences described in the literature confirm that robotic approach is a good and safe alternative to videothoracoscopic approach, and is considered an easier and more intuitive procedure to afford difficult cases, or anatomical segmentectomy. The improved view and intuitive movements seem to favor an increased radicality in locally advanced disease at mediastinal level.

The paradigm shift—encapsulated by the phrase "from maximum tolerated treatment to minimum effective treatment"—hat has involved many areas of surgical oncology, may now also be widely adopted by thoracic surgeons.

Main limitation of robotic procedures is still represented by higher costs of the technique compared to vats as a single company is on the market thus no competition able to reduce prices is possible.

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Footnote

Conflicts of Interest: I've been proctor in robotic thoracic surgery for Abi medicar.

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Robotic lung segmentectomy for malignant and benign lesions

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Objective: Surgical use of robots has evolved over the last 10 years. However, the academic experience with robotic lung segmentectomy remains limited. We aimed to analyze our lung segmentectomy experience with robot-assisted thoracoscopic surgery.

Methods: Prospectively recorded clinical data of 21 patients who underwent robotic lung anatomic segmentectomy with robot-assisted thoracoscopic surgery were retrospectively reviewed. All cases were done using the da Vinci System. A three incision portal technique with a 3 cm utility incision in the posterior 10th to 11th intercostal space was performed. Individual dissection, ligation and division of the hilar structures were performed. Systematic mediastinal lymph node dissection or sampling was performed in 15 patients either with primary or secondary metastatic cancers.

Results: Fifteen patients (75%) were operated on for malignant lung diseases. Conversion to open surgery was not necessary. Postoperative complications occurred in four patients. Mean console robotic operating time was 84±26 (range, 40-150) minutes. Mean duration of chest tube drainage and mean postoperative hospital stay were 3±2.1 (range, 1-10) and 4±1.4 (range, 2-7) days respectively. The mean number of mediastinal stations and number of dissected lymph nodes were 4.2 and 14.3 (range, 2-21) from mediastinal and 8.1 (range, 2-19) nodes from hilar and interlobar stations respectively.

Conclusions: Robot-assisted thoracoscopic segmentectomy for malignant and benign lesions appears to be practical, safe, and associated with few complications and short postoperative hospitalization. Lymph node removal also appears oncologically acceptable for early lung cancer patients. Benefits in terms of postoperative pain, respiratory function, and quality of life needs a comparative, prospective series particularly with video-assisted thoracoscopic surgery.

Keywords: Lung resection; robotic surgery; segmentectomy; lung cancer

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Introduction

Anatomic segmentectomy of the lung is the removal of a segment of the lobe. For many decades pulmonary segmentectomy has been used for the treatment of bronchiectasis and tuberculosis via thoracotomy. Recently, with the developments in video instrumentation and refinements in surgical techniques, segmentectomy has been a popular approach with video-assisted thoracic surgery (VATS). It has been preferred for tumors smaller than 2 cm and negative lymph nodes (1,2) and for larger tumors in patients with poor pulmonary function who could not tolerate lobectomy, especially those who do not have visceral pleural invasion (2,3). Although VATS has been used for segmentectomy for the past 5 years, robotic anatomic lung segmentectomy has been reported to be feasible only in two articles in the pubmed search (4,5).

As an academic thoracic surgery center performing minimally invasive anatomical lung resections with VATS for 8 years, we have recently developed a robotic surgery program with the da Vinci Robotic System (Intuitive Surgical, Inc, Mountain View, California, USA) which started on October 2011. In this study we aimed to analyze the segmentectomy operations performed for various etiologies.

Figure 1 (A) The CT shows an 84-year-old male with squamous cell carcinoma who previously had colon carcinoma; (B) the CT shows a 37-year-old male admitted with hemoptysis, after bronchoscopy revealed no pathology. He underwent a left lower lobe common basal segmentectomy with the diagnosis of echinococcus alveolaris; (C) the CT shows a 67-year-old male with a history of undiagnosed cerebral mass of 1 cm. He underwent mediastinoscopy and resection of superior segment of right upper lobe. Pathology revealed adenocarcinoma.

Patients and methods

From the prospectively recorded database, anatomical segmentectomy patients' data was retrieved. The data was analyzed for age, gender, etiology, pulmonary function tests, complications, mortality, duration of chest tube and duration of postoperative hospital stay. The number of mediastinal lymph node stations dissected and the number of dissected lymph nodes in patients with either primary or secondary lung cancer were also analyzed. For metastasectomies only single lesions close to the segmentary bronchus and primary lung cancer smaller than 2 cm were candidates for robotic segmentectomy operations (*Figure 1*). Patients who had primary lung tumors larger than 2 cm but smaller than 4.5 cm (2 patients) with compromised pulmonary functions were also underwent robotic common basal segmentectomy operations. According to our protocol; all patients who had an indeterminate nodule, or proven lung cancer or a possible metastatic lung cancer, had a PET-CT. Mediastinoscopy was reserved only for the patient who had a possible brain metastases.

Robotic operations for indeterminate nodules were performed after localization of the nodule either with operative view (retraction of visceral pleura), after palpation with finger prior to the docking without access thoracotomy, or from 3 dimensional (3D) images of chest tomography.

All operations were performed by a single console surgeon (AT). All patients had anatomical segment resections as described below. Chest tubes were removed during the hospital stay if the length of stay was shorter than 5 days. If the drainage lasted longer and patients did not have any other problems (one patient), then the patients were discharged with chest tubes attached to the Heimlich valve.

Surgical technique

The patient was positioned on lateral decubitus position. The table was tilted either anteriorly or posteriorly depending on the type of segmentectomy operation to be performed. For superior segments of both lower lobes and posterior segment of the right upper lobe anterior tilt was preferred. For the resection of other segments a posterior tilt was preferred. Three ports were opened while trying to keep 10 cm between each port and 10 to 15 cm from the target which was hilum of the lobe containing the segment to be resected. The camera was placed in the middle port. The robot was docked from the posterior of the patient with 30 to 45 degrees between the vertebral column of the patient and transverse axis of the cart (*Figure 2*).

With the robotic camera in up position, ports and instruments were placed and pleural symphyses were divided. Service port was performed at 10^{th}-11^{th} intercostal space at the posterior part of the thoracic wall. The rest of the operation was done with the camera in down position. Maryland or curved bipolar forceps for right arm and prograsper for left arm were used as needed. Segmentectomies were performed by dissecting the fissure and removing the nodes around the segmentary artery and bronchus. Arteries and veins were clipped with Hem-o-Lok (Teleflex Medical, Research Triangle Park, NC) or stapled with a vascular stapler. Bronchus was always stapled (*Figures 3-5*). Imaginary intersegmental plane was stapled after ventilating

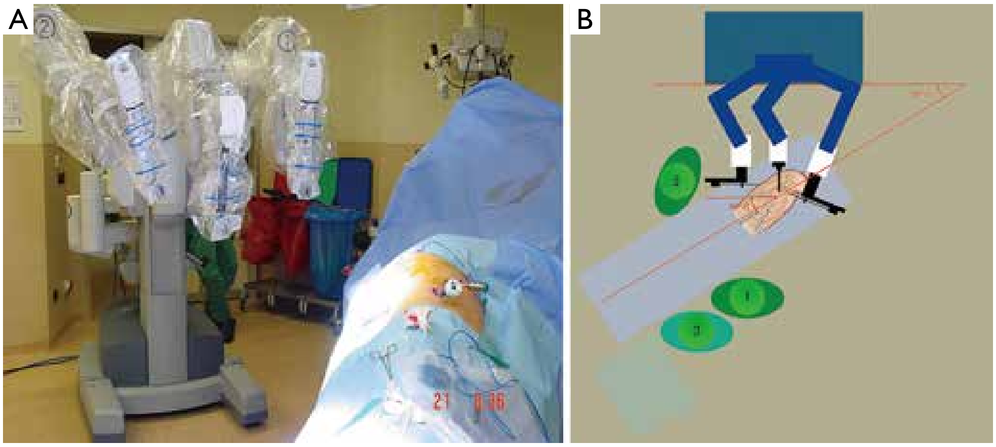

Figure 2 Docking of da Vinci. Arm numbers should be seen by the surgeon 1 at the table (arrows). The transverse axis of the da Vinci approaches from posterior of the patient with 30 to 45 degrees to vertebral column of the patient. 1, surgeon responsible from docking (may shift to console); 2, assistant surgeon is responsible for service, retraction, clipping and stapling; 3, nurse position.

Figure 3 Resection for a lingual sparing left upper lobectomy needs division of the superior segmentary vein, and proximal arteries to the left upper lobe and apicoposterior segment of the upper lobe bronchus.

Figure 4 Robotic right lower lobe superior segmentectomy (6). Available online: http://www.asvide.com/articles/257

Figure 5 Robotic mediastinal lymph node dissection (7). Available online: http://www.asvide.com/articles/258

Table 1 Data of patients who underwent pulmonary segmentectomy operation

Items	RATS (n=21) [range]
Age	59±16 [28-84]
Gender	
Male	12 (57.1%)
Female	9 (42.8%)
Side	
Right	10 (47.6%)
Left	11 (52.3%)
Location	
Upper lobe	8
Apicoposterior right	4
Lingula sparing lobectomy	2
Lower lobe	13
Superior segmentectomy	5
Common basal segmentectomy	8
Mean duration of Console time (minutes)	84±26 [40-150]
Mean FEV_1 (mL)	2,278±662 [1,274-4,870]
Mean duration of drainage (days)	3±2.1 [1-10]
Mean duration of postoperative stay (days)	4±1.4 [2-7]
Morbidity rate	4 (19%)
Mortality rate	0
Pathology	
Malignant	15 (71.4%)
Benign	6 (28.5%)
Mean number of lymph nodes dissected from mediastinum (stations 2-9) (nodes)	14.3 [2-21]
Mean number of lymph nodes dissected from N1 stations (10-11-12) (nodes)	8.1 [2-19]
Mean number of mediastinal stations dissected	4.2 [2-6]
Pain scale	
Visual analog scale on postoperative day 2 and day 15	3.4-1.4
Histology of primary lung cancer	
Adenocarcinoma with lepidic pattern	5
Adenocarcinoma	3
Squamous cell carcinoma	2
Large cell neuroendocrine tumor	1
TNM staging of primary lung cancer patients	
T1aN0M0	6
T1bN0M0	2
T1aN1M0	1
T1bN1M0	1
T2aN0M1	1

and deflating the remnant lung. In none of the patients, glues or sealants were used. Chest was closed by placing a single 28 F chest tube from the camera port.

Pain management

Routine pain management was with intercostal blocks to two intercostal spaces upper and two intercostal spaces lower around the ports (not more than 20 mL Marcaine) (Astra Zeneca, Istanbul) and 1 gram perfalgan (Bristol-Myers Squibb, New York City) intravenous infusion every 6 hours, and voltaren SR 75 mg (Novartis, Basel) are given through intramuscular route twice a day until chest tube is removed. After the removal of the chest tube or discharge of the patient oral medication with paracetamol and non-steroid anti-inflammatory drugs were given. Visual Analog Scale (VAS) was recorded by the anesthesiologists at 48 hours after the operation and by surgical team on postoperative day 15 as a part of data collection for possible evaluation of our pain management approach.

Results

The mean age was 59 (range, 28-84) years. Twenty-one segmentectomies, 10 from the right lung and 11 from the left lung were performed. Eight patients had a segmentectomy from the upper lobes and 13 patients from the lower lobes. Common basal segmentectomy (eight patients) and superior segmentectomy of the lower lobes (five patients) were the most commonly employed segmentectomies. Mean duration of console time was 84±26 (range, 40-150) minutes. Mean force expiratory volume (FEV_1) in the first second was 2,278±662 (range, 1,274-4,870) mL. The mean duration of chest tube drainage and postoperative hospital stay were 3±2.1 (range, 1-10) and 4±1.4 (range, 2-7) days respectively. Conversion to open surgery was not necessary. Postoperative complications occurred in four patients (19%). The prolonged air leak (>5 days) was the cause of morbidity in all patients. None of the patients experienced a major cardiopulmonary complication. The mean number of mediastinal stations and number of dissected lymph nodes were 4.2 and 14.3 (range, 2-21) lymph nodes from mediastinal stations and 8.1 (range, 2-19) lymph nodes from hilar and interlobar stations, respectively. VAS was 3.4 and 1.4 on postoperative day 2 and day 15 (*Table 1*). The mean diameters of the malignant lesions were 1.9 (range, 1-4.3) cm. There were eight (72.7%) adenocarcinoma histology including five patients with lepidic pattern as the most common primary lung cancer. Eight patients (72.7%) out of 11 primary lung cancer were recorded to be in stage 1A. Six patients were operated on for benign diseases (bronchiectasis one patient, granuloma four patients and echinococcus alveolaris one patient). Four patients had segmentectomy operation for single pulmonary metastases (three patients for colon carcinoma and one patient for uterus leiomyoma).

Discussion

VATS segmentectomy has been proved to be a safe procedure with fewer complications and a reduced hospital stay when compared with an open segmentectomy (8). The peri-operative outcome, including operative time, blood loss, duration of chest tube drainage and length of hospital stay, have been shown to be similar in another comparative study (9). This study also demonstrated that thoracoscopic segmentectomy is feasible with regard to peri-operative and oncological outcomes for Stage IA non-small cell lung cancer (NSCLC), especially T1a and carefully selected T1b descriptor (9). Thoracoscopic segmentectomy has been compared to thoracoscopic lobectomy when analyzing oncologic results in small (≤2 cm) peripheral stage IA NSCLC (10). Local recurrence rates with thoracoscopic segmentectomy (5.1%) have been reported to be similar to the thoracoscopic lobectomy (4.9%). No significant difference has been observed in 5-year overall or disease-free survival (10). Recent literature also demonstrated support for less invasive video thoracoscopic surgical techniques in pulmonary segmentectomy operations like uniportal and total thoracoscopic segmentectomies (11,12).

It is clear that, as lung screening programs increase around the world, the need for minimally invasive segmentectomies is also increasing. Certainly, robotic lung segmentectomies might be another minimally invasive lung segment resection technical option.

Growing knowledge of robotic lobectomies for lung cancer would provide additional experience for performing segmentectomy operations for lung cancer. Yet, there are only two articles published to assess the feasibility of robotic segmentectomy operation (4,5). In one of them Dylewski *et al.* (5) reported 35 segmentectomy patients and in the other Pardolesi *et al.* (4) reported 17 segmentectomy patients. Mean duration of surgery was reported to be 189 minutes with no major intraoperative complications and conversion to open procedure was reported as unnecessary (4). In this study postoperative morbidity rate was 17.6% with a median postoperative stay of 5 (range, 2-14) days, and postoperative mortality was 0% (4). The final pathology was reported to be NSCLC in eight patient, typical carcinoids in two, and lung metastases in seven. Because the other study (5) described a robotic series of almost 200 patients with mainly lobectomies, we do not have a detailed data regarding to segmentectomy operations.

Our indications and perioperative and postoperative outcomes are quite similar to those of Pardolesi and colleagues (4). In our experience, 15 out of 21 patients (75%) were operated on for malignant lung diseases. Conversion to open surgery was not necessary. Postoperative complications occurred in four patients (19%). Mean console robotic operating time was 84±26 (range, 40-150) minutes which was quite similar to that of Dylewski's experience (5). The duration of our console time was shorter than the reported experiences even with VATS. Mean duration of chest tube drainage and postoperative hospital stay were 3±2.1 (range, 1-10) and 4±1.4 (range, 2-7) days respectively, which was also quite similar to the above mentioned study (4). The mean number of mediastinal stations and number of dissected lymph nodes were 4.2 and 14.3 (range, 2-21) lymph nodes. From hilar and interlobar stations, a mean of 8.1 (range, 2-19) lymph nodes were dissected in patients primary or secondary lung cancer. We need to stress that, five of our patients were not good candidates for lung resection due to compromised pulmonary, renal and cardiac problems. But we did not experience any adverse event in those patients. Our surgical technique demonstrated similarities with those of Pardolesi's (4). However, our access port, similar in size to their experience (4), was located at posterior thoracic cavity at 10^{th}-11^{th} intercostal space. This port may not only have allowed the greater movement of the equipment within the cavity but also may have avoided the disturbance of the mammary gland in female patients. In our experience, we used only one Maryland forceps or curved bipolar forceps and one Prograsper forceps for each patient. Expenditures for these including the drapes cost a total of 600 USD, excluding the maintenance and initial costs of the robot.

The major difficulty in robotic segmentectomy operation is the resection without palpation. This could be overcome by palpating and tattooing the lesion prior to the implementation of the robotic arms. If this was not possible, 3D images could be used to identify the lesion, the vessels and the bronchus. Segmentectomy operation with robotic surgery requires a good knowledge of the anatomy of pulmonary vessels and bronchi in each patient (13).

The foreknowledge of the anatomy of each patient would contribute to the safety and accuracy of the operation (13). It has been reported that presurgical planning based on patient's actual 3D pulmonary model was useful for patients with stage IA NSCLC ≤2 cm in diameter and for selecting an appropriate VATS lung resection for an individual (14). Apparently, this may be a required preoperative technique in robotic segmentectomy as well. Although we only had three patients with this preoperative investigation, we discussed with experienced radiologists before each operation to delineate the borders of resection from axial, coronal and sagittal tomographies. Especially for metastasectomies, we believe that CT image evaluation on monitor with a qualified radiologist is essential to ensure that the lesion is solitary.

Robotic segmentectomy may provide better dissection capabilities around smaller vessels and the lymph nodes around lobar and segmentary bronchi. However, developing these techniques may require preparation and patience to overcome the difficulties of a correct docking, developing dissection techniques.

Yet, the provided data and results about performing robotic segmentectomies may not fully satisfy the thoracic surgical community. However, we have demonstrated that the robotic anatomic lung segmentectomy is a feasible and safe procedure with an acceptable operating time, adequate lymph node dissection, less pain and few complications.

Acknowledgements

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Subxiphoid uniportal video-assisted thoracoscopic middle lobectomy and anterior anatomic segmentectomy (S3)

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Abstract: The video-assisted thoracoscopic surgery (VATS) approach for combined lobectomy and segmentectomy in the same lung is an infrequent procedure, rarely reported in the literature. Currently, Most of the surgeons still use 2–3 thoracic incisions for thoracoscopic anatomic resections. However, the uniportal approach is gaining worldwide acceptance in the recent years. The main advances of uniportal VATS during the last years are related to improvements in surgical technique by implementing new technology. The experience acquired with the uniportal technique allows expert uniportal VATS surgeons to explore new approaches in order to minimize even more the surgical invasiveness. Recently the aim to avoid the intercostal nerve damage created by the transthoracic incision has led to the creation of a novel procedure entitled uniportal VATS subxiphoid approach. Here we report the first case of a lobectomy combined with anatomic segmentectomy performed through a uniportal subxiphoid approach.

Keywords: Subxiphoid approach; uniportal VATS; segmentectomy; lobectomy; uniportal subxiphoid

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Introduction

The video-assisted thoracoscopic surgery (VATS) approach for combined lobectomy and segmentectomy is an infrequent procedure, rarely reported in the literature. There is no doubt that VATS is currently a better choice than thoracotomy for segmentectomies. However, anatomical segmental resections are more demanding procedures because they require a better knowledge of the distal lung anatomy (1). These lung sparing procedures are usually indicated for deeply located benign lesions, metastasis or early stage lung cancer such as ground glass opacities (GGO). Several studies recently published have shown that segmentectomies can be performed safely without compromising oncologic results in this group of patients (2).

Most of the surgeons doing segmentectomies implement a thoracoscopic approach through a transthoracic utility incision of 4–6 cm, with one to three additional ports in different positions (3). However, the anatomic resection can be performed by opening only one intercostal space, through a single utility incision. Since 2011, when the first uniportal VATS lobectomy was published (4), the single incision technique has been stablished as the approach of choice in many thoracic departments all over the world (5,6). Since then, a growing number of articles are available in the literature showing the feasibility, safety and good outcomes of this procedure for major pulmonary resections (7,8). Recently the aim to avoid the intercostal nerve damage created by the transthoracic ports has led to the creation of a novel procedure described in 2014 for lobectomy through a single subxiphoid incision (9). Here we report the first case of a lobectomy combined with anatomic segmentectomy performed through a uniportal subxiphoid approach (10).

Clinical case

A 53-year-old female was admitted to our department for surgery. The patient suffered from cough, and a CT

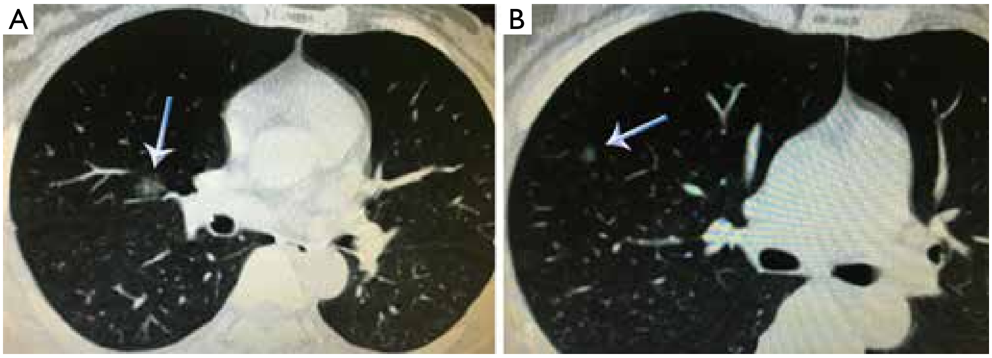

Figure 1 CT scan showing the GGO lesions located on the middle lobe (A) and on the anterior segment of the right upper lobe (B).

Figure 2 Subxiphoid uniportal video-assisthed thoracoscopic middle lobectomy and anterior anatomic segmentectomy (10). Available online: http://www.asvide.com/articles/904

scan revealed two GGO lesions located in the Middle lobe and anterior segment of RUL (S3) respectively (*Figure 1*). Pulmonary function tests were normal. The patient was proposed for uniportal VATS subxiphoid middle lobectomy and anterior anatomic segmentectomy of the right upper lobe.

Surgical technique (*Figure 2*)

The procedure was performed under general anesthesia and double lumen endotracheal intubation. The patient was positioned in lateral position with 60 degrees of inclination. The surgeon and scrub nurse were located in front of the patient and the assistant in the opposite side. A 3-cm midline vertical incision was made below the sterno-costal triangle, (longitudinal incision is made when the infrasternal angle is <70°). The rectus abdominis was divided and the xiphoid process was partially resected in order to have more space for instrumentation. Upon finding the infra-sternal angle between the xiphoid process and the subcostal margin, the right pleura was opened by finger dissection via the infra-sternal angle above the level of the diaphragm. The pericardial fatty tissue was removed and a wound protector was placed. The use of a wound protector helps the insertion of the camera and instruments, without the need of a sternal lifter. A 10-mm, 30-degrees video camera and double articulated instruments combined with several specific longer VATS instruments were used through the same subxiphoid incision. The lung was free of adhesions and a middle lobectomy and anterior anatomic segmentectomy of the right upper lobe (S3) were performed. The mean postoperative time was 70 minutes. A single chest tube was placed at the end of the operation through the subxiphoid incision.

Postoperative pain was managed with PCA (Patient-controlled analgesia) pump as required with sufentanyl citrate 1 mL: 50 mcg and regular medication with flurbiprofen 50 mg every 4 hours alternated with paracetamol 1 gr every 4 hours.

The postoperative course of the patient was uneventful, the chest tube was removed on the second postoperative day and the patient was discharged home on the 4th postoperative day with no complications. The final pathology revealed the GGO located on the middle lobe as a 1.2-cm adenocarcinoma *in situ* and no malignancy was found in the anterior segment lesion of the RUL.

Discussion

The subxiphoid approach is a variant of uniportal VATS approach without opening the intercostal space. It has been employed during the last years for thoracic minor procedures such as thymectomies, pulmonary

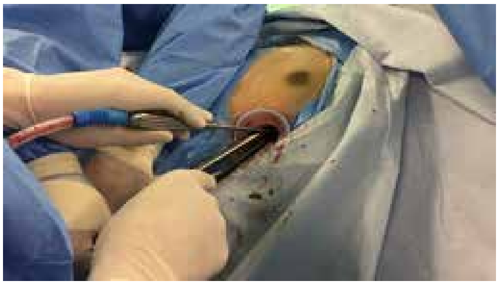

Figure 3 Surgical photo showing bimanual instrumentation through the subxiphoid incision.

metastasectomies, pneumothorax (11,12).

However, this technique was recently introduced for major pulmonary resections in selected patients. After reviewing the literature, we have found few cases reporting about the subxiphoid approach incision for lobectomy (9) showing similar values to transthoracic uniportal VATS with regards to chest drain duration, hospital stay, operating time, rate of conversion and complications (8). Based on our previous experience with the uniportal VATS technique, we started to perform the subxiphoid approach for lobectomy with the potential advantage of decreased postoperative pain, better cosmesis and easier specimen retrieval compared to the transthoracic approach (13). Segmental anatomic resections are more complex procedures and require a perfect knowledge of the distal lung anatomy (14). The increased use of low-dose CT for screening will result in more diagnosed lung cancer in the early stage (15) therefore segmentectomy is being performing more frequently. For GGO lesions, anatomic segmentectomy should be sufficient for complete removal without risk of recurrence, and conserves an important amount of normal lung tissue in order to maintain better lung function (16).

To attempt the subxiphoid approach it is mandatory to have a previous experience in uniportal VATS lobectomies and a skilled assistant. As it happens with the transthoracic uniportal approach, bimanual instrumentation is crucial to achieve a good anatomic hilar dissection through a single incision (*Figure 3*). The view is caudal-cranial and anterior to posterior. The access for the view of the posterior mediastinum is difficult. Particularly challenging and difficult to accomplish is the need to apply traction to the lung in order to assess the lesions as well as the complete resection of subcarinal lymph node dissection. Moreover, this technique has several limitations such as the control of major bleeding and the performance of a complete oncologic lymph node dissection. When an emergent conversion to open surgery is necessary, an extension of the subxiphoid incision is unlikely to be useful and an additional thoracotomy must be performed. Despite these disadvantages, this novel approach has potential for widespread use after the developing of new technology, wireless cameras, instruments adapted to this approach or single port robotic technology also adapted to the subxiphoid approach (17).

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

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Footnote

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

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Totally thoracoscopic left upper lobe tri-segmentectomy

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With continued growing interest in sublobar resections from the international surgical community (1,2), mastering thoracoscopic segmentectomy is an important challenge for the surgeon. With respect to sublobar resections of the left upper lobe, it is now considered that for T1 tumors, a lingual-sparing upper lobectomy is oncologically equivalent to an upper lobectomy (3).

The main segmental resections involving the left upper lobe are: tri-segmentectomy (S1 + S2 + S3) (lingula-sparing lobectomy), apicoposterior segmentectomy (S1 + S2) and lingulectomy (S4 + S5). In this article, we will describe the technique of a full thoracoscopic approach and illustrate it with a video. Lymph node dissection is similar to lymphadenectomy for an upper lobectomy and hence will not be described here.

Clinical summary

The presenting case is a 66-year-old female patient who had an incidental finding of a nodule during follow-up of a severe chronic obstructive pulmonary bronchitis. The nodule was 1 cm in diameter and was located at the junction between the posterior and apical segments of the left upper lobe (*Figure 1*). PET-CT revealed an isolated tumor (SUVmax: 2.7). As the patient was fragile and had a FEV1 of 61% predicted, it was decided to perform a sublobar resection.

Anatomical landmarks

The landmarks are obtained from CT-scans with 3-dimensional reconstruction (*Figure 2*). The use of CT reconstruction can be helpful at the beginning of a thoracoscopic experience (4,5).

Bronchi

The segmental bronchi are concealed by arteries which must be divided first (*Figure 2A*). The upper lobe bronchus

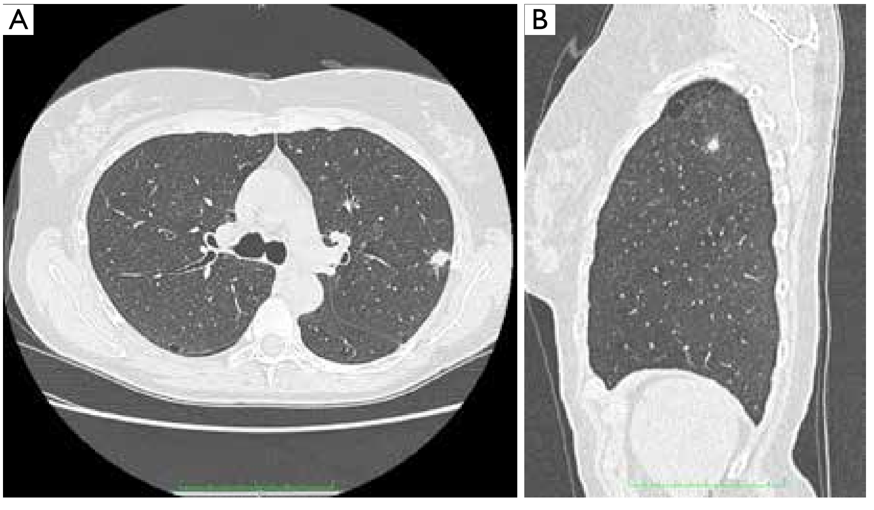

Figure 1 Preoperative CT-scan.

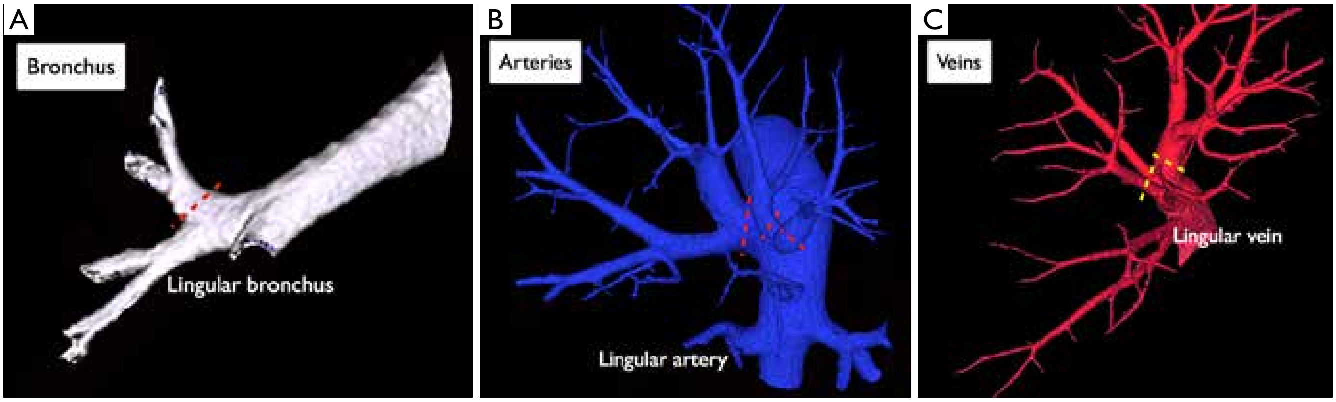

Figure 2 Anatomical landmarks. (A) Bronchi; (B) Arteries; (C) Veins. Dotted lines: level of division.

splits immediately into the lingular bronchus and a common stem which separates into an anterior bronchus and an apicoposterior bronchus. These segmental bronchi have short courses which can make their dissection and identification difficult.

Arteries

The truncus anterior, posterior and lingular arteries supply the left upper lobe (*Figure 2B*). The truncus anterior is often broad and short and supplies the apico-posterior and anterior segments. The posterior segmental arteries originate in the fissure and distribute themselves over the curve of the pulmonary artery. Their number varies from 1 to 5, but most often from 2 to 3. All but the lingular artery, must be divided.

Veins

The superior pulmonary vein usually has three major tributaries (*Figure 2C*). The superior branch drains the apicoposterior segments and frequently blocks access to the apicoposterior arteries. The middle branch drains the anterior segment and the lowermost branch drains the lingula. The latter must be preserved.

Technique

The procedure is performed under general anesthesia with split ventilation using a double-lumen endotracheal tube. Patients are positioned in the right lateral decubitus position. We use a deflectable scope housing a distal CCD (LTF, Olympus, Tokyo, Japan) connected to a high definition camera system (HDTV) (Exera II, Olympus, Tokyo, Japan). Only endoscopic instruments are used. These are inserted through 3 to 4 trocars, depending on whether an additional lymph node dissection is performed. Ports are inserted as indicated in *Figure 3*.

The procedure is similar to a left upper lobectomy, sparing the lingular vessels and the anterior portion of the fissure.

Step 1: division of the fissure and arteries

The lobes are separated to expose the middle portion of the fissure. The upper lobe is gently pulled forward, avoiding any undue traction which could injure the vessels. Dissection is conducted cephalad and all encountered posterior arteries are divided by turn. Traction helps exposing the first segmental artery whose dissection is usually easy. It is controlled by clipping, with a vessel sealing device or with a combination of both.

As the posterior segmental arteries are sequentially divided, the upper lobe unfolds and uncovers the posterior aspect of the truncus anterior which can be approached posteriorly. It is then also dissected from above and from the front, using various views thanks to the deflectable scope. Gentle blunt dissection is used to clear the origin of the trunk. If the trunk bifurcates into two large branches, these are dissected with caution and stapled independently.

An inferior branch of the truncus anterior is present in one-quarter of patients (*Figure 4*). It is usually impossible to predict whether this branch supplies the anterior segment or the lingula or both. When in doubt, it is advisable to preserve it.

Step 2: division of the segmental veins

The upper lobe is retracted posteriorly. The mediastinal

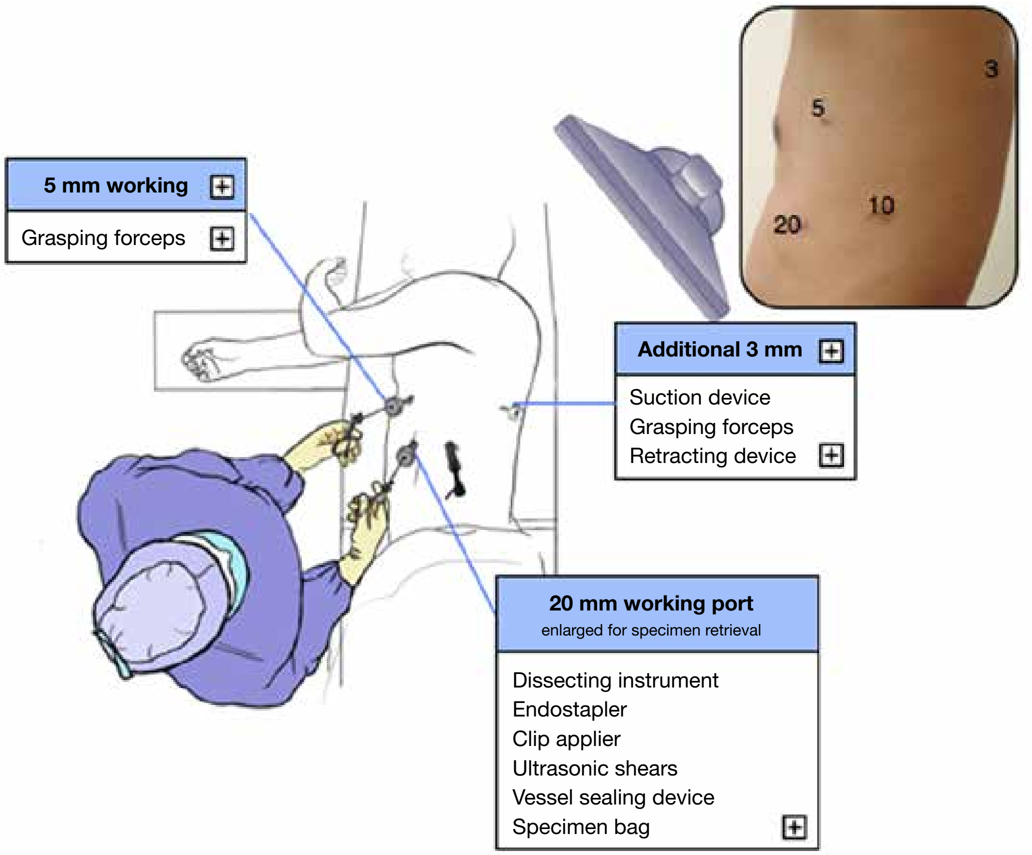

Figure 3 Ports for totally thoracoscopic left upper lobe tri-segmentectomy.

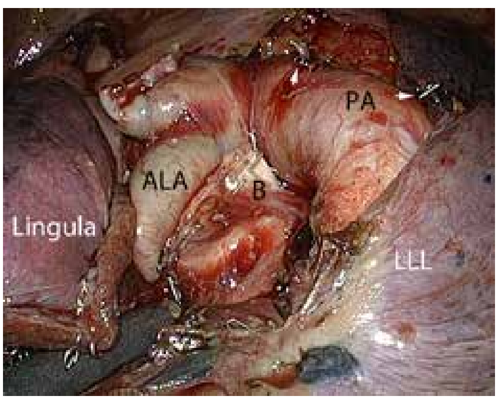

Figure 4 Accessory lingular artery arising from the truncus anterior. ALA, accessory lingular artery; PA, pulmonary artery; B, bronchial trunk; LLL, left lower lobe.

pleura is then incised posterior to the phrenic nerve. Dissection of the vein is achieved by a combination of blunt dissection and bipolar electrocautery. Only the two superior branches are divided using either a stapler, or clips or a vessel sealing device, depending on their diameter. The inferior tributary which drains the lingula is preserved (*Figure 5*).

Step 3: division of the bronchial trunk and parenchyma

Once the arteries and veins have been divided, traction on the parenchyma helps to expose the segmental bronchi. The origin of the lingular bronchus is visualized and the upper trunk—which separates into an anterior bronchus and an apico-posterior bronchus—is exposed, cleared using a blunt tip dissector and stapled as a stem (*Figure 6*).

The parenchyma must be stapled between the lingula and the upper division. A clamp is applied on the parenchyma, the lung is reventilated to identify the intersegmental plane and the parenchymal division is then performed using an endostapler loaded with thick-tissue staples.

The specimen is removed in the usual fashion and the inferior pulmonary ligament is divided.

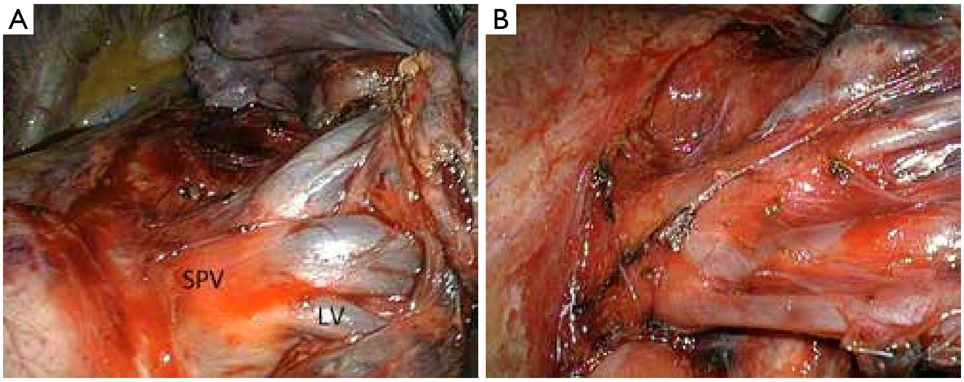

Figure 5 Exposure of the superior pulmonary vein. (A) Normal distribution; (B) Multiple branches. SPV, superior pulmonary vein; LV, lingular vein.

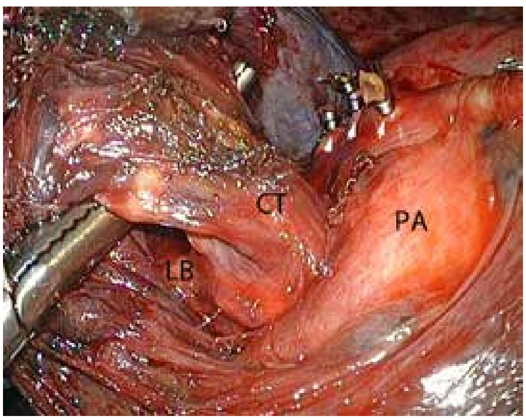

Figure 6 Exposure of the bronchus. CT, common bronchial trunk; LB, lingular bronchus; PA, pulmonary artery.

Comments

A left trisegmentectomy is similar in conduct to a right upper lobectomy. However, control of the truncus anterior may be more difficult on the left side because there are more anatomical variations and because the artery can be short.

Possible risks of the procedure are as follows:

- ❖ Inadvertent injury of the lingular vein when the distribution of the superior pulmonary vein comprises multiple small branches, as shown in *Figure 5B*;
- ❖ Twisting of the lingular segments when the anterior part of the fissure is loose. If in doubt, the lingula must be anchored to the lower lobe;
- ❖ Confusion between the anterior bronchus (B3) of the common trunk and the lingular bronchus;
- ❖ Ignorance of an accessory lingular artery that could be mistaken for a branch of the truncus anterior (*Figure 4*).

Some authors advocate against using stapling for division of the parenchyma because this can impair the expansion of the lingular segments (6). As shown in the video, this has not been an issue in our practice. Although stapling can slightly reduce the volume of the lingula, it has the major advantage of minimizing postoperative air leaks. In our series of 129 thoracoscopic segmentectomies, with stapling of the intersegmental plane, the mean postoperative stay was 4.9 days and only one patient had a prolonged air-leak. Miyasaka *et al*. failed to demonstrate a difference in postoperative complications and pulmonary function, between stapling of the intersegmental plane and division with electrocautery (7).

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Thoracoscopic superior segmentectomy

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Clinical vignette

The patient is a 59-year-old formerly smoking male with a history of T2N0M0, stage I colon cancer. He underwent a left hemicolectomy five years prior to presentation and was referred for an enlarging 7 mm pulmonary nodule noted on surveillance imaging. His past medical history was significant for coronary artery disease and hypertension. Given the deep location of the pulmonary nodule and the patient's limited pulmonary function, we opted to perform a diagnostic and therapeutic superior segmentectomy.

Surgical technique

Preparation

All patients undergoing a pulmonary resection are evaluated pre-operatively with pulmonary function testing (spirometry and diffusion capacity). Upon arrival at the operating room and induction with general anesthesia via a dual lumen endotracheal tube, the patient is placed in a lateral decubitus position with the bed flexed just above the hip. The surgeon stands anterior to the patient and the assistant drives the thoracoscope while standing posteriorly to the patient.

Exposition

The patient is prepped and draped in a sterile fashion. We use a two-incision approach—the first incision is at the eighth interspace at the posterior axillary line and the second access incision is at the fifth interspace anteriorly. The access incision is approximately 3 cm in length.

Operation

The hemithorax is explored for evidence of pleural disease, effusions, or additional, unexpected pulmonary nodules. The presence of the lung nodule of interest is confirmed. The lung is retracted superolaterally as the inferior pulmonary ligament is incised, along with the pleura anterior and posterior to the hilum. With the lung retracted superolaterally, the inferior pulmonary vein is encountered first. The branch draining the superior segment is identified, circumferentially dissected out and ligated. More superolateral retraction reveals the lower lobe bronchus, and the segmental bronchus to the superior segment is identified. Once the superior segmental bronchus is circumferentially dissected out and transected, more superolateral retraction on the lung exposes the pulmonary artery. The pulmonary artery branch to the superior segment is circumferentially dissected out and ligated.

Upon division of the hilar structures, the fissure is completed and the parenchymal margin is divided. The parenchymal margin is occasionally identified by a segmental fissure. Otherwise, a test inflation may assist in delineating the parenchymal margin. The segment is removed from the hemithorax in a specimen bag. All structures are divided using a linear stapler with a vascular load for the vein and artery and a 3.5 to 4.5 mm load (or equivalent) for the bronchus and parenchyma.

Completion

Upon completion of the segmentectomy, a mediastinal lymph node dissection is performed. The vascular and bronchial stumps are inspected for hemostasis. A thoracostomy tube is introduced via the camera incision and the lung is reinflated under direct visualization. All ports and the camera are then removed. The anterior access incision is closed using absorbable suture to reapproximate the serratus fascia and skin.

Comments

Clinical results

Segmentectomy was originally popularized as a procedure for tuberculosis, bronchiectasis and other suppurative pulmonary processes. While still useful in this scenario, segmentectomy is now more commonly utilized in the treatment of early stage lung cancer in patients with limited pulmonary function and in the treatment of pulmonary metastasectomy. Although a technically more challenging operation than lobectomy, segmentectomy has been shown to have similar complication rates, local recurrence rates, and 5-year survival (1). The only randomized trial comparing sublobar pulmonary resection with lobectomy demonstrated a higher recurrence and cancer-related death rate in the sublobar resection cohort (2). However, this study did not distinguish between wedge resection and segmentectomy. The study also did not specifically assess the role of segmentectomy in smaller nodules and one third of the tumors were greater than 2 cm. A more recent series by Okada *et al*. reviewed the outcomes of segmentectomy versus lobectomy in over 500 patients with tumors less than 2 cm (3). They report that the 5-year survival in both cohorts were similar.

Advantages

A meta-analysis of 24 studies from 1990 to 2010 demonstrated the benefit of lobectomy over sublobectomy—but not over segmentectomy—in overall survival and cancer specific survival for patients with stage I NSCLC (4). This survival advantage was lost, however, in patients with stage IA tumors less than 2 cm. Current literature suggests that compared to lobectomy, segmentectomy has equivalent cancer-free survival and local control with its main advantage being preservation of lung parenchyma (5). Postoperative pulmonary function testing in patients undergoing lobectomy found a significantly decreased forced expiratory volume in one second (FEV1) at two and six months and reduced exercise capacity when compared to patients undergoing segmentectomy (6). Reduced morbidity, decreased hospital length of stay, and lower cost are additional advantages of thoracoscopic segmentectomy over segmentectomy by thoracotomy (5). Furthermore, when compared to wedge resection of small pulmonary nodules, segmentectomy has been associated with a better lymph node dissection and increased parenchymal margin (7).

Caveats

Despite its advantages, thoracoscopic segmentectomy is more technically challenging than lobectomy. Additionally, this technique should be reserved for small pulmonary lesions (≤2 cm) that can be fully resected with an adequate parenchymal margin by segmentectomy. Data from randomized trials investigating the role of segmentectomy versus lobectomy are currently under way.

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None.

Footnote

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

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Case Presentations

Minimally invasive VATS left upper lobe apical trisegmentectomy

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Clinical vignette

The patient is a 75-year-old female with a 40-pack-year smoking history. Low dose lung screening computed tomography (CT) scan found a 1-cm left upper lobe (LUL) mass. The patient denies any hemoptysis, weight loss, bone pain or neuro status changes. Her pulmonary function tests are not normal. Her pulmonary function tests demonstrated that the forced expiratory volume (FEV_1) was 58% of predicted FEV_1 and 80% of predicted diffusion lung capacity (DLCO). A lingular sparing LUL apical tri-segmentectomy was thus planned.

Surgical techniques

Preparation

The patient is intubated with a dual lumen endotracheal tube. The left lung is then isolated. The patient is positioned on a beanbag in the right lateral decubitus position, with the left side up. The break in the table is between the level of the nipples and the iliac crest.

Exposition

Four incisions are made.

1st incision (2 cm): inferiorly and medial, one space below mammary crease, generally in the 6th intercostal space and tunneled posteriorly. A finger is placed into the thoracic cavity and the costophrenic angle palpated.

2nd incision: mid axillary line, between 8th or 9th intercostal space. A 5-mm trocar is placed through the space to accommodate the 5-mm, 30-degree thoracoscope.

3rd incision (4-5 cm): utility incision is made in the intercostal space directly over the level of the superior pulmonary vein. This incision is 4 cm and is started on the anterior border of the latissimus muscle and extended anteriorly. A wound retractor is placed in this incision to keep the tissues from co-apting and causing a vacuum during the use of the suction device.

4th incision: four fingers below tip of the scapula, halfway to spine in the auscultatory triangle.

Operation

The thoracoscope is inserted and the hilum is exposed. The level 5 & 6 lymph nodes are dissected free. The lung is retracted laterally and posteriorly through the posterior and the anterior incisions. The Vagus and recurrent laryngeal nerve are identified and preserved. Dissection is carried out along the superior border of the superior pulmonary vein as far up onto the hilum as possible, generally until the descending aorta is visualized. This will help in freeing the superior aspect of the anterior trunk of the pulmonary artery. The superior pulmonary vein is inspected and care is taken to ensure that a common trunk is not present. The lingular vein is identified and preserved. The veins draining the superior segment are isolated. A stapler is passed from the 4th incision below the scapula and the veins transected.

The lung is now pulled inferiorly to help expose the anterior trunk of the pulmonary artery. Lymph nodes present on the LUL bronchus must be dissected free. This node dissection will in turn aid visualization of the anterior trunk and allow for safer dissection of the plane between the bronchus and the anterior trunk. The plane between the bronchus and the anterior trunk is established. A stapler is passed from the 4th incision below the scapula and the anterior trunk is transected. The second branch is often visible from this exposure and may be taken at the same time as the anterior trunk.

Through the posterior incision, the lung is now positioned superiorly and slightly anteriorly. There will often be a slight notch in the periphery that can aid in identifying where the fissure should be, between the apical trisegment and the lingula. The pulmonary artery is identified in the hilum/fissure. A stapler passed through incision 1 separates the lingula from the apical trisegment to the level of the hilum. Blunt dissection is used to create a tunnel between the artery and the rest of the fissure. The lung parenchyma is lifted away from the artery, exposing the tunnel created on top of the artery. A stapler is passed through incision 1 and the fissure is transected. This is repeated until the fissure is completely transected. The lingual and the posterior segment are rolled forward onto the stapler anvil which is held in place and not advanced. The lingular artery is identified and preserved. This in essence duplicates a division of the fissure between the lingual and the upper division from posterior to anterior.

The lung is then returned to its anatomic position and the lingula is retracted superiorly and anteriorly via the posterior port. The pulmonary artery is again identified and now dissected in the fissure to expose the upper lobe arterial branches. Then the lingular artery is identified and kept safe. The stapler is passed from incision 1 and the artery to the posterior segment is divided, taking care not to injure the lingular artery. Careful inspection is carried out to ensure all arterial branches to the apical trisegment have been transected. If any remain they may be transected either from incision 1 or 4, depending on which incision allows for the safest angle of approach.

The lung is now retracted anteriorly to help expose the bronchus. The bronchus is dissected towards the lung parenchyma until the carina between the upper division and the lingula is identified. A stapler passed from incision 1 is used to transect the upper division bronchus, while taking care to preserve the lingular bronchus.

Completion

Upon division of the segment, it will be placed in a large Cook brand lap sack and removed via the utility incision (#3 incision). Local anesthetic is used to accomplish intercostal nerve blocks from T2-T8. Chest tubes are placed. The incisions are then closed in three layers.

Comments

Clinical results

We evaluated the results of our institutional outcomes for VATS trisegmentectomy (1). A total of 73 VATS trisegmentectomies were performed between 1998 and 2010. The average age was 72 years old; 49 female, 24 male. Diagnoses for the trisegmentectomies included: primary lung cancer 91% (66/73), benign disease 4% (3/73) and metastatic disease 5% (4/73). Of the patients undergoing VATS trisegmentectomy for primary lung cancers, 68% (45/66) were for stage IA, 17% (11/66) were for stage IB, 15% (10/66) were for stage 2 and above. A total of 73 LUL trisegmentectomies were performed. The mean hospital stay for patients undergoing VATS trisegmentectomy was 3.8 days (SD =3.3) *vs.* 5.5 days (SD =7.9) for VATS LUL lobectomy P=0.0736 (P>0.05). There was no statistical difference in overall complication rates between the two groups. There was also no difference in survival between patients undergoing VATS trisegmentectomy and those undergoing LUL lobectomy for either stage IA lung cancer or stage IB lung cancer.

Advantages

We believe that segmentectomy can be performed by VATS with no more morbidity or mortality than that for VATS lobectomy (1,2). Additionally, LUL trisegmentectomy provides the same chance of survival as lobectomy for stage IA and IB tumors (1,3). Transecting parenchyma for the segmentectomy does not translate into a longer stay than post lobectomy (1,4). The lingula does not need to be resected for small apical lung cancers, as LUL trisegmentectomy provides the same survival as lobectomy for stage IA and IB tumors (1-5). Our experience supports the use of lingula-sparing trisegmentectomy in the treatment of IA and IB lung cancer.

Caveats

The biggest concern for a cancer operation is survival rates. In our series, the overall survival was the same for the segmentectomies and the lobectomies. That rate however, can be affected by many factors, including staging and comorbidities. Some studies have shown better survival with lobectomy, however the debate continues in regards to optimal approaches.

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Footnote

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

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Case Presentations

A 2-cm single-incision thoracoscopic left upper division segmentectomy

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Background: A video-assisted thoracic surgery (VATS) sublobar resection for early lung malignancy has been applied recently in selected patients with the improvement in surgical technique.
Methods: From 2012, we began VATS segmentectomy with 2-cm single incision in early lung cancer (T1a, tumor size <2 cm) and no lymph node metastasis with preoperative dual localization for lung lesion.
Results: In the video clip, we performed a 2-cm single-incisional VATS segmentectomy for early lung cancer at left upper lobe upper divisional segment and lymph node dissection using a 5-mm thoracoscope, articulating or curved endoscopic devices. Dual localization for lung lesion could help to identify the specific location of lung lesion. The potential benefits of single-incisional VATS segmentectomy include less intercostal pain, better postoperative outcomes more over than less incisional scar.
Conclusions: A single-incision VATS segmentectomy might be a feasible option for the treatment of early lung cancer in selected patients.

Keywords: Segmentectomy; minimally invasive thoracic surgery; single-incisional thoracoscopic surgery; video-assisted thoracic surgery (VATS)

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Single-incision thoracoscopic segmentectomy with ultra-small (2 cm) incision could be a feasible option for treatment in early lung cancer.

Video-assisted thoracic surgery (VATS) is an approach for performing thoracic procedures, and usually performed through three or four access ports with minimal incisions and no rib spreading (1). This approach is associated with not only less postoperative pain and low morbidity and mortality in the immediate postoperative period (2), but also with a shorter hospitalization time and lower medical costs (3).

Recently, there has been renewed interest in a single-incision thoracoscopic surgery. Most thoracic procedures using conventional multi-port VATS could be performed through a single, minimal incision (3-5 cm), with acceptable outcomes in treating lung malignancy (4). It has been reported that single-incision VATS is feasible even in complex VATS procedures, such as sleeve resection, segmentectomy, and vascular reconstruction (5-7). However, the potential advantages of this variant of VATS still remain controversial.

It has generally been accepted that sublobar resections, specifically segmentectomy and wedge resection, should be considered for patients in whom lobectomy is contraindicated because of insufficient lung reserve and comorbidity. Sublobar resection is still not a standard treatment for early lung cancer. However, it could be an alternative, low-risk option for cT1N0 or smaller cancers in selected patients because of the better postoperative courses relative to lobectomy. With the increased detection of early, and therefore smaller, lung lesions, lobectomy may

Figure 1 A 2-cm single-incision thoracoscopic left upper division segmentectomy (13).
Available online: http://www.asvide.com/articles/687

no longer be the most appropriate standard procedure for the removal of small lesions because smaller tumors have a better prognosis and a lower chance of local recurrence or systemic metastasis. Segmentectomy could promise better postoperative outcomes and quality of life, with lower surgical risks, in patients with poor lung function (8).

There have been a few reports of single-incision VATS segmentectomy with surgeons using their own methods and instruments (9). At our center, we began using single-incision VATS in 2009 in patients with pneumothorax or in those who required a simple wedge resection. We have performed more than 100 surgical cases of anatomic resection since 2010. We began using single-incision VATS segmentectomy in 2012 and then minimized the incision length to 2 cm by using the 3-mm thoracoscope in 2014. Our rationale for this ultra-minimal incision is based on our surgical experiences, which have shown the feasibility of applying segmentectomy to early lung cancer without compromising surgical outcomes (10).

In addition, preoperative localization with hookwire, lipiodol, or radioisotope (^{99m}Tc) has been routinely employed in our center for patients who were indicated for lung segmentectomy and who had no contraindications (11,12). Preoperative localization helps to identify the specific location of small lung lesions during VATS and prevents inappropriate division of the intersegmental plane. In addition, double localization with lipiodol or occasionally with a radioisotope, could lower the likelihood of missing deep lung lesions during the procedure. Intraoperative real-time fluoroscopy was used to detect lesions injected with lipiodol and a thoracoscopic gamma probe was used to detect deep lesions injected with radioisotope.

In this video (*Figure 1*), we performed a 2-cm single-incision VATS segmentectomy and complete lymph node dissection in a patient with a ground glass lesion at the left upper divisional segment, and suspected the presence of cT1aN0 lung cancer. During the operation, along with a 5-mm thoracoscope, we used an articulating device, a curved endoscopic instrument, and specially designed graspers with a shorter shaft length. An energy device was used for tissue dissection and endostaplers were used for vascular and fissural division. We used vascular clips for small segmental vascular branches, wherein the surgical angles made the use of staplers difficult. Whether to dissect lymph node in all station in early lung cancer is controversial. We sampled the aortic and subcarinal lymph nodes. There was no difficulty in removing the resected segment through the 2-cm incision because the volume of the lung segment was not large and could be removed through the small incision.

Considering our smaller incision (2 cm), complex, single-incision VATS might be still difficult for VATS beginners, and even for experts. The potential advantages of single-incision VATS include less postoperative pain and shorter hospital stays, compared to multiport VATS. However, it is still unclear whether using a smaller incision during single-incision VATS is superior to conventional VATS and this should be addressed in future studies. VATS has evolved from using three or four incisions, 2-5 cm in length, to a single, 3-5 cm incision, with an aim towards a more minimally invasive approach. Further attempts, such as the use of a 2-cm incision in the present study, could promote the future development of related instruments and high definition cameras with smaller diameters. The recent introduction of a robotic surgical system for single port surgery reflects the current trends for developing minimally invasive surgical approaches.

In summary, single-incision VATS segmentectomy could be performed safely and without difficulty, even through a 2-cm incision, by using an appropriate combination of conventional instruments and a thoracoscope with a small diameter, as well as a high definition system.

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Case Presentations

Video-assisted thoracic surgery left S1+2+3 segmentectomy for lung cancer

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Abstract: A 49-year-old female presented with a solitary pulmonary nodule on the chest screening computed tomography (CT) scan. The nodule was 1.3 cm in diameter and located in the apical segment of left upper lobe. The lesion was considered to be cT1aN0M0 non-small cell lung cancer (NSCLC) and a 3-port video-assisted thoracic surgery (VATS) wedge resection was performed. Intraoperative frozen sections revealed a lung adenocarcinoma. Therefore, sequential S1+2+3 segmentectomy of the left upper lobe was performed, also systematic lymph node dissection was carried out. The final pathological stage was pT1aN0M0 (Ia).

Keywords: Video-assisted thoracic surgery (VATS); segmentectomy; systematic lymph node dissection; lung cancer

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Introduction

Although the use of segmentectomy for early lung cancer is still controversial, it has recently been accepted as a radical surgery for cT1aN0M0 non-small cell lung cancer (NSCLC). This surgery can be performed safely as open procedure (1,2). According to several recent reports, the clinical outcomes of segmentectomy are equal to lobectomy (1-4).

A 49-year-old female presented with a solitary pulmonary nodule on the chest screening computed tomography (CT) scan. The nodule was 1.3 cm in diameter and located in the apical segment of left upper lobe. The lesion was considered to be cT1aN0M0 NSCLC. There were no remarkable enlarged lymph nodes in pulmonary hilum and mediastinum on CT scan. No distal metastasis was found according to preoperative examinations including abdominal CT scan, enhanced head MRI and bone scanning. Pulmonary function was normal. Video-assisted thoracic surgery (VATS) wedge resection was thus performed and intraoperative frozen sections revealed a lung adenocarcinoma. Therefore, sequential S1+2+3 segmentectomy of the left upper lobe was performed, also systematic lymph node dissection was carried out. The final pathological stage was pT1aN0M0 (Ia). The patient was well recovered and discharged on postoperative day 4.

Operative techniques (*Figure 1*)

The patient was positioned in the right lateral decubitus position and intubated with a dual lumen endotracheal tube. The surgeon stood in front of the patient, and the assistant stood behind the patient. Three-port approach was applied. The observation port was in the 8^{th} intercostal space at the middle axillary line about 1 cm in length. The main operation incision was in the 4^{th} intercostal space at anterior axillary line about 3 cm in length.The assisted operation port was located in the 8^{th} intercostal space at the posterior axillary line about 0.5 cm in length.

The nodule was in the apical segment of left upper lobe and palpable. Wedge resection was performed first and intraoperative frozen sections revealed a lung adenocarcinoma. Therefore, sequential S1+2+3 segmentectomy of the left upper lobe was decided to perform.

The upper lobe was gently retracted backward, the pleura covering the surface of superior pulmonary vein was opened with an electric hook. Combination of electric hook and blunt dissection, the S1+2+3 segmental pulmonary vein was dissociated, but the vein was not cut off yet. At the same time, the lingular vein should be identified and be preserved. Then pulled the upper lobe forward, opened the mediastinal pleura around the hilum and dissected

Figure 1 Video-assisted thoracic surgery left S1+2+3 segmentectomy for lung cancer (5).
Available online: http://www.asvide.com/articles/401

the anterior trunk of the pulmonary artery. Devided the posterior part of the fissure with endo-GIA (blue stapler) and continued to dissected the S3 segmental pulmonary artery, then the artery was devided with endo-GIA (white stapler). There was bleeding at the anterior trunk when the artery was dissected, and the artery was pressed with a gauze to stop the bleeding and to be dissected later. Therefor we retracted the upper lobe backward and cut off the S1+2+3 segmental pulmonary vein with endo-GIA (white stapler). The anterior trunk was visualized clearly when the vein was separated and the bleeding had already stopped, then the artery was devided with endo-GIA (white stapler). Now the S1+2+3 bronchus was dissected easily and the linguar bronchus could be identified clearly, then the S1+2+3 bronchus was devided with endo-GIA (green stapler). Lymph nodes around the bronchus were dissected at the same time. At last, the lung was re-inflated and the segmental boundary was identified, and endo-GIA (green stapler) was used to devide the parenchyma. The specimen was removed in a glove.

Systematic lymph node (include station 5, 7, 8 lymph nodes) dissection was carried out subsequently. Station 4L lymph node was invisible in this patient. At last, the inferior pulmonary ligament was divided.

To avoid damaging left recurrent nerve, the nerve shoule be dissected carefully. Also, the vagus should be preserved. Electric hook and ultrasonic scalpel was used in the procedure of lymphadenectomy. Aspirator also acts as an important role in this surgery.

Comments

With the advances in radiographic devices such as high-resolution computed tomography (CT) and the widespread practice of low-dose helical CT for screening, more and more early NSCLCs are detected (6). For some patients in high risk, there is a decreased likelihood of having a second or even a third NSCLC. So, segmentectomy is more often performed and it can be applied to complicated operation such as bilateral segmentectomy (7).

Because the assisted operation port is only 0.5 cm in length, the endo-GIA should be introduced into the thoracic cavity through the main operation port. Therefore, the artery should be divided first for VATS left upper lobectomy or S1+2+3 segmentectomy, then the vein and bronchus could be divided easily.

To avoid damaging more intercostal nerves, the observation port and the assisted operation port is always located in the same intercostal space. Postoperative chest pain could be reduced with a 0.5 cm assisted operation port.

Combination of electric hook and ultrasonic scalpel, and cooperated with aspirator can make the surgery smoothly.

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Footnote

Conflicts of Interest: The corresponding author has received a signed release form from the patient recorded on the video. The authors declare no conflict of interest.

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Case Presentations

Nonintubated thoracoscopic segmentectomy—left upper lobe trisegmentectomy

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Introduction

Enhanced computed tomography screening protocols have recently identified increasing numbers of small lung tumors in patients with high surgical risks (1). Consequently there has been increasing interest in minimally invasive surgical approaches, including thoracoscopic approaches, parenchyma-sparing resection, and less invasive anesthesia for management of lung tumors (2). The role of thoracoscopic segmentectomy is therefore increasingly reevaluated, not only as a traditional parenchyma-sparing procedure in high-risk patients with compromised medical conditions but also in patients with non-small cell lung cancer less than 2.0 cm (1).

From 2009, we started a nonintubated thoracoscopic surgery program for patients who were reluctant or unsuitable to have a conventional intubated single lung ventilation during thoracic surgery (3). With a combination of target-controlled sedation and regional anesthesia—either by thoracic epidural anesthesia or intercostal nerve blocks with intrathoracic vagal blockade—the results of nonintubated thoracoscopic surgery are encouraging (2-5). In the current video, we demonstrate how a nonintubated technique was applied in thoracoscopic segmentectomy and mediastinal lymphadenectomy to treat a patient with early stage lung cancer (*Video 1*).

Clinical vignette

A 74-year-old man, who had undergone a total gastrectomy for gastric cancer in a different institution in 2003, was transferred to our hospital for management of an incidentally discovered left upper lobe lung nodule. Computed tomography-guided biopsy of the tumor revealed a primary pulmonary adenocarcinoma. Preoperative pulmonary function tests showed that he had a mild obstructive defect with forced expiratory volume in one second being 84.9% of predicted. Considering his age and reduced lung function, lingual-preserving left upper lobectomy (left upper lobe tri-segmentectomy) was planned instead of left upper lobectomy to preserve more lung parenchyma after surgery.

Surgical techniques

Preparation

After standard monitoring, the patient was induced with target-controlled infusion of propofol. The patient spontaneously breathed oxygen through a ventilation mask. Depth of sedation and respiratory rate were monitored by bispectral index and capnography, respectively. The patient was then placed in the right lateral decubitus position.

Exposition

Thoracoscopic segmentectomy was performed using a 3-port method. The operative lung was deflated gradually after creation of an iatrogenic pneumothorax.

Operation

Under thoracoscopic guidance, we first performed intercostal nerve blocks by infiltration of 0.5% bupivacaine from the third to the eighth intercostal nerve under the parietal pleura, 2 cm lateral to the sympathetic chain. Vagal block was also produced at the level of the aortopulmonary window to prevent triggering of cough reflex. After identifying the tumor site, incomplete interlobar fissures to the affected segment was divided. Hilar dissection was then performed to isolate and divide the apicoposterior segmental artery, upper division of left superior pulmonary vein and upper division of left upper bronchus with endoscopic stapling devices. The resected segment was removed in a protective bag through the utility port. Mediastinal lymph node dissection was then performed.

Completion

At the end of the surgery, the operated lung was manually ventilated through the mask to check air leakage. A 28 F chest tube was placed through the lowest incision.

Comments

Using regional anesthesia—either by thoracic epidural anesthesia or intercostal nerve blocks—with intrathoracic vagal blockade and target-controlled sedation, we had performed 51 cases of nonintubated thoracoscopic segmentectomies, including anterior and apicoposterior segmentectomy of right upper lobe, lingulectomy and apical trisegmentectomy of left upper lobe, and superior segmentectomy of the lower lobes of both sides.

Clinical results

There were 44 patients with primary or metastatic lung cancer and 7 patients with benign tumors. No patients required conversion to a thoracotomy or lobectomy. However, one patient required conversion to intubated one-lung ventilation because of vigorous mediastinal and diaphragmatic movement. The mean duration of postoperative chest tube drainage and mean hospital stay were 2.2 and 4.8 days, respectively. Operative complication was only developed in one patient who had an air-leak for more than five days after surgery. No death or major complications occurred.

Advantages

The reasons to use nonintubated technique for thoracoscopic surgery are mainly to avoid adverse effects associated with general anesthesia and endotracheal intubation for single-lung ventilation. In our cohort, nonintubated patients reported less postoperative nausea and vomiting, early recovery of oral intake and clear consciousness, and better postoperative analgesia in comparison with intubated patients (2-4). In high-risk patients, such as the elderly, this technique also has fewer overall complication rates, compared to intubated general anesthesia (5).

Caveats

Although nonintubated thoracoscopic anatomical segmentectomy was feasible and safe in our cohort (2), further investigations are still necessary to clarify its efficacy and true benefits in different groups of patients, such as medically compromised patients or those with early stage lung cancer. For readers who hope to use this technique, we suggest a cooperative and well-communicating thoracic surgical team, including the thoracic surgeon and anesthesiologist.. Patients should be carefully selected in the early learning phase. Obese patients often use significant abdominal effort during respiration, associated with vigorous diaphragmatic movement after iatrogenic pneumothorax, which makes invasive hilar dissection difficult. Although intrathoracic vagal blockade may be effective to attenuate a cough reflex, surgeons are still reminded to retract the lung and manipulate the hilum gently. In cases of dissection of subcarinal lymph nodes, the contralateral main bronchus can be occasionally irritated, which might induce transient coughing. Oxygenation is usually satisfactory after supplemental oxygen during spontaneous one-lung breathing but mild to moderate hypercapnia may occur because of carbon dioxide rebreathing. Although the incidence of conversion to intubated general anesthesia or thoracotomy is low, a conversion protocol in cases of failed nonintubated method should be prepared in advance.

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Footnote

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VATS segmentectomy utilizing the Copenhagen approach

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Clinical vignette

The patient is a 68-year-old woman with a history of thoracoscopic (VATS) lobectomy of the right lower lobe in 2011 for T2aN0M0, stage Ib (4.9 cm) adenocarcinoma. She did not receive adjuvant chemotherapy and her comorbidities include hypertension and alcohol consumption. On follow-up computed tomography (CT) scans, a growing tumor central in the left upper lobe was discovered. Her pulmonary function tests demonstrated 69% of predicted FEV_1 and 59% of predicted DLCO. VATS left upper trisegmentectomy was scheduled. This article and the accompanying video (*Video 1*) will discuss the minimally invasive segmentectomy approach used in this case.

Surgical techniques

Preparation

The basic set-up used for a VATS segmentectomy is the same as previously described for VATS lobectomy (1,2). The patient is positioned on the side, with the table bending at the level of the xiphoid to allow the intercostal spaces to open. The surgeon and the assistant are positioned on the anterior (abdominal) side of the patient and with the surgeon cranially. All VATS segmentectomies are performed with a 10 mm, 30 degree angled HD video-thoracoscope. A double-lumen tube is used for deflation of the left lung.

Operation

A 4 cm anterior utility incision is made without any tissue retractor or rib spreading. The wound is protected by a plastic soft tissue retractor (Alexis Retractor, Applied Medical USA), which also improves exposure. This incision is later used for specimen retrieval and is positioned between the breast and the lower angel of the scapula in the fourth intercostal space, just anterior to the latissimus dorsi muscle. In case of a conversion to open procedure, this incision can be easily expanded to a 10 to 15 cm muscle sparring thoracotomy. Through this incision, the cavity is evaluated with the camera looking for unexpected pathology, adhesions, and the level of the diaphragm. A low anterior 1 cm camera-port is positioned at the level of the top of the diaphragm and anterior to the level of the hilum and the phrenic nerve. The third incision is 1.5 cm, positioned at the same level but more posteriorly and inferiorly from the scapula and anterior to the latissimus dorsi muscle. To palpate, free and prepare the structures, we used an array of peanut or sponge sticks and an electrocautery blade hook controlled with a normal surgical handhold. The tip of the hook can then be used to lift and divide the tissue. To present vessels and other structures to be divided, we use an elastic vessel loop made of rubber.

Localization of the tumor is confirmed by palpation. The pleura over the hilum is divided and the vein branches from the upper lobe segments are visualized. The plane between the artery and the upper lobe vein is opened, so the vein from the three upper segments can be exposed using a vessel loop. The branches are divided with a tan Tri-stapler (Covidien, USA) introduced from the posterior port. Next the superior branch of the pulmonary artery is divided in the same way and thereafter, a plane between the artery and the bronchus can be created. The bifurcation of the left upper and lower lobe bronchi is identified, and the left upper lobe bronchus is dissected to the next level of division to visualize the bronchus to the three upper segments. Following application of a sling, a purple Tri-stapler is subsequently introduced via the posterior port. The bronchi to the three upper segments are closed with the stapler and the left lung is inflated by the anesthesiologist. The borders of the segments are visualized and the level of division is confirmed, allowing subsequent division of the bronchus. Hilar lymph nodes are removed, followed by stapling with a purple or black Tri-stapler along the borders of the segments. The port protector is removed and the segment is removed in a protective bag.

Lymph node dissection is performed with an en-block removal of lymph nodes from station 5, 6, 7, 8. The remaining lung is inflated under water to ensure expansion and is then tested for air leak. Finally, one intercostal drain is placed through the anterior camera incision. After surgery, the patient was transferred to an intermediate ward and to the normal ward the day after.

Comments

Clinical results

The postoperative course of the patient was uneventful, with an in-hospital stay of four days. Final pathology revealed another primary lung cancer (adenocarcinoma 11 mm T1aN0M0, stage Ia). She was scheduled for follow up with CT scans for the next five years.

Advantages

The Copenhagen anterior approach for a VATS segmentectomy represents a standardized, effective approach to VATS lobectomy, with secure access to the mains vessels in the hilum. In case of conversion, the anterior utility incision can be expanded to a muscle sparring anterior thoracotomy within few minutes. The utility incision allows for bi-digital palpation of even small tumors deep in the lung parenchyma, making it easier to secure sufficient resection margin in segmentectomies.

Caveats

Since the approach is anterior, difficulties can occur during exposure of the posterior field in superior segmentectomies of the lower lobe. Occasionally, the camera is introduced through the posterior port in these cases. Like any other procedure, there is a learning curve. However for surgeons experienced in VATS lobectomy, this approach will allow shorter operative duration compared to transition from open to VATS lobectomy (3).

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Conflicts of Interest: Both authors declare they are speakers for Covidien. The authors declare no other conflict of interest.

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VATS left upper lobe posterior segmentectomy

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Abstract: A 56-year-old male patient was admitted due to one small pulmonary nodule in the posterior segment of left upper lobe. Preoperative examinations showed no distant metastasis, pulmonary ventilation function and small airway function were highly damaged and could not tolerate lobectomy. Chest computed tomography (CT) showed one small pulmonary nodules on the posterior segment of left lung, which was considered to be early malignant lesions. In addition, no remarkably swollen lymph node was visible in the mediastinum. Therefore, video-assisted thoracic surgery (VATS) left upper lobe posterior segmentectomy was performed, and intraoperative frozen section confirmed the diagnosis of adenomatous hyperplasia of alveolar epithelial. Sequential dissection (or, single-direction approach) was applied in this surgery to avoid frequent turn-over of the lung lobes and shift of visual angle during the procedures. The Electric hook used in this surgery enables careful dissection and dissociation, with clear visual field and small blood loss.

Keywords: Video-assisted thoracic surgery (VATS); segmentectomy; electric hook; sequential dissection

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Case report

A 56-year-old male patient was admitted due to one small pulmonary nodule in the posterior segment of left upper lobe. Preoperative examinations showed no distant metastasis, pulmonary ventilation function and small airway function were highly damaged and could not tolerate lobectomy. Chest computed tomography (CT) showed one small pulmonary nodules on the posterior segment of left lung, which was considered to be early malignant lesions. In addition, no remarkably swollen lymph node was visible in the mediastinum. Therefore, video-assisted thoracic surgery (VATS) left upper lobe posterior segmentectomy was performed (*Video 1*), and intraoperative frozen section confirmed the diagnosis of adenomatous hyperplasia of alveolar epithelial.

Procedure

The three-port method was applied: the observation port was made in the 7th intercostal space at the middle axillary line, the main working port was in the 4th intercostal space at the anterior axillary line, and the remaining one auxiliary port was located in the 8th intercostal space at the posterior axillary line.

Sequential dissection (left posterior segmental vein, left segmental bronchus, branches of left posterior segmental arteries) was applied. The main device used in the surgery was electric hook. Firstly, a VATS lung clamp was applied to lift the left upper lobe to expose the pulmonary hilum. Electric hook was then applied to open the pleura covering the surface of superior pulmonary vein and continued downwards to identify the presence of inferior pulmonary vein. Meanwhile, the spaces between the first branch of superior pulmonary vein and its deep bronchi were separated, and the lymph nodes in the pulmonary hilum (station 10, near the root of left lung artery) were dissected. After the left pulmonary trunk was exposed, the left superior pulmonary posterior segmental vein was dissociated, followed by the treatment using Ethicon Endo-Surgery endoscopic cutter and white staple cartridge.

The left posterior segmental bronchus was dissociated,

Video 1 VATS left upper lobe posterior segmentectomy.
Available online: http://www.asvide.com/articles/159

and the station 7 (subcarinal) lymph nodes were dissected behind the pulmonary hilum. After the left bronchus was completely exposed and the left upper lobe posterior segmental bronchus was completely dissociated at the bifurcation of the upper lobe anterior and posterior bronchi, Ethicon Endo-Surgery endoscopic cutter and blue staple cartridge were applied.

The distal stump of the left upper lobe posterior segmental bronchus was clamped to tract the left upper lobe backwards. Electric hook was used to dissect the interlobar lymph nodes near the pulmonary trunk and to dissociate the branches of the left upper lobe posterior segmental pulmonary artery. The first branch was treated with Ethicon Endo-Surgery endoscopic cutter and white staple cartridge. The remaining branches were anterior and lingual segmental arteries.

The left upper posterior segment pulmonary was divided using Ethicon Endo-Surgery endoscopic cutter and blue staple cartridge, and then the posterior segment of left upper lobe was placed in an endobag and extracted.

Comments

Sequential dissection (or, single-direction approach) was applied in this surgery to avoid frequent turn-over of the lung lobes and shift of visual angle during the procedures. The Electric hook used in this surgery enables careful dissection and dissociation, with clear visual field and small blood loss.

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None.

Footnote

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Double segmentectomy for T4 lung cancer in a pulmonary-compromised patient

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Abstract: Complete resection is the optimal treatment for primary lung cancer. The choice of surgical methods varies depending on tumor size, tumor location, and each patient's respiratory reserve. Currently, lobectomy with lymph node dissection is the gold standard for the surgical management of lung cancer. However, many thoracic surgical candidates also have chronic obstructive pulmonary disease or emphysema and thus present with minimal lung reserve. In the past few years, more reports have been published on the outcomes of patients who underwent anatomic segmentectomy for lung cancer. Herein we report the surgical outcomes of a patient with limited respiratory reserve, who underwent double segmentectomy.

Keywords: Lung segmentectomy/wedge resection; lung cancer surgery; lobectomy; pneumonectomy; preoperative care

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Introduction

Surgical treatment for lung cancer started in 1933 with the first successful pneumonectomy by Dr. Graham and continued to develop to the present day (1). In 1973, Dr. Jensik suggested that segmentectomy may be an adequate resection method for early-stage lung cancer in patients incapable of tolerating a standard lung resection (2). This suggestion has been widely debated for years and remains controversial.

Recently, more reports on the outcomes of patients who underwent anatomic segmentectomy for lung cancer, have been published. Segmentectomy is considered an alternative to lobectomy for tumors <2 cm in size (3). The method is a proven oncologic procedure for patients with significant morbidities and reduced cardiopulmonary reserve particularly. However, questions remain regarding safety, morbidity, mortality, and recurrence rate. We have performed anatomical segmentectomy with systematic nodal dissection as part of our commitment to provide surgical options to patients unfit for traditional lobectomy. In the present study, we report a case of a patient with limited respiratory reserve, who underwent double segmentectomy.

Case presentation

A 69-year-old man was referred to our pulmonology clinic with symptoms of dyspnea and chronic cough. He had a history of smoking approximately 50 pack/years. Clinical examination including osculation revealed decreased sounds on the left hemithorax. Blood test results were all in normal ranges. Chest X-ray demonstrated two distinct opacities in the left lung. Thorax computed tomography revealed a 2 cm × 2 cm lesion located in the apicoposterior segment of the left upper lobe and another 3 cm × 3 cm lesion in the superior segment of the left lower lobe (*Figure 1*). Preoperative bronchoscopic examination however did not yield a definitive diagnosis. Transthoracic fine needle aspiration biopsy of the lesion located in the left lower lobe indicated squamous cell carcinoma.

Positron emission tomography revealed two areas with ^{18}F-fludeoxyglucose (^{18}F-FDG) hyperintensity: one being 22 mm × 18 mm in size in the apicoposterior segment

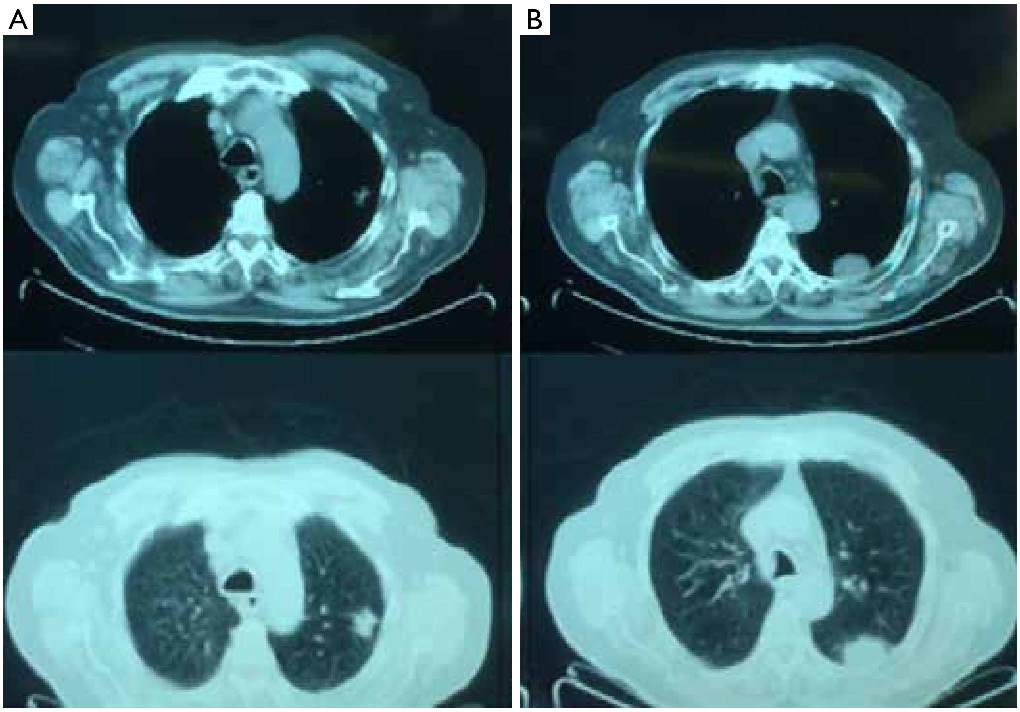

Figure 1 Thorax CT; lesions located in the apicoposterior segment of left upper lobe (A) and in the superior segment of the left lower lobe (B).

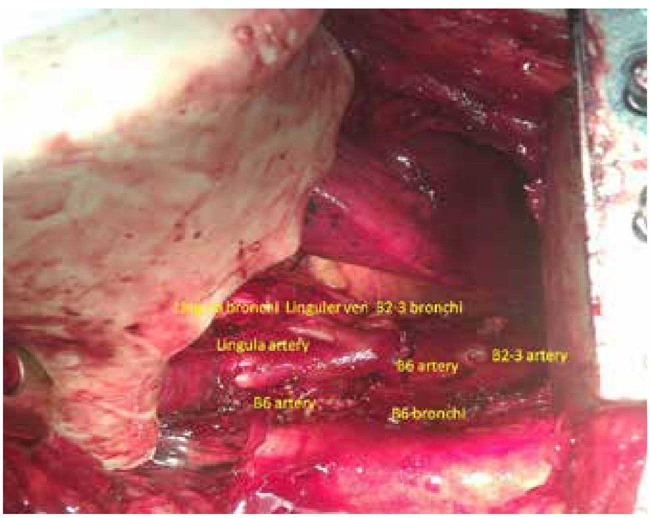

Figure 2 Operation field after the "apicoposterior plus B6 segmentectomy" linguler segmenter branches of both vessel and bronchi can be seen.

of left upper lobe [maximum standardized uptake value (SUV_{max} =13.6)] and the other being 36 mm × 21 mm in size in the superior segment of the left lower lobe (SUV_{max} =11.9) (*Figure 1A,B*). There was no observation of other high uptake areas suspicious for metastasis. Skeletal system and intracranial structures did not show any elevated FDG uptake either. Respiration function test results were as follows: forced vital capacity (FVC), 70%; and forced expiratory volume in 1 second (FEV_1), 44%. Arterial blood gas analysis showed partial pressure of oxygen as 76 mmHg, partial pressure of carbon dioxide as 37.6 mmHg, and oxygen saturation as %95. Preoperative cardiopulmonary exercise testing for evaluation purposes was also performed in order to estimate operative risk. Maximum oxygen consumption during exercise (VO_{2max}) value was 12.3 mL/kg/min; oxygen desaturation was not observed in 6-minute walk test with 420 m walked.

A left muscle-sparing thoracotomy was performed. On exploration, a 2 cm × 3 cm lesion in the left upper lobe and another 3 cm × 3 cm lesion in the lower lobe were detected. Histological analysis of frozen sections from a wedge resection of the preoperatively undiagnosed tumor revealed squamous cell carcinoma. Preresectional mediastinal lymph node dissection was performed. Histological analysis of the sampled mediastinal lymph nodes revealed no evidence of tumor. Poly-segmentectomy from different lobes was planned. The fissure was dissected, and anatomical segmentectomy of the left upper division and superior segment of the lower lob (B6 segment) was performed (*Figure 2*). The patient's postoperative course was uneventful, and he was discharged on the fifth day after surgery. Definitive pathology result showed squamous cell carcinoma with no nodal involvement, and the tumor was classified as stage IIIB (T4N0M0) according to the seventh revision of the International Association for the Study of Lung Cancer Tumor-Node-Metastasis staging system for lung cancer.

Discussion

Our study suggested that preoperative pulmonary evaluation should be performed according to each patient's specific characteristics and the type of surgery planned. All available guidelines recommend that when spirometry results predict postoperative FEV_1 and diffusing capacity of the lung for carbon monoxide values are less than 40%, an exercise test should be performed to measure VO_{2max} (4).

A VO_{2max} between 10 to 15 mL/kg/min or a predicted postoperative VO_{2max} of <10 mL/kg/min is usually considered contraindicative for surgery. Nevertheless, no single criterion should be used to exclude a patient from a curative surgery. Instead, the use of multiple preoperative studies is needed to select patients who are capable of tolerating and will benefit from pulmonary resection. Surgical intervention other than standard lobectomies or pneumonectomies can therefore be offered to selected high-risk patients. Experience from lung volume-reduction surgery has shown that some patients who would have been considered inoperable can safely undergo resection of lung cancer (5).

Harada *et al*. compared the outcomes of postoperative pulmonary function between segmentectomy and lobectomy in patients with stage I non-small cell lung cancer (NSCLC) and similar preoperative pulmonary function. Postoperative reductions of FVC and FEV1 were significantly lower in the segmentectomy group compared to those in the lobectomy group (6).

Anatomic segmentectomy can be an alternative to lobectomy for the protection of lung functions. Anatomically complete maximal parenchyma-saving resection can be performed in patients with limited respiration capacity. Removing a relatively large volume of healthy lung tissue could result in a poorer quality of postoperative life and a higher frequency of operative morbidity despite a reduced likelihood of having a second lung tumor resected.

The discussion on such a topic has been controversial with conflicting results in studies comparing lobectomy and sublobar resections. Many of those have included segmentectomy and wedge resection in the same group. Sublobar resection is usually performed for most patients with insufficient postoperative pulmonary reserve because they cannot tolerate a lobectomy. According to reports in recent years, segmentectomy in selected patients showed similar results to those of lobectomy (4-6). The selection criteria were tumor <2 cm in size, peripheral lesion location, and a 1 cm parenchymal surgical margin. However, questions remain regarding safety, morbidity, mortality, and recurrence rate with this method.

Kilic *et al*. compared the outcomes of 78 elderly patients (aged >75 years) with stage I NSCLC who underwent segmentectomy and lobectomy (7). The mortality rates were 1.3% for segmentectomy and 4.7% for lobectomy. Postoperative major complication rates were 11.5% for segmentectomy and 25.5% for lobectomy. These parenchyma-sparing methods also help increase the success of oncological treatment. The most undesirable and worst outcome of limited but adequate resection of lung cancer is local recurrence.

Multivariate analysis confirmed that recurrence rate and prognosis associated with sub-lobar resection were not inferior to those achieved with lobar resection, and overall survivals were similar in both groups. Local recurrence does not result in cancer-related death if it can be treated sufficiently (3).

Cancer and Leukemia Group B (CALGB 140503) has activated a phase III randomized trial investigating lobectomy versus sub-lobar resection for <2 cm, peripheral, node-negative, non-small cell lung cancer. A multi-institutional trial was also in the planning phase by the Japan Clinical Oncology Group (JCOG0802). The trial will similarly randomize patients with <2 cm peripheral NSCLC to the lobectomy or segmentectomy group. Future results from the randomized phase III limited resection trials CALGB and JCOG0802 for peripheral <2 cm NSCLC will hopefully clarify the role of sub-lobar resection as an alternative to lobectomy (8). Standard surgical resection for lung cancer is constantly evolving. Segmentectomy could be a reasonable treatment option in selected patients.

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Footnote

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Case Presentations

Uniportal video-assisted thoracoscopic left basilar segmentectomy

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Abstract: Uniportal video-assisted thoracoscopic surgery (VATS) has recently been introduced as an acceptable alternative to the traditional three-port VATS. Uniportal VATS lobectomy and segmentectomy actually gained increasing popularity. Until now there have been few reports about uniportal VATS basilar segmentectomy; we herein reported our experience with a patient who suffered from recurrent hemoptysis with 1-cm nodule in the basilar segment of the left lower lobe. A left basilar segmentectomy was performed through a single port. Operating time was 90 minutes, and postoperative course was uneventful. Pathology revealed cryptococcosis. Follow-up at 6 months after surgery demonstrated a normal chest computed tomographic (CT) scan and complete recovery without complications.

Keywords: Lobectomy; segmentectomy; wedge resection; postoperative complications; surgery/incisions/exposure/techniques; thoracoscopy/video-assisted thoracoscopic surgery (VATS)

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Introduction

Uniportal video-assisted thoracoscopic surgery (VATS) has recently been introduced as an alternative to the traditional three-port VATS. Uniportal VATS lobectomy and segmentectomy actually gained increasing popularity (1-4). Until now there have been few reports about uniportal VATS basilar segmentectomy. Herein we reported our experience with a patient who suffered from recurrent hemoptysis with a 1-cm nodule in the basilar segment of the left lower lobe, and received VATS basilar segmentectomy of the left lower lobe through a single port.

Clinical summary

A 48-year-old male patient was referred to our department because of recurrent hemoptysis for 3 months, refractory to medications. Past history and physical examination were unremarkable. Chest computed tomographic (CT) scan revealed a poorly demarcated nodule with a diameter of 1 cm (*Figure 1*); a low-grade malignancy could not be excluded. Bronchoscopy did not show visible lesions. Pulmonary function tests and other systemic examinations were unremarkable. The patient underwent a left basilar segmentectomy through a single port. Postoperative pathologic examination revealed cryptococcosis. He was well at 6-month follow-up, and chest CT scan revealed excellent healing without any complications.

Surgical technique (*Figure 2*)

In December 2013, a 4-cm incision was made in the fourth intercostal anterior axillary line, after achievement of general anesthesia with a double-lumen endobronchial tube. After placement of a wound protector, a 30-degree video scope provided visualization. There were no pleural adhesions and no evidence of pleural metastasis in the left thoracic cavity. The nodule was located by palpation in the basilar segment of the left lower lobe, and marked with electrocautery. We first opened the oblique fissure to isolate the superior and basilar branches of the lower lobe artery, and transected the basilar branches using 3-cm EndoGIA linear white stapler (Covidien, Mansfield, MA, USA). The basilar bronchus of the left lower lobe was mobilized, and several station 11 lymph nodes were dissected. After division of inferior pulmonary ligament, basilar tributary of

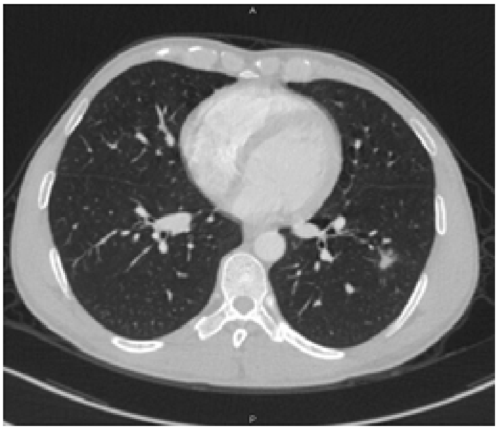

Figure 1 Chest CT scan showed one 1-cm spiculated nodule in the basilar segment of the left lower lobe. CT, computed tomographic.

Figure 2 Uniportal VATS basilar segmentectomy of the left lower lobe (5). Available online: http://www.asvide.com/articles/400

Figure 3 Chest X-ray examination showed the left lung was fully expanded and two chest tubes properly positioned.

Figure 4 Postoperative examinations revealed satisfactory healing of the chest incision.

the inferior pulmonary vein was isolated and divided with 3-cm white stapler, sparing the superior tributary. Then, the basilar bronchus was divided with 4.5-cm green stapler. After inflating the residual superior segment of the lower lobe to demarcate the intersegmental plane, the basilar segment was divided along the plane, and removed in a specimen bag, sent for frozen section, which confirmed a benign lesion. Two chest tubes were routinely placed in the chest (*Figure 3*). Operation time was 90 minutes, and operative blood loss 50 mL. After an uncomplicated recovery, the patient was discharged home 3 days after operation (*Figure 4*).

Discussion

Operative uniportal VATS is an interesting approach to malignant and benign lung diseases, with both a diagnostic and therapeutic intention, especially in patients with borderline cardiorespiratory function or advanced age. According to our clinical experiences, uniportal VATS patients had a shorter hospital stay and generated lower postoperative costs and a better aesthetic result than conventional VATS, and the technique might suffice for most situations treated by conventional VATS. Herein we reported our experience with a uniportal VATS left basilar segmentectomy of the left lower lobe.

Uniportal VATS segmentectomy is technically demanding operation whose difficulties are compounded by the inherent disadvantages of VATS though single port, including the limited maneuverability, unsatisfactory ergonomic characteristic of the instruments, poor visualization, and instrument-videothoracoscope interference. The placement of the incision in the fourth intercostal anterior axillary line depends on the location of the nodule in the chest, bearing in mind that an adequate distance between the single port and the target area. During the surgical procedure, it was easier to divide the basilar artery and vein branches firstly, which provided enough space to pass the straight anvil of an endoscopic stapler for division of the bronchus. Finally, because we sometimes find one of these tubes being obstructed, we routinely place two chest tubes through the same incision as video shows, to provide best chest drainage, with one tube directing upward for removal of air, the other downward for evacuation of fluid.

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Footnote

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

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Case Presentations

Video-assisted thoracoscopic superior segmentectomy of the right lower lobe

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Abstract: Sublobar resections are still controversial for lung cancer, but for patients who can't tolerate lobectomy, such as those suffering from cardiopulmonary comorbidities and aged people, sublobar resections are better choices. Lobectomy and sublobar resections have similar surgical effect on patients with tumors ≤2 cm. A 64-year-old patient with chronic obstructive pulmonary disease (COPD) and poor pulmonary function on pre-operation evaluation underwent thoracoscopic superior segementectomy with systemic mediastinal lymph node dissection. Three holes were adopted, the major operation hole was a 3 cm mini-incision in the 4th intercostal space of anterior axillary line. The patient has recovered well after the surgery.

Keywords: Video-assisted thoracoscopic; sublobar resections; segmentectomy; chronic obstructive pulmonary disease (COPD); video; case

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Introduction

Lobectomy and pneumonectomy with systemic mediastinal lymph node dissection is the standard procedure for lung cancer, but for patients who can't tolerate lobectomy (such as those suffering from cardiopulmonary comorbidities and aged people), sublobar resections, including both segmentectomies and wedge resections, are better choices. For lung cancer, sublobar resections are still controversial. According to related literature reports, the recurrence rate after sublobar resections is higher than that of lobectomy, but the 5-year survival rates are similar. Lobectomy and sublobar resections have similar surgical effect on patients with tumors ≤2 cm. Thoracoscopic surgery is a minimally invasive technique for lung cancer, and segmentectomies, compared with lobectomy, contribute less trauma as well as faster postoperative recovery. Now segmentectomies are appropriate procedures for adenocarcinoma *in situ* ≤2 cm.

A 64-year-old patient with chronic obstructive pulmonary disease (COPD) had poor pulmonary function (FEV1 of 1.14 L, 45.6% of the predicted value, MVV of 54.57 L, 54.8% of predicted value) on pre-operation evaluation. According to the chest CT, the mass lesion was on the superior segment of the right lower lobe, without hilar and mediastinal lymph nodes metastases. Before the operation, a CT-guided percutaneous lung biopsy was done, which revealed malignant cell suggesting the possibility of adenocarcinoma. The patient underwent thoracoscopic superior segementectomy with systemic mediastinal lymph node dissection (*Video 1*) and has recovered well after surgery.

Operative techniques

Three holes were adopted: the major operation hole was a 3 cm mini-incision in the 4th intercostal space of anterior axillary line, and a 1.5 cm mini-incision with a 10 mm trocar was done as the thoracoscopic observation hole in the 7th intercostal space of midaxillary line. Furthermore, a 0.5 mm mini-incision was done as an assisted operation hole in the 7th intercostal space of scapular line. The surgeon stood in front or back of the patient in the surgeon's favor. In the operation, surgeon detected the specific position of the tumor, and confirmed the target pulmonary segment based

Video 1 Video-assisted thoracoscopic superior segmentectomy of the right lower lob.
Available online: http://www.asvide.com/articles/146

on the preoperative chest CT, and then dissected the target pulmonary segment. After being dissected and isolated in the interlobar fissure, the superior segmental branch of pulmonary artery was ligated and closed by Hem-o-lock, and was then cut off.

After that, inferior pulmonary ligament was cut off, and the mediastinal pleura around hilum was dissected. Then bronchial artery was cut off, and subcarinal lymph nodes were dissected. The next step was to dissect superior segmental vein along the inferior pulmonary vein, and deal with Hem-o-lock in the same way. Then segmental bronchus was isolated and lymph nodes between segments were dissected. Before cutting off the bronchus, we inflated the lung and identified the target segmental bronchus, and then cut it off by endo-GIA (blue or green staple). At last, we confirmed the segmental boundary after inflating the lung, and used endo-GIA to deal with segmental boundary. Then the specimen was resected and remaining hilar and mediastinal lymphadenectomy was done.

In the operation, aspirator and operation equipment was used through the 0.5 mm assisted operation hole, which helped reduce the injury of chest wall, especially the intercostal nerves. At the same time, surgeon cooperated aspirator with electric coagulation and ultrasonic scalpel, in order to eliminate hemorrhage and fog in time, keeping the operative field clear.

Comments

Currently, segmentectomies for lung cancer are still controversial due to the higher recurrence rate, and are mainly used in aged people and patients who suffer from cardiopulmonary comorbidities. Therefore, lobectomy is the first choice for patients who have good cardiopulmonary functions. This surgical video follows the principle mentioned above. In addition, the video provides clear operative field, proper surgical operation, as well as hilar and mediastinal lymphadenectomy. But the video would have been better if thoracoscopy was adjusted in time at some points. Besides, lymph nodes should be intact during the mediastinal lymphadenectomy, in order to avoid the possible plant metastasis of positive ones.

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Case Presentations

Intrathoracic desmoid tumor arising at a distance from thoracotomy sites after thoracoscopic segmentectomy: report of a case

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Abstract: We report a case involving an intrathoracic desmoid tumor in a 68-year-old woman who had undergone video-assisted thoracoscopic right basal segmentectomy for lung cancer 1 year earlier. The well demarcated tumor was 9 cm × 6 cm × 6 cm in size, was located in the right apico-posterior thorax and had invaded the chest wall. The patient complained of a dull shoulder pain as a result of rapid tumor enlargement. En bloc tumor resection, including the apico-posterior chest wall extending from the 1st to the 4th rib, was successful. The patient had no recurrent tumor at 5 years after the second surgery. Intrathoracic desmoid tumor could occur, even when the tumor arises at a distance from the port and thoracotomy sites after thoracoscopic surgery.

Keywords: Postoperative desmoid tumor; chest wall; thoracoscopic surgery

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Introduction

Desmoid tumors are fibroblastic proliferations originating from deep soft tissue and are relatively rare neoplasms. These tumors seldom metastasize to distant areas, but they are characterized by invasive growth and may require wide resection (1). Desmoid tumors appear in various generations and can develop after injury or surgery. It has recently been reported that an intrathoracic desmoid tumor can arise after thoracotomy or even after thoracoscopic surgery (2,3). Herein, we report a case of an intrathoracic desmoid tumor in a 68-year-old woman who underwent video-assisted thoracoscopic right basal segmentectomy for lung cancer 1 year earlier. The tumor developed away from the thoracoscopic wound. The etiology is discussed.

Case report

A 68-year-old woman underwent right basal segmentectomy and lymphadenectomy for lung adenocarcinoma by means of video assisted thoracoscopic surgery. The pathologic stage was T1aN0M0 stage IA as categorized using the UICC 7th classification. The 7 cm long utility window was made at the fifth intercostal space and two ports were made at the seventh intercostal space. Double chest drainage tubes with a size of 24 Fr were inserted into the apical and supra-phrenic spaces. Both drainage tubes were left in place until postoperative day 4. The patient was uneventfully discharged on postoperative day 8. A chest X-ray taken at 9 months after surgery showed a right apical mass and the tumor had rapidly enlarged on the chest X-ray taken at 1 year after surgery (*Figure 1*). There was no antecedent history of trauma or other chest surgery. The patient complained of dull pain in the right shoulder with an increase in the size of the tumor. A computed tomography scan demonstrated new development of a soft tissue tumor in the right apex of the lung after the initial surgery (*Figure 2A,B*). Magnetic resonance imaging revealed a heterogeneous tumor of medium intensity relative to the muscle on T1-weighted images and invasion to the intercostal muscles. T2-weighted images exhibited high intensity (*Figure 2C*). Positron emission tomography with ^{18}F-fluorodeoxyglucose (FDG) showed FDG accumulation in the tumor. The maximum standardized

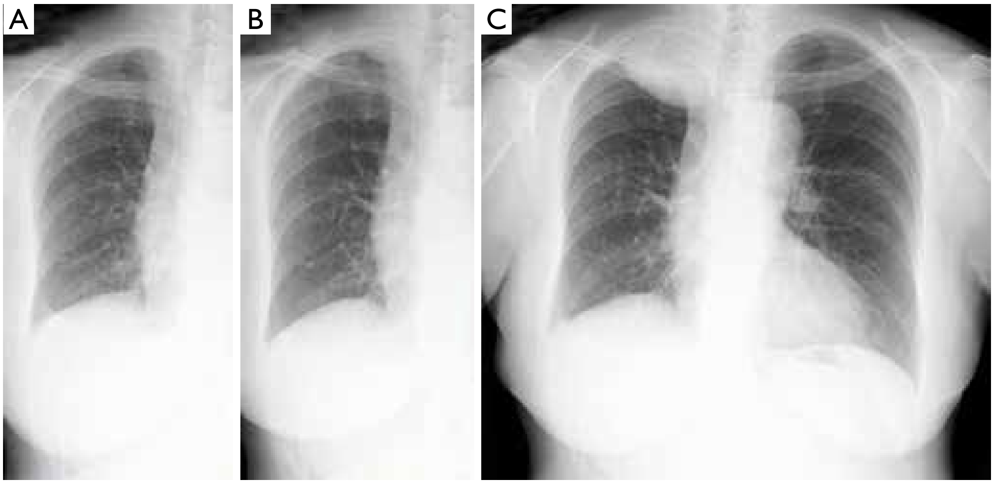

Figure 1 A chest X-ray taken at 9 months after surgery showed a right apical mass and the tumor had rapidly enlarged on the chest X-ray taken at 1 year after surgery. (A) 3 months after surgery; (B) 9 months after surgery; (C) 1 year after surgery.

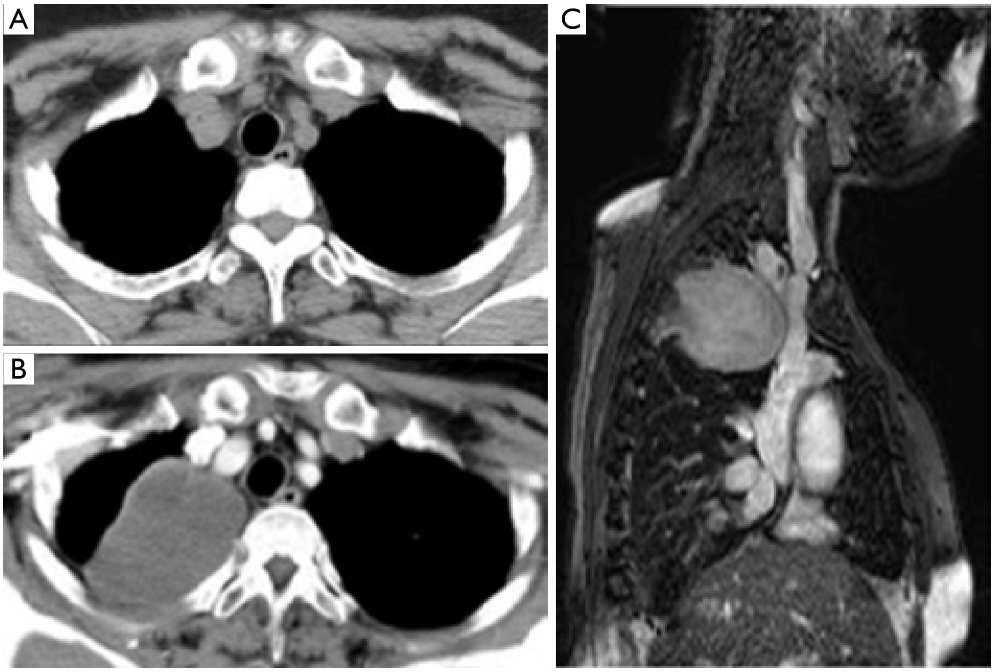

Figure 2 (A) Preoperative chest computed tomography scan at the time of the lung cancer surgery showing no chest wall tumor; (B) chest computed tomography scan 1 year after the initial surgery showing a soft tissue tumor in the right apical thoracic cavity; (C) chest magnetic resonance image showing a heterogeneous tumor invading the apico-posterior chest wall.

uptake value was 4.05. Exploratory thoracoscopy for definite diagnosis suggested the tumor was not lung cancer recurrence, but a demarcated soft tissue tumor arising from the chest wall. A right postero-lateral thoracotomy for complete resection was performed at the 5th intercostal space. The pale yellow demarcated tumor was found to have invaded the chest wall involving the 1st to the 4th ribs, but the tumor did not adhere to the lung. Chest wall resection including the soft tissue tissues around the tumor was performed with adequate margins which were >2 cm away from the tumor.

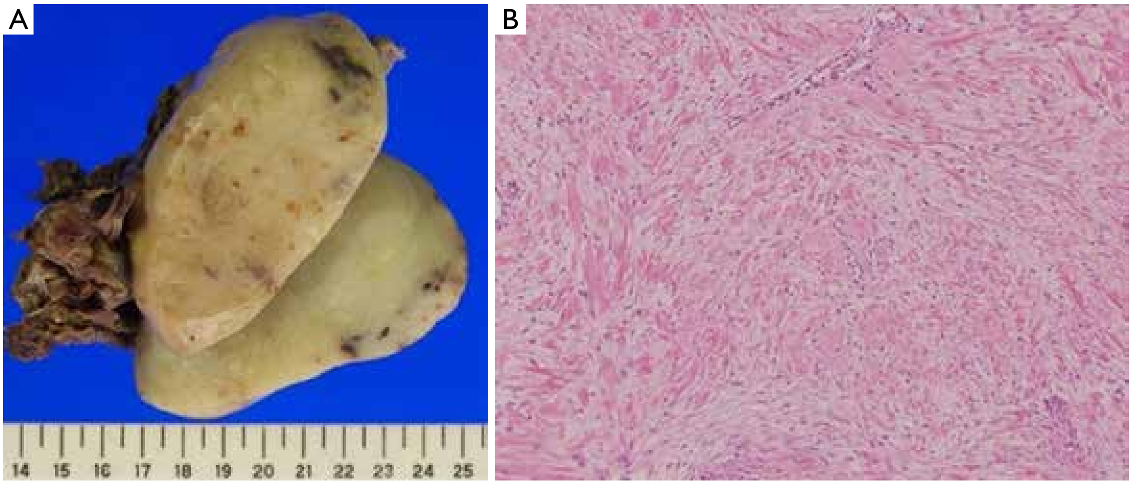

Figure 3 (A) Tumor was well demarcated, colored yellowish white and measured 9 cm × 6 cm × 6 cm; (B) histopathologically, the tumor consisted of a proliferation of well-differentiated fibroblasts with collagenous bundles.

The chest wall defect measured 14 cm × 10 cm and was not reconstructed.

The tumor measured 9 cm × 6 cm × 6 cm, and a cross section showed it to be yellowish white in color (*Figure 3A*). Histopathologically, the tumor consisted of a proliferation of well-differentiated fibroblasts with collagenous bundles (*Figure 3B*). The cells exhibited sparse mitotic activity and the MIB-1 index was <5%. There were no cytological features of malignancy and an absence of necrosis. The tumor had invaded the periosteum and the intercostal muscle. The surgical margin showed no tumorous lesion. The final diagnosis was an intrathoracic desmoid tumor, and the patient was discharged uneventfully on postoperative day 13. She was in good health with neither recurrent signs of lung cancer nor desmoid tumor at 5 years after the second surgery.

Discussion

Desmoid tumors are clinicopathologically classified into three types: the extra-abdominal type; the abdominal type arising from musculoaponeurotic structures of the abdominal wall; and the intra-abdominal type arising in the pelvis or mesentery. Intrathoracic desmoid tumors contained in extra-abdominal desmoids grow invasively and insidiously, and cause little or no pain (4). Desmoid tumors do not usually metastasize, but slowly and locally advance. Therefore, the mainstay for the treatment is enblock surgical resection. However, the recurrence rates for desmoid tumors after excision are high and are directly related to the status of the surgical margin. Abbas *et al.* reported that 89% of patients with a positive surgical margin had recurrences, whereas only 18% with a negative resection margin had relapses (1). Furthermore, the diagnosis of a safe surgical margin is difficult using frozen sections. Consequently, radical resection with incision lengths as long as 2-4 cm is to be recommended (1,4).

There is a close relationship between familial adenomatous polyposis and Gardner's syndrome, suggesting the role of an intrinsic genetic defect in the development of desmoid tumors. Estrogen has also been implicated in the multifactorial development of desmoid lesions because they tend to occur in women of reproductive age; some tumors express estrogen and progesterone receptors. Trauma or surgery can also be associated with the etiology. One patient in four with a desmoid tumor has been reported to have a history of trauma (5). Some studies have recently reported that thoracic desmoid tumors developed after thoracotomy or thoracoscopic surgery (2,3). Desmoid tumors can develop not only at the wound site but also at a distance from the port and thoracotomy sites. Postoperative chronic inflammation under the following scenario was suspected as representing the etiology of this intrathoracic desmoid tumor at a distance from the surgical incision. The first factor was irritation by thoracoscopic procedures. The second was irritation by the tip of the chest drainage tube positioned in the apical thoracic cavity. The third was stress caused by stretching of the intercostal space during the extraction procedure (2).

In conclusion, the presence of an intrathoracic desmoid tumor should be considered in patients who have undergone thoracoscopic surgery, even when the tumor arises at a distance from the port and thoracotomy sites.

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None.

Footnote

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Uniportal video-assisted thoracoscopic surgical (VATS) segmentectomy with preoperative dual localization: right upper lobe wedge resection and left upper lobe upper division segmentectomy

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Clinical vignette

A 75-year-old male presented with abnormalities upon chest computed tomography (CT) scanning at a routine check. He had a 1.7-cm sized ground glass opacity (GGO) on the posterior segment of the right upper lung (RUL) and a 1.2-cmsized semisolid lung nodule on the left upper lung (LUL). To differentiate synchronous metastasis, sequential CT-guided core biopsy was performed for the GGO lesion on the posterior segment of the RUL and the posterior segment of the LUL. Both lesions were suspected to be adenomatous hyperplasia or non-small cell lung cancer. Adenocarcinoma was detected in situ upon pathologic examination. A positron emission tomography (PET) scan showed no lymph node metastasis or extrathoracic distant metastasis. The LUL semisolid lesion showed mild hypermetabolism, while the RUL pure GGO lesion showed no definite uptake on PET scan. Pulmonary function was as follows: forced vital capacity (FVC), 3.07 L (75%); forced expiratory volume in 1 second (FEV1), 2.34 L (88%); carbon monoxide lung diffusion capacity (DLCO), 20.7 mL/mmHg/min (116%). The patient was referred for surgical resection of bilateral synchronous lung lesions. In this case, by employment of the dual localization technique (hook-wire and lipiodol), we performed bilateral uniportal video-assisted thoracoscopic surgery (VATS) resection. Wedge resection was carried out for the GGO lesion on the posterior segment of the RUL and left upper divisional segmentectomy was carried out for the semisolid lesion on the posterior segment of the LUL (*Video 1*).

Surgical technique

Preparation and exposition

Preoperative CT-guided dual localization with a hook-wire and lipiodol for bilateral lung lesions was performed two hours before surgery. The operation was performed under general anesthesia with double lumen endotracheal tube intubation. The patient was positioned in both lateral decubitus positions with arm elevation for each surgery. All participants in the operating room wore lead aprons during real-time fluoroscopy for localization of the lung lesions. We used a 5-mm diameter 30-degree thoracoscope (Karl Storz, Tuttlingen, Germany) and articulating and curved endoscopic instruments. A wound protector was inserted through the port to protect the port site from contamination in case of lung malignancy and to achieve better instrumental performance (*Figure 1*). The surgeon always stood on the right side of the patient, regardless of the operation side. Surgical assistants stood on the left side of the patient.

Operation

Uniportal VATS wedge resection for GGO lesion with guidance by real-time C-arm fluoroscopy

Uniportal right upper lobe wedge resection was initiated by the creation of a 1.5-cm long incision in the right upper

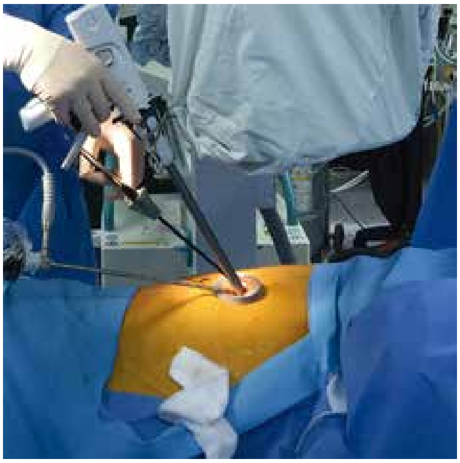

Figure 1 Instrumentation during uniportal video-assisted thoracoscopic surgery (VATS) segmentectomy under real-time C-arm guidance.

Figure 2 Incision for uniportal video-assisted thoracoscopic surgery (VATS) segmentectomy.

fifth intercostal space, along the anterior axillary line. Thoracoscopic exploration revealed the hook-wire from the pleura localized to the target lung lesion. Dislodgment of the hook-wire is a common event in preoperative localization. Therefore, the advantage of dual localization with a radiopaque contrast media such as barium or lipiodol is a higher detection rate of lung lesions in the case of hook-wire dislodgement. The dual localization technique also benefits from correct localization of the target lung lesion with a hook-wire from the pleural surface by thoracoscopy and a sufficient resection margin of more than 2 cm from the lesion with lipiodol and guidance using real-time C-arm fluoroscopy. After insertion of an intrapleural continuous analgesia infusion system and a 16-French chest drain at the incision site, the wound was closed. The patient was then positioned in the right lateral decubitus position for left upper divisional segmentectomy.

Uniportal VATS LUL divisional segmentectomy

A 2-cm long incision was created in the fifth intercostal space along the anterior axillary line (*Figure 2*). The hook-wire was easily identified at the LUL lesion. First, the interlobar fissure was dissected to isolate the posterior and lingular segmental branches of the pulmonary artery. Then, the upper divisional trunk of the pulmonary artery could be divided by opening the mediastinal pleura after lung traction posteriorly and further dissection could be performed through the space between the left upper pulmonary artery and vein. Interlobar and segmental lymph nodes could be dissected by careful manipulation. The segmental branches of the upper divisional pulmonary vein were divided more easily after division of the upper divisional branches of the pulmonary artery. To divide the upper divisional segmental plane, intraoperative optic bronchoscopy was used before stapling the segmental bronchus. The intersegmental plane between the lingular and upper divisional segments could be delineated by inflation and deflation using pressure jet ventilation (2 kg/cm^2) of the segmental bronchus. Alternatively, a breath was given to visualize the non-inflating segment after occlusion of the target segmental bronchus.

The intersegmental plane was divided along the plane identified by the above procedure and combined use of real-time C-arm fluoroscopy. We performed lobe specific sampling in this case, as there was no lymph node enlargement or uptake upon PET scanning.

Completion

A chest drain and intrapleural continuous analgesia pump were inserted through the same incision and the wound was closed. The incisional length was 1.5 cm on the right thorax and 2 cm on the left thorax (*Figure 3*). After extubation in the operating room, the patient was transferred to the surgical intensive care unit for postoperative care.

Comments

Clinical results

Between March 2012 and June 2015, we performed more

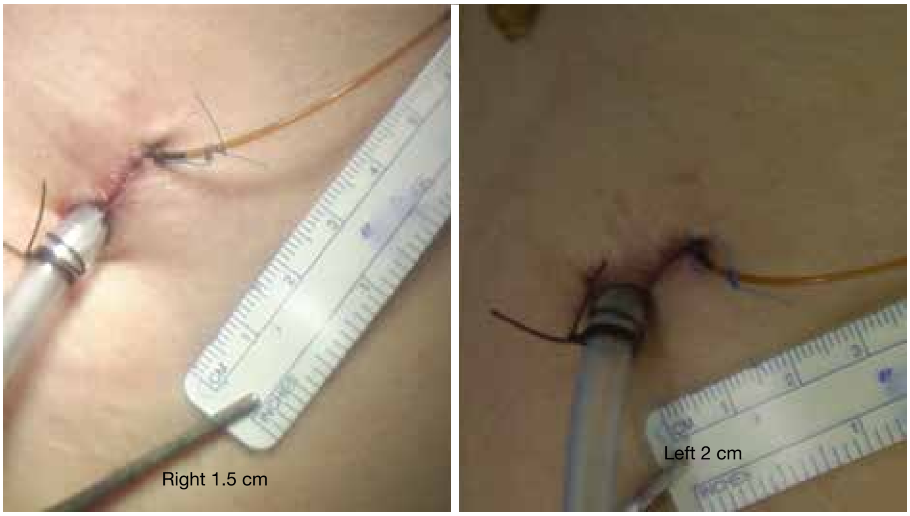

Figure 3 Postoperative wound.

than 300 uniportal VATS major lung resections and 30 of these patients underwent VATS segmentectomy using a uniportal approach. Our indications for uniportal segmentectomy were early lung malignancy (peripheral cT1N0) with a tumor less than 2 cm in diameter and a GGL that was less than 50% solid (1). Pulmonary segmentectomy carried out in patients not suitable for wedge resection and those with inflammatory lung disease in order to preserve pulmonary reserve was also included in our series. Of the 30 cases of uniportal segmentectomy, 21 (70%) cases had lung malignancy with a mean tumor size of 1.6±0.5 cm (range, 0.9–2.7 cm). The mean operation time was 147.2±59.3 minutes (range, 30–236 minutes). Preoperative localization was successful in 14 (73.7%) patients. There was one case of conversion to lobectomy in a patient who had not undergone preoperative localization, because we failed to find the lesion after segmentectomy. There was no lymph node metastasis in any patient upon pathologic examination. There was one case of prolonged air leak (>5 days) and two patients had postoperative pneumonia; they recovered with conservative management. There was one early mortality (<30 days) due to septic shock developing after systemic arterial embolism due to underlying disease. The mean chest tube indwelling time was 4.6±1.6 days.

Advantages

In addition to a smaller incisional scar, as compared to multi-port VATS, the potential benefits of uniportal VATS segmentectomy are less postoperative intercostal neuralgia via a reduction in the number of ports, a better postoperative course, earlier removal of the chest drain and a shorter hospital stay (2). Chest wall paresthesia can also be reduced by decreasing the number of ports and removing the need for a trocar to reduce intercostal neuralgia. Uniportal VATS segmentectomy may be a better option in elderly patients with poor pulmonary reserve (3). In addition, this approach can be applied in early lung cancer, elderly surgical candidates and patients who require lung preservation such as those undergoing pulmonary metastasectomy for metastases from other malignancies. One-stage bilateral surgery can be performed safely in patients with bilateral lung lesions.

Specifically, in our series, we focused on reducing the incisional length (to 2–3 cm) as compared to other case series of uniportal VATS major lung resection (in which incision size is usually 3–5 cm). However, based on our experience, a smaller volume of segmentectomy specimen can be removed through 2–3 cm incisions. This issue should be evaluated by future researchers.

Conversion to lobectomy is prevented with the use of a proper preoperative localization technique such as the use of a hook-wire (4), radiocontrast material or radioisotope or fiducial placement by the recently described electromagnetic navigational bronchoscopy procedure.

Caveats

Although it has the potential merits mentioned above, our surgical approach required a learning curve, even for surgeons experienced in conventional multi-port VATS major lung resection. Reducing the number of ports systematically from three to two to one can help thoracic surgeons to adopt the uniportal VATS procedure (5). With improvement of endoscopic devices, the strategy for the VATS approach might be transitioned to a more minimal incision. Appropriate selection of endoscopic devices and surgical staplers plays an important role when performing uniportal VATS segmentectomy. This can be facilitated by the use of articulating endoscopic instruments, curved devices, vascular clips, energy devices and a high definition camera system with a 3.3-mm diameter endoscope.

More recently, respectable long-term outcomes can be achieved by uniportal VATS segmentectomy of early lung cancer in selected population, which is comparable with conventional multi-port VATS (Diego Gonzalez-Rivas, presented at the European Lung Cancer Conference 2015, unpublished data). Further studies in larger populations and randomized trials are required to adopt our strategy as a first choice of thoracic procedure.

Conclusions

Our results suggest the safety of uniportal VATS segmentectomy in selected cases and its potential application in more candidates. This approach can be performed successfully with proper localization of the target lung lesion. Further work is required to determine the long-term outcomes and clear benefits of this technique as compared to conventional VATS.

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Footnote

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