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TUBELESS VIDEO-ASSISTED THORACIC SURGERY
Editors: Jianxing He, Eugenio Pompeo, Jin-Shing Chen

Tubeless Video-Assisted Thoracic Surgery

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Tubeless Video-Assisted Thoracic Surgery

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Preface

The outcomes of surgery should be beneficial to every aspect of a patient's life, starting from the surgery itself. This means a less invasive surgical procedure, resulting in a faster postoperative recovery, better postoperative quality of life, and longer postoperative survival. In the past, even 3 months ago, patients, surgeons, and anesthesiologists alike would be hard pressed to imagine that a carina or tracheal reconstruction could be performed under non-intubated anesthesia, that a patient can partake of food and drink normally within 3hrs post lobectomy, or that it is even possible for a patient to be discharged within 24 hours after thoracic surgery. Historically speaking these outcomes have been only a dream in the minds of minimally invasive surgeons. Under tubeless VATS these dreams have become a reality.

Tubeless VATS entails procedures carried out under Non-intubated spontaneous respiration anesthesia without the use of a chest drainage tube or urinary catheter. By forgoing the use of the 'tubes' all pain and complications associated with tracheal intubation, muscle relaxants, chest tubes, discomfort at the site of incision, and urinary catheters are avoided. The most prominent desire of surgeons and patients is less surgical trauma, with a resulting faster recovery and better post-operative quality of life. The benefit of tubeless VATS can be seen in the incredibly speedy post-operative discharge and recovery.

An important aspect of tubeless procedures is its flexibility. Tubeless VATS is unique in that the majority of patients with a BMI <23 are eligible for the procedure. In China specifically, this means more than 50% of thoracic surgery patients may be eligible for tubeless procedures. Moreover, in some instances, though a patient may not be suitable for a non-intubated procedure, he may still be eligible to undergo a procedure without the use of the chest drainage tube or urinary catheter. The same goes for use of chest drainage tube or urinary catheter. Hence it demonstrates flexibility and adaptability depending on patient's condition.

Finally of note, tubeless VATS is feasible in not just simple procedures, but also complicated procedures. In fact, tubeless VATS may be preferred in trachea operations where traditional tracheal intubation may obstruct the surgeon's operative view. Without the use of tracheal intubation, anastomosis during a tracheal operation can be completed in a little as 15-20 minutes. Of course, the options for application of tubeless VATS in various simple procedures should go without saying.

Increasing adoption of tubeless procedures is being seen and popular worldwide. Though training of both surgeons and anesthesiologists in necessary to familiarize themselves with the indications and the complete surgical procedures, in the coming future it is feasible that tubeless VATS may be applied in more than 50% of thoracic surgical patients worldwide; that is to say that more than 1 million patients can benefit from a faster recovery or day chest operation around the world each year.

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Preface

Tubeless video-assisted thoracic surgery (VATS) entails procedures carried out without tracheal intubation and with maintenance of spontaneous ventilation. This in order to summing up advantages deriving from avoidance of intubated anesthesia with one-lung mechanical ventilation to those of a minimally invasive surgical access.

Following sparse experiences in few centers of excellence, adoption of tubeless VATS is now expanding and many surgical procedures are increasingly carried out through tubeless strategies, which basically include fully awake anesthesia management or mild target sedation.

The basic perspective was initially to pursue a less morbid surgical management and a quicker recovery in geriatric patients, and in subjects with poor pulmonary function or multiple comorbidity. However, novel intriguing perspectives have been progressively added including the potential for a lesser impact on early immunological defense, an easier management of patients with small tracheal caliber and creation of fast track pathways for patients with thoracic trauma, multi-organ impairment or complex infections requiring surgical care. As a result, adoption of tubeless VATS has switched from simple procedures such as treatment of recurrent pleural effusion and of spontaneous pneumothorax to a broader range of procedures including lung volume reduction surgery, anatomical lung resection and even tracheal resection and sleeve lobectomy (*Figure 1*). In addition, the recent development of single-port VATS approaches has allowed the proposal of combination strategies including use of VATS with single skin incision and tubeless anesthesia, which now promise a novel micro-invasive or minimalistic surgical care.

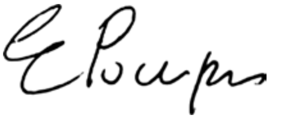
Research in tubeless VATS is favoring creation of cooperative multidisciplinary groups of investigation that include thoracic surgeons, anesthesiologists and other specialists working together to help elucidate the numerous issues that are still underinvestigated or fully obscure.

I recommend expert thoracic surgeons who desire to up-date their knowledge as well as trainees and any other stakeholders who are interested in familiarizing with tubeless VATS to read this book, which collects all recent articles published in AME Publishing Company scientific Journals and offers a useful summary of the most meaningful advancements achieved in the field by recognized experts from Asia, Europe and USA.

I am also confident that as an additional goal, thoracic surgeons with no experience in tubeless VATS will be stimulated to start adopting these highly promising surgical strategies.

Enjoy your reading,

Figure 1 Drs. Pompeo (left) and He (right) during a discussion about tubeless VATS at the first affiliated Medical University of Guangzhou.



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Preface

The era of tubeless thoracoscopic surgery has come!

The introduction of one lung isolation devices (double lumen endobronchial tube or endobronchial blocker) and successful management of one lung ventilation have enriched the rapid growth of modern thoracic surgery. For decades, thoracic surgeons request a fully collapsed lung to operate upon, especially in the era of minimally invasive thoracoscopic surgery. To achieve a sounding operating environment, we are trained and getting used to regard the intubated general anesthesia as a prerequisite in thoracic surgery. Complications resulting from tracheal intubation are not negligible; however, we usually simply deem that are the prices for a surgery.

Things has changed. Cumulating reports had again and again proved that a variety of thoracic procedures could be safely and effectively performed in patients without endotracheal intubation, including management of pleural diseases, minor and major pulmonary resections, and excisions for mediastinal tumors. With effective loco-regional anesthesia combined with or without targeted sedation (i.e. tubeless, non-intubated, or awake video-assisted thoracic surgery), thoracic patients are no longer have to face risks of intubated general anesthesia. In addition, patient-centered outcomes are improved to facilitate an enhanced recovery after surgery.

This monograph is a timely collection of cutting-edge experiences of tubeless video-assisted thoracic surgery performed in a global fashion. Through the inspiration of the articles, readers can have a clear idea regarding the initiation and implementation, as well as the current indications and future perspectives of this novel technique. I am grateful to our authors who have shared their expertise and contributed diverse and comprehensive knowledge for this excellent monograph. With refined anesthetic technologies and thoracoscopic instruments, it is time to consider the application of tubeless video-assisted thoracic surgery in our daily practice.

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(FIRST EDITION)

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Present and Future for Tubeless VATS

Complicated Tubeless VATS

Non-intubated video-assisted thoracoscopic surgery anatomical resections: a new perspective for treatment of lung cancer

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Abstract: The lung isolation under general anaesthesia with double lumen tubes has become an indispensable part of video-assisted thoracoscopic surgery (VATS) for lung cancer. However, with an attempt to avoid the residual effects of muscle relaxants and the systemic complications due to tracheal intubation, anesthesia without tracheal intubation has also been applied in VATS surgeries for lung cancer. Currently, non-intubated anesthesia under spontaneous breathing has been widely applied in VATS, contributing to more stable anesthesia and lower rate of switching to intubated anesthesia. It can be applied in most VATS procedures including anatomical pulmonary lobectomy, anatomical segmentectomy, and radical resection for lung cancer. In the selected lung cancer patients, non-intubated anesthesia under spontaneous breathing makes the VATS procedures safer and more feasible. With an equal chance for surgery as the intubated anesthesia, this technique lowers the incidences of peri-operative complications and speeds up post-operative recovery. As a novel surgical option, the anatomic VATS under non-intubated anesthesia under spontaneous breathing have shown to be promising. Nevertheless, the long-term outcomes require further evaluation in more multi-center prospective clinical trials with larger sample sizes.

Keywords: Lung cancer; non-intubated anesthesia; spontaneous breathing; switching to intubated anesthesia; anatomical lobectomy; anatomical segmentectomy

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Authors' introduction:

Professor Jianxing He (*Figure 1*) is the Director and Professor of the Thoracic Surgery Department, First Affiliated Hospital of Guangzhou Medical University, Guangzhou Institute of Respiratory Diseases (GIRD), as well as the President of the First Affiliated Hospital of Guangzhou Medical University, China. He has the world-largest clinical experience in video-assisted thoracic surgery and non-intubation minimally invasive thoracic surgery. *Figure 2* is a photo of his surgical team. Dr. Jun Liu is a chief physician who specializes in minimal thoracic invasive surgery. His research interests presently focus on clinical

Figure 1 Professor Jianxing He.

Figure 2 Surgical team.

and experimental study on Non-intubated VATS under spontaneous breathing.

Introduction

While the past decades have witnessed the increase in incidence of non-small cell lung cancer (NSCLC), lobectomy plus systematic lymph node dissection remains the standard radical treatment for this aggressive disease The use of video-assisted thoracoscopic surgery (VATS) lobectomy for the treatment of lung cancer was first reported in 1992 (1). Since then, VATS has become increasingly sophisticated and widely applied, with its feasibility and safety in the radical treatment being widely recognized. VATS has been included in the US National Comprehensive Cancer Network (NCCN) Guidelines since its 2006 edition; in the 2014 edition, the Guidelines further emphasizes that "VATS or other minimally invasive resection of lung is strongly recommended in early NSCLC patients without anatomic or surgical contraindications, in case that such procedure does not violate the tumor treatment criteria and/or chest surgery principles". Therefore, VATS has become a mainstream technique for early NSCLC.

The current minimally invasive procedures such as VATS lobectomy and VATS segmentectomy have become quite sophisticated and can benefit most surgical patients. However, how to develop an "overall minimally invasive" surgery (including anesthetic micro-injury), beginning from the apparently minimally invasive incisions, has become a hot research topic in the field of minimally invasive thoracic surgery.

Anesthesia for VATS should not only ensure an adequate depth of anesthesia but also properly control the negative intrathoracic pressure and the lung expansion during the surgery. In 1940, Zavod proposed anesthesia with double-lumen endobronchial tube intubation, which not only ensures the intra-operative lung ventilation and good lung isolation but also provides a sufficiently large and quiet surgical field for the operators (2). However, the systemic complications due to the use of muscle relaxants and endotracheal intubation during anesthesia as well as various post-operative discomforts such as sore throat and cough due to intubation trauma bring pain to patients and delay the post-operative recovery (3,4). The non-intubated anesthesia, in contrast, can satisfactorily avoid these problems. In 2004, Pompeo first reported the successful application of non-intubated anesthesia (thoracic epidural block in their cases) under spontaneous breathing in VATS wedge resection of lung masses (5). The non-intubated anesthesia techniques have their unique advantages: (I) the spontaneous breathing can be maintained; (II) only simple intravenous drug use, local infiltration anesthesia, intercostal nerve block, or epidural block is needed for anesthesia and analgesia. The one-lung ventilation can meet the needs during VATS by using the artificial pneumothorax. Thus, this technique can avoid the shortcomings of the intubated anesthesia. Currently, non-intubated anesthesia under spontaneous breathing has been widely applied in VATS. It can be applied in most VATS procedures including lobectomy, segmentectomy, and radical resection for lung cancer. Some experienced surgeons can even perform highly challenging surgeries (e.g., bronchoplasty) under spontaneous breathing (6-13). Furthermore, the intravenous anesthesia under spontaneous breathing can avoid the residual effects of muscle relaxants, lower the incidences of systemic complications, and thus achieve faster recovery of respiratory muscle function (11).

Advances in anesthetic techniques and intra-operative management

Anesthetic methods

The non-intubated anesthesia for VATS has developed from the single thoracic epidural anesthesia to more diversified combined anesthesia under spontaneous breathing in the past 10 years. Initially the non-intubated anesthesia was is only applied in some simple VATS procedures such as pleural biopsy, resection of pulmonary bullae, and removal of peripheral nodules but not in more complicated surgeries such as lobectomy. One of the reasons was is cough reflex; in fact, the pulling of the pulmonary hilum during the surgery may stimulate the vagus nerve and thus cause the swinging of the mediastinum and the uplifting of the diaphragm, which severely affect the surgical operations (14). Vischnevski had applied cervical vagus nerve block to reduce the cough reflex due to the traction of lung hilum (15). In 2011, Chen *et al*. reported that the blockage of thoracic vagus nerve with bupivacaine dramatically reduced cough reflex within a certain period of time. This technique provides a relatively quiet field for VATS, facilitates the dissociation/dissection of vessels and bronchus at the lung hilum, and thus makes the non-intubated anatomical lobectomy possible. This innovative technique payed the way for the advances in non-intubated VATS (6). In our center, the non-intubated anesthesia further develops into the tailored combination of various anesthetic modes including intravenous anesthesia, epidural anesthesia, local anesthesia, intercostal nerve block, intra-operative vagus nerve block, and pleural surface infiltration anesthesia, depending on the patients' specific conditions and the surgical procedures. Such a strategy can both ensure the intra-operative stability and facilitate post-operative recovery.

Tracheal intubation during surgery

An anesthesiologist must be able to timely and properly manage complicated situations (e.g., hypoxemia and hypercapnia) during non-intubated anesthesia. In addition, a qualified anesthesiologist must also be able to switch the anesthesia mode during the surgery and perform tracheal intubation when the patient is in a lateral position. If hypoxemia and hypercapnia occurs during the surgery and can not be resolved after non-invasive management, the single-lumen tube should be inserted under the guidance of fiber optic bronchoscope when the patient is in a lateral position, and a blocker can be used to achieve lung isolation. The rate of switching to intubated anesthesia is directly related with the surgical procedures and skills (15). For instance, it reached 10% in 30 patients who had received lobectomy but was only 4.9% in 285 patients who had undergone different surgical procedures (16). In one of our previous reports enrolling 174 patients undergoing VATS under non-intubated anesthesia, 7 patients (4%) were switched to intubated anesthesia. Among 156 patients undergoing radical treatment for lung cancer, 9 (5.8%) were switched to intubated anesthesia due to various reasons. This percentage was significantly higher than the overall rate (2.2%, 21/938) in our center (under review). Notably, the final case of the switching of anesthetic mode (No. 57, VATS radical treatment for lung cancer under intravenous combined anesthesia under spontaneous breathing) occurred on July 24, 2013; no such case has been recorded since then (till 2015). This may be explained by the following reasons: (I) the anesthesiologist have improved capabilities in dealing with various complicated conditions such as hypoxemia and hypercapnia during the surgeries; (II) with accumulated experiences, the operators are more self-confident and will not easily switch the anesthetic mode when facing problems such as extensive pleural adhesions, small tumors (<6 cm in diameter), and invasion of bronchus, which used to be the contraindications of VATS; (III) the surgical maneuvers are more reasonable. Pulling and traction are the main maneuvers, and tough actions such as lifting and compression are avoided; by doing so, the operation has less stimulation on the lung hilum and thus reduces the swinging of mediastinum; and (IV) the medical team is adapted to the surgical operation under spontaneous breathing, making the whole operation process much smoother.

Various VATS procedures under non-intubated anesthesia for lung cancer

Anatomical lobectomy

For patients with early NSCLC, lobectomy plus systematic lymph node dissection remains the first-choice treatment for most surgeons. In the earlier years, when the VATS under non-intubated anesthesia was applied for treating lung cancer, if peripheral pulmonary nodules were confirmed by frozen pathology during the surgery, the surgeons often had to switched to intubated anesthesia for lobectomy due to technical limitations (5). Along with advances in non-intubated VATS, lobectomy plus systematic lymph node dissection under spontaneous breathing has become possible for selected patients (6,11). Comparison of the non-intubated and intubated VATS lobectomy in two centers showed that the intra-operative indicators (e.g., surgical duration and intra-operative hemorrhage) were not significantly different between these two groups and the incidences of some complications were significantly decreased in the non-intubated group, which demonstrated the safety and feasibility of this technique; meanwhile, the non-intubated group had significantly better results in terms of post-operative rehabilitation indicators including antibiotic use, post-operative feeding time, thoracic drainage volume, and post-operative hospital stay.

Anatomical segmentectomy

In recent years, many centers have reported the application of anatomical segmentectomy for treating early NSCLC. Compared with lobectomy, this technique had statistically similar prognosis (17-20) and maximized the post-operative lung protection (21,22). The role of segmentectomy for selected lung cancers have increasingly been recognized. These include: *in situ* or microinvasive adenocarcinoma; stage Ia invasive adenocarcinoma less than 2 cm in diameter; synchronous or metachronous multiple primary ground-glass opacity (GGO)/small nodules; NSCLC patients who cannot tolerate lobectomy (17,23,24). Since 2010, the NCCN Guidelines have has clearly stated that segmentectomy can be applied for NSCLC treatment in selected patients. In 2013, Hung *et al*. reported 13 patients with primary lung cancer underwent non-intubated segmentectomy, four patients because they could not tolerate lobectomy and the remaining nine patients because had early lung cancer sized <2 cm (25). In 2014, our center reported ten patients who had undergone non-intubated VATS segmentectomy for early lung adenocarcinoma (12). After the segmentectomy, the patients had smaller incidences of post-operative complications and shorter post-operative hospital stay, which enabled them to recover rapidly. When the tumor was radically removed, the post-operative quality of life was also improved.

Lymph node dissection

Meanwhile, we also evaluated the quality of lymph node dissection (including the number and stations of the dissected lymph nodes), another key indicator of the completeness of the VATS under spontaneous breathing for lung cancer. In 2011, Chen *et al*. performed radical treatment in 30 patients with lung cancer and found that the number of the dissected lymph nodes was (13.8±6.0) in non-intubated group and (14.0±6.0) in intubated group (P=0.915). In 2013, the same group enrolled 36 lung cancer patients aged 65 years or above and found that the number of the dissected lymph nodes was (13.1±7.7) in the non-intubated group and (15.5±8.1) in the intubated group (P=0.133) (26); in contrast, the number of sampled lymph nodes was (6.5±5.9) in patients who had undergone segmentectomy for lung cancer (25). In one of our studies (under review), the number of the dissected lymph nodes in patients who had undergone lobectomy was (17.1±9.0) in the non-intubated group and (16.5±9.4) in the intubated group, with no significant intergroup difference; Among patients who had received segmentectomy, the number of the dissected lymph nodes was (9.5±6.2) *vs*. (6.6±4.7), respectively in these two groups, and the number of the sampled lymph nodes was (3.5±1.0) *vs*. (2.7±3.5). Both comparisons were not significantly different. These findings demonstrated that intravenous combined anesthesia under spontaneous breathing did not negatively affect the completeness of lymph node dissection as compared to intubated anesthesia.

Other surgical procedures

In our center, we performed non-intubated right lower lobe sleeve resection for a male patient with lung cancer. The surgery lasted 165 minutes, with an intra-operative blood loss of about 120 mL. The patient began to eat 4 hours after the surgery, and the chest tube was withdrawn on the third post-operative day. He was discharged on the 6^{th} post-operative day. The lesion was confirmed to be a squamous cell carcinoma by pathology. The bronchial stump was negative. Also, 18 lymph nodes from six stations were found to be negative (13). This was the first report on the application of the non-intubated lung lobe sleeve resection, which represented a breakthrough in surgical treatment and also marked the maturation of non-intubated VATS as a suitable option for complex lung resections.

Conclusions

Every innovation faces a range of challenges from its very beginning; meanwhile, such challenges drives the innovators to constantly update and vitalize their products. For selected patients with lung cancer, the feasibility, safety, and effectiveness of anatomical VATS under non-intubated anesthesia under spontaneous breathing have been well documented. It is a promising technique with certain socioeconomic values due to its superiorities (e.g., faster post-operative recovery) over intubated anesthesia. Along with the adoption of non-intubated VATS in more centers, the improvements in anesthetic techniques and surgical skills, and the expansion of surgical indications, more lung cancer patients will benefit from this technique. Nevertheless, establishing a complete and systematic assessment system and standards of practices will ensure the safety of these surgeries. Meanwhile, the long-term outcomes require further evaluation in more multi-center prospective clinical trials with larger sample sizes.

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Nonintubated thoracoscopic lobectomy plus lymph node dissection following segmentectomy for central type pulmonary masses

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Introduction

Lung cancer is the most common cancer worldwide. In the United States, it causes more cancer-related deaths than the next four causes (breast cancer, prostate cancer, colon cancer, and pancreatic cancer) of cancer-related mortality combined (1). About 30% of people have already progressed to stage III lung cancer and 40% to stage IV at the time they are diagnosed (2). Although chest X-ray and sputum cytology, when applied in health check-ups, can identify some relatively small tumors, they are not able to lower the overall mortality (3). More recently, the low-dose spiral CT scanning reduces the mortality of lung cancer when applied for lung cancer screening (4,5).

Along with the wider application of chest CT for lung cancer screening, an increasing number of small pulmonary masses can now be identified. About 40-60% of these small masses are primary lung cancer or lung metastases, for which surgical treatment is required. CT-guided biopsy is the common pathological approach before surgical treatment. For small lung cancer, however, the results of lung biopsy are not always reliable. Therefore, microscopic examination of frozen tissue sections is often performed firstly. Surgical decision (lobectomy and/or mediastinal lymph node dissection) is made based on the pathological findings (6).

We recently treated a patient with a small pulmonary nodule located in the central part of the left lower lobe. Upon the request of the patient, lobectomy and mediastinal lymph node dissection was not performed until the nodule was pathologically confirmed to be lung cancer.

Case report

A 60-year-old man was admitted due to "a mass in the left lower lobe of his lung during health check-up one week ago". Routine blood test and tests for liver, kidney, heart, and lung functions at admission did not show any abnormal finding. Whole-body PET/CT showed that the mass was located at the middle part of the left lower lobe (*Figure 1*). It was 2.3 cm × 3.0 cm in size, with heterogeneous density and a maximum SUV value of 3.4. The patient was informed about his conditions and the need for surgical treatment. The patient agreed to receive surgical treatment, but requested that the pathology should be confirmed via lobectomy before the application of radical treatment. On July 7, 2012, he received surgical treatment under epidural anesthesia without endotracheal intubation. During the surgery, after the bronchi, arteries, and veins at the basilar segments of the left lower lobe were exposed and dissected, anatomical resection was performed for the basilar segments of the left lower lobe using Johnson & Johnson surgical stapler (*Figure 2A*). The specimen was immediately sent to the pathology department for frozen section, which reported "invasive adenocarcinoma" (*Figure 2B*). Then the arteries and veins at the dorsal segment of the left lower lung were separated and dissected, the root of the left lower lobe bronchus was dissected, and thus the left

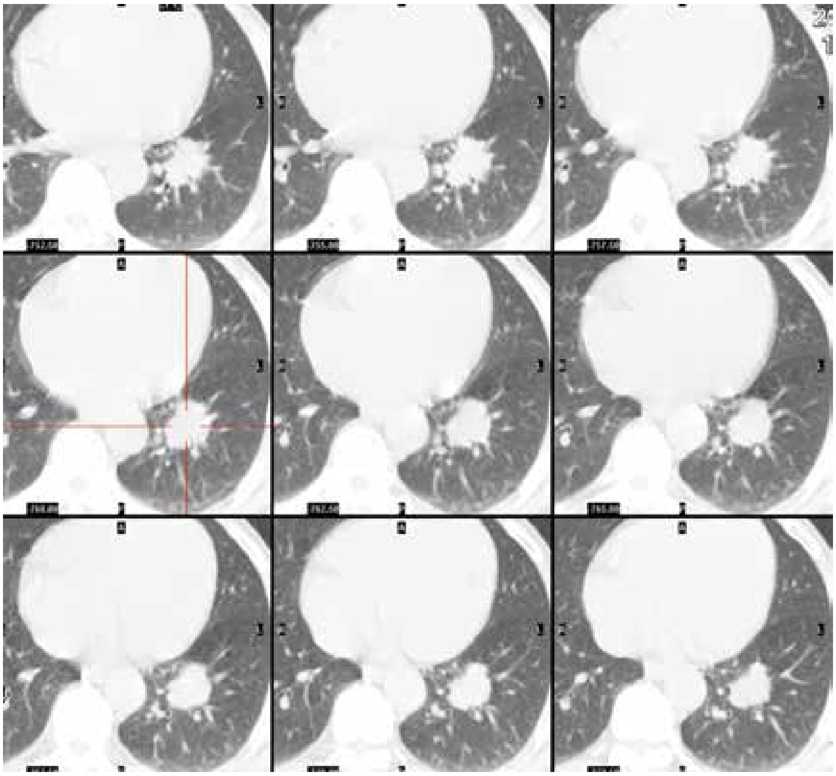

Figure 1 PET/CT shows the mass is located at the central part of the left lower lobe.

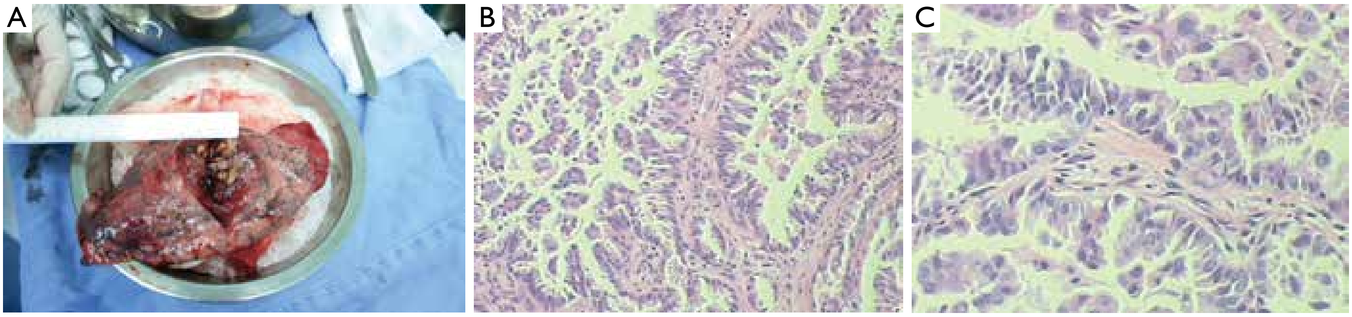

Figure 2 Anatomical resection of the basilar segments of the left lower lobe and the mass at the central part (A); the mass is pathologically confirmed as adenocarcinoma (B,C).

lower lobe was resected. After the dissection of the superior mediastinum, subcarinal, and inferior pulmonary ligament lymph nodes, and left upper mediastinal lymph nodes through an incision in the mediastinal pleura, the surgery was completed. During the 95-minute surgery, the intra-operative blood loss was 100 mL. A chest tube was placed for the first 48 hours post surgery. Eleven lymph nodes were removed, and metastasis was found in station 10 (2/5). The post-operative recovery was smooth. He was discharged on the 5th post-operative day.

Discussion

An increasing number of small lung nodules have been detected along with the application of chest CT for health check-ups (4,5). It has been found that about 0.2% of small lung nodules were detected by low-dose CT, although 40-60% of these nodules can be malignant (7). Also, as confirmed by pathological examinations, about half (53.6%) of the small pulmonary masses found during health check-ups can be primary lung cancer and pulmonary metastases (6), and the prognosis is directly related with the sizes of these masses (8,9). However, a definitive diagnosis usually can not be made by pre-operative bronchoscopy, percutaneous lung biopsy, or PET, and timely surgical treatment is essential for these patients.

Before the surgery, marking of the mass is useful for localizing the mass intraoperatively and for mass resection for biopsy (10-12). Currently the most common methods for pre-operative localization include percutaneous placement of annular metal ring, percutaneous methylene blue injection, and transbronchial ultralocalization (13-15). However, these methods are often associated with high incidences of complications and high failure rate. In another study, patients with small pulmonary nodules underwent injection of a solution composed of [99] Tc-labeled human serum albumin microspheres into the nodule. During the surgery, the area of major radioactivity was resected. However, drug leakage and localization failure still occurred; meanwhile, due to the rapid decay of the radioactive element, reasonable control of the injection time is also a challenging task (6). In our patient, since the mass was deep inside the lobe, it is impossible to localize it.

For patients with small pulmonary nodules detected during health check-up, video-assisted thoracoscopic surgery (VATS) resection is a good option (7,16). In fact, since the introduction of VATS in our department in 1994, VATS has been applied for the surgical treatment of many chest diseases. VATS assisted small incision surgery can be used for more complicated sleeve pneumonectomy (17-19). In our current patient, pulmonary wedge resection was difficult because the mass was located at the central part of the left lower lobe. Since the pre-operative pathology was unclear, it would be unwise to perform lobectomy if the mass turned out to be benign. A better option is: segmentectomy is performed firstly, and the following procedure is decided on the basis of the pathological findings.

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Nonintubated video-assisted thoracoscopic surgery for management of indeterminate pulmonary nodules

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Abstract: Indeterminate pulmonary nodules are common findings in clinical practice, especially after widespread use of high-resolution computed tomographic scans for cancer screening. To determine whether the nodule is malignant or not, surgery is usually required for either diagnostic or therapeutic purposes in the early stages. Current development in minimally invasive surgery and anesthesia using video-assisted thoracoscopic surgery without tracheal intubation (nonintubated VATS) are feasible and safe for resection of peripheral lung nodules, including nonintubated needlescopic or uniportal approaches. In addition, nonintubated VATS may offer high-risk patients for intubated general anesthesia opportunities to receive surgery. Therefore, nonintubated VATS can provide an attractive alternative for early diagnosis and treatment of indeterminate lung nodules.

Keywords: Thoracoscopy/VATS; lung nodules; anesthesia; tracheal intubation; minimally invasive surgery

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Authors' introduction:

Professor Chen (middle right) and Professor Cheng (middle left) lead the nonintubated thoracoscopic surgery program in National Taiwan University Hospital since 2009 with core team members, Dr. Hsu (left) and Dr. Hung (right) (*Figure 1*).

Figure 1 From left to right: Dr. Hsu, Prof. Cheng, Prof. Chen and Dr. Hung.

Introduction

Pulmonary nodules are approximately round lesions that are defined as less than 3 cm in diameter and that are completely surrounded by lung parenchyma, without other abnormalities (1). An incidental finding of pulmonary nodules on a chest radiography is one of the most common scenarios faced by clinicians, with a reported incidence of 0.1% to 0.2% of all chest radiographs (2). Since the introduction of helical computed tomography (CT) and multi-detector row CT in 1990s and their widespread use for lung cancer screening programs, the detection of focal rounded pulmonary nodules as small as 1 to 2 mm in diameter are becoming routine (3).

The most relevant issue in managing an incidentally found solitary pulmonary nodule is to diagnose whether the lesion is malignant or benign. While early diagnosis of malignancy facilitates timely treatment for best chance of survival in lung cancer patients, unnecessary repeated radiological examinations or invasive thoracic procedures with inherent risks should be avoided for benign lesions. Various modalities have been evaluated to aid in the early differential diagnoses of indeterminate pulmonary nodules, including flexible bronchoscopy, sputum cytology, endobronchial and transbronchial biopsy, CT-guided percutaneous, fine needle aspiration biopsy, high-resolution CT, and positron emission tomographic scanning (3-5). However, in the absence of a definite diagnosis, surgery remains the only option, which offers both diagnostic and therapeutic purposes at the same time.

The role of surgery for management of indeterminate pulmonary nodules is not concluded yet, especially in small lung nodules. Recommendations are focusing on the probability of malignancy to warrant surgery or not, which is predicted by nodule size, growth rate on serial follow-up studies, radiologic characteristics, and presences of relative risks (e.g., age, history of smoking, family history of lung cancer) (3). Recent advancements in minimally invasive thoracic surgery, both in surgical approaches and anesthetic techniques, may impact on the evaluation of risks and therefore on the decision management of indeterminate pulmonary nodules (6-16). In this article, we review current use of video-assisted thoracoscopic surgery without tracheal intubation (nonintubated VATS) for management of indeterminate pulmonary nodules.

Rationale for a nonintubated VATS

In the last 2 decades, thoracic operation by VATS has been well demonstrated as an effective and safe surgical approach for various thoracic diseases (17). Conventionally, intubated general anesthesia with one-lung ventilation by a double-lumen endotracheal tube or an endobronchial blocker is deemed mandatory for pulmonary VATS resections (17,18). However, adverse effects after intubated general anesthesia and one-lung ventilation are not negligible, including intubation-related airway trauma, residual neuromuscular paralysis, pulmonary atelectasis and ventilator-induced lung injury, arterial desaturation, impaired cardiac performance and postoperative nausea and vomiting (19-21). Avoidance of tracheal intubation can thereby prevent inherent risks of an intubated general anesthesia and reflect in a faster and smoother postoperative recovery with early return of daily activities and shorter hospital stay (6). In addition, compromised patients with impaired cardiopulmonary function may therefore get a chance to have surgical therapy by nonintubated VATS (22,23).

Feasibility of nonintubated VATS for indeterminate pulmonary nodules

Previously reported nonintubated VATS using locoregional anesthesia were mostly applied in high-risk patients for an intubated general anesthesia who receive pleural treatments (24-28). In 2004, Pompeo *et al.* were among the first pioneers to evaluate the feasibility of nonintubated VATS for resections for pulmonary nodules (6,8). They included 30 patients with solitary pulmonary nodules undergoing conventional VATS under sole thoracic epidural anesthesia without conscious sedation (awake VATS). Comparing to patients with intubated general anesthesia, their results showed that the awake technique was safe and feasible with more patient satisfaction, less requirement of postoperative nursing care (2.5 *vs.* 4 calls per day) and shorter in-hospital stay (2 *vs.* 3 days). In surgical perspective, the operated lung collapsed satisfactorily with an excellent surgical feasibility score in awake spontaneously breathing patients. Nonetheless, there were two awake patients who required intraoperative conversion to intubated general anesthesia because of lung cancer approved by frozen examination and requiring lobectomy via a thoracotomy approach (6). They further reported similar results in patients with metastatic lung nodules using awake VATS metastasectomy, but some patients experienced anxiety or panic, which necessitated conscious sedation (8). In addition, Lesser *et al.* also reported awake thoracoscopic laser resection of subpleural nodules in 28 patients under local anesthesia (9). On the same reason for a definte treatment of lung cancer, three of them were converted to intubated general anesthesia for further lobectomy.

Our group has employed nonintubated VATS using thoracic epidural anesthesia to perform wedge resections for diagnoses and treatments of peripheral lung nodules since 2009 (29). In contrast to the awake technique, we prefer to sedate our patients (non-awake technique). Since the undetermined nature of their pulmonary nodules, intraoperative frozen examinations are mostly necessary to confirm malignancy or not. Patients are usually anxious about the final results and opt for amnesia during the process. We believe that a sedative adjunct wil facilitate a nonintubated VATS procedure to alleviate the cooperability of the patients, in particular when further lobectomy and lymphadectomy for primary lung cancer can be a lengthy and unconfortable procedure, if necessary (30). It is important to note that creating an surgical pneumothorax is inevitably induce a hypoventilative status in a spontaneously breathing patient (10,30). Therefore, non-awake technique using sedative and/or opioid analgesics can also help to attenuate the tachypneic response of an open pneumothorax, but over-sedation should be meticulously avoided. Excessive sedation can further inhibit ventilation and oxygenation of the nonintubated VATS patients and jeopardize their safety (30,31). Depth of sedation can be titrated according to a Ramsay sedation score (target at level III: patients are sedated but retain response to comands) in awake patients (32), but a bispectral index using electroencephalograic analysis (target at levels between 40 and 60) will be more a convenient tool to spare the caring anesthesiologist for more vigorously observing the respiratory patterns of pateints on surgical videos and capnographic monitor (16).

Intense traction of lung parenchyma and hilar manipulation may be necessary to treat deeply located nodules, by which may trigger a coughing response. Unexpected or intractable cough not only interfere with surgical manipularities but also cuase dangerous complications, which may require emergency convesion to tracheal intubation and thoracotomy (32). To abolish the afferent input of a cough relfex, we found that a simple intrathoracic vagal blockade is effective without affecting the heart rate, breathing rate, and blood pressure (32). An effective vagal blockade also decreases the requirement of opioid analgics to attenuate the tachypneic responses resulting from surgical pneumothorax and coughing reflex, thereby alleviate the risks of symptomatic hypoventilation (30). The combinations of a sedative technique and vagal block enable us to convert from a wedge resecton of indeterminate pulmonary nodules to more extensive anatomical resections such as segmentectomies or lobectomies with mediastinal lymoph node dissections under the same type of anesthetic management without conversion to tracheal intubation, once frozen pathological results show primary lung cancer (13,23,32). Our nonintubated VATS method was also feasible to perform simultaneous bilateral VATS wedge resections of indeterminate pulmonary nodules in both lungs (33).

Nonintubated needlescopic and uniportal VATS for indeterminate pulmonary nodules

Conventional VATS is widely performed through a 2- or 3-port approach with 5- or 10-mm instruments. To further reduce the postoperative chest pain and cosmetic satisfaction after conventional VATS, modifications of VATS using 3-mm needlescopic instruments or single-access approach have recently developed (34). Needlescopic VATS has rarely been tried because of several limitations, including an inferior visual field of needlescope and inadequate strength of the instruments. In 2012, Tseng *et al.* combined nonintubated technique and needlescopic VATS to treat 46 patients with peripheral lung nodules (13). In their study, two miniports were made for 3-mm endograsper and 3-mm endoscope while a 12-mm thoracic port was made for 10-mm endostapler to resect indeterminate lung nodules. Their results showed that nonintubated needlescopic VATS was feasible and safe to remove peripheral lung nodules and to obtain a definite diagnoses of the nodules. However, extension of the 3-mm incisions was required in three primary lung cancer patients for lobectomies, in three patients with unexpected pleural adhesions and in two patients with difficulty to identify or resect the nodule. In addition, conversion to tracheal intubation was only required in two patients because of pleural adhesions. Most of patients completed needlescopic VATS without conversion to conventional VATS reported very satisfied or satisfied about wounds without residual neuralgia (13).

Single-access, or uniportal VATS is another emerging trend in minimally invasive thoracic surgery and has been shown to reduce postoperative pain, residual paresthesia, and hospital stay compared with conventional multiport VATS (35). However, instrumental interferences and limited access for finger-palpation of lung nodules are concerned. To evaluate the feasibility and safety of a combination of nonintubated anesthetic management and uniportal VATS approach, Hung *et al.* recruited 32 patients with peripheral lung nodules less than 2 cm undergoing a diagnostic wedge resection (15). For very small lung nodules less than 1 cm with ground-glass opacities, they used CT-guided dye-localization to target the lesion site before surgery. In addition, two-anchoring lung sutures were made for two-directional traction to spare the single access for maneuverability of endoscopic linear cutter (36). Their results showed that peripheral lung nodules could be easily resected via their modifications of nonintubated uniportal VATS to obtain a definite diagnosis. Only one patient without preoperative CT-guided dye-localization was converted to 3-port VATS because of difficulty locating an 11-mm ground-glass opacity. For 20 patients (59%) confirmed to be primary lung cancer, further resection for adequacy of margins and mediastinal lymph node dissections were also feasible while only three of them required conversions to multiport VATS and one of them required conversion to tracheal intubation due to limited instrumental maneuverability and vigorous mediastinal movement during nodal dissection, respectively. Not surprisingly, nearly all patients were very satisfied or satisfied (97%) with their scars (15).

Potential roles of nonintubated VATS for indeterminate pulmonary nodules

With refinements of surgical approach and anesthetic management after years of experiences on nonintubated VATS, we believe that our combination of uniportal incision and intercostal block can be a least invasive diagnostic modality for surgical management of indeterminate lung nodules. Once a definite diagnosis obtained after wedge resection and frozen examination of nodules, conversion to segmentectomy or lobectomy with mediastinal lymph node dissection for primary lung cancer can also performed under the same type of anesthesia with conventional multiport VATS, if necessary (14-16). Therefore, nonintubated uniportal VATS may increase the acceptability of surgical management of indeterminate lung nodules for early diagnosis and treatment of potential primary lung cancer.

Conclusions

Currently, increasing numbers of indeterminate lung nodules are necessitating surgery for either diagnostic or therapeutic purposes in the early stages because of the popularity of high-resolution CT and new cancer screening policies. Nonintubated VATS can provide an attractive alternative for early diagnosis and treatment of indeterminate lung nodules, especially using minimally invasive surgical and anesthetic approaches.

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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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Non-intubated video-assisted thoracic surgery as the modality of choice for treatment of recurrent pleural effusions

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Abstract: This review will establish that the best mode of treatment for recurrent pleural effusions is non-intubated video-assisted thoracic surgery (VATS) with chemical talc pleurodesis. The nature of recurrent pleural effusions mandates that any definitive and effective treatment of this condition should ideally provide direct visualization of the effusion, complete initial drainage, a low risk outpatient procedure, a high patient satisfaction rate, a high rate of pleurodesis and a high diagnostic yield for tissue diagnosis. There are various methods available for treatment of this condition including thoracostomy tube placement with bedside chemical pleurodesis, thoracentesis, placement of an indwelling pleural catheter, pleurectomy and VATS drainage with talc pleurodesis. Of these treatment options VATS drainage with the use of local anesthetic and intravenous sedation is the method that offers most of the desired outcomes, thus making it the best treatment modality.

Keywords: Recurrent pleural effusions; talc pleurodesis; video-assisted thoracic surgery (VATS)

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Authors' introduction:

Figure 1 is a picture of the two authors from the Sinai Hospital of Baltimore in Baltimore, USA. They are Dr. Solange E. Cox (right), a Surgery Resident at Sinai Hospital, and Dr. Mark R. Katlic (left), who is the Chairman of Department of Surgery.

Figure 1 From left, Dr. Mark R. Katlic and Dr. Solange E. Cox.

Introduction

Pleural effusions are a common manifestation of various types of malignant disease and the presence of a pleural effusion often portends a poor prognosis. Pleural effusions are associated with a significant amount of morbidity and mortality making their management crucial for establishing a better quality of life for the patients with symptomatic complications. There are several means of managing pleural effusions which include thoracostomy tube placement with bedside chemical pleurodesis, thoracentesis, placement of an indwelling pleural catheter, pleurectomy and video-assisted thoracic surgery (VATS) drainage with chemical talc pleurodesis (1). The treatment modality chosen is commonly based on the medical stability and needs of the patient. Malignant pleural effusions will often re-accumulate following initial drainage which makes effective pleurodesis to prevent recurrence, an important factor in their definitive management. Ideally the best management of recurrent pleural effusions should provide complete initial drainage, adequate pleurodesis to prevent re-accumulation and have a high diagnostic yield for biopsy in the event that a tissue sample is needed to establish a definitive diagnosis and treatment plan (2).

Treatment methods for recurrent pleural effusions

VATS with talc pleurodesis

VATS has become a more common method for treating recurrent pleural effusions over the past few years. It is a less invasive alternative to a thoracotomy with or without pleurectomy. It provides various advantages over other methods of treatment which include complete initial drainage under direct visualization, talc placement for pleurodesis under direct visualization which allows for more adequate placement of talc and subsequently more effective pleurodesis. In addition, this procedure is minimally invasive and can be done using local anesthetic and intravenous sedation thus avoiding the risks associated with intubation and resulting in the highest patient satisfaction rate of all treatment modalities (3-7). One of the most important advantages of this treatment method is the ability to obtain a tissue sample for diagnosis under direct visualization which increases the diagnostic yield of the biopsy (8). The disadvantages of this method include the higher cost associated with use of the operating room and increased required resources. This treatment method may also require a short inpatient stay, however with the use of local anesthetic and IV sedation this procedure can be done as an outpatient if the patient is an appropriate candidate. Patient undergoing this procedure often times also require chest tube placement for continued drainage initially. The patients often go home with the chest tube which allows for the procedure to be done on an outpatient basis. The rate of pleurodesis with this procedure is high and one of the most successful of any treatment modality. Thus, despite the fact that the patient will go home with a thoracostomy tube initially, this tube is usually not needed over the long term. Elective patients are discharged the same or next day, usually with a small drainage container (Atrium Mini-Express®, Atrium Medical Corporation, Hudson, New Hampshire, USA) attached to the chest tube or, in some cases, with a PleurX® catheter (CareFusion Corporation, San Diego, CA, USA). The chest tube is removed in the office as appropriate.

Thoracostomy tube and talc slurry

Tube thoracostomy is a minimally invasive bedside procedure with a low associated cost. It is well tolerated in patients who are not appropriate candidates for VATS procedures. It is an outpatient procedure and talc slurry can be instilled through the tube to achieve pleurodesis (9,10). Despite the low cost and general ease of placement, the tube does not allow for direct visualization of the pleural cavity. In some instances complete drainage may not initially be obtained. The lack of direct visualization makes placement of the talc for chemical pleurodesis not as optimal leading to lower rates of pleurodesis than with VATS procedures where the talc can be placed under direct visualization (11). With thoracostomy tubes there may be a need for additional procedures for drainage if adequate pleurodesis is not achieved. Patient satisfaction is also lower for bedside tube placement as this is associated with a higher level of anxiety for the fully awake patient and a higher amount of pain since this procedure is not done with IV sedation but instead only using local anesthetic. Additionally patients often go home with a chest tube in place. Based on the fact that a lower rate of pleurodesis is achieved with this procedure the chest tube may remain in place for longer periods than with a VATS procedure with IV sedation and local anesthetic.

Thoracentesis

This is a quick cost effective method of treating pleural effusions. It is a minimally invasive outpatient procedure with minimal risk of complications (12,13). Thoracentesis has a less important role in the setting of a recurrent pleural effusion due to the fact that this procedure does not involve any aspect of preventing recurrence. There is no pleurodesis associated with this procedure and considering that most of these effusions will re-accumulate this method is not a definitive treatment method (14). In addition to this, the diagnostic yield for tissue diagnosis is low as a tissue biopsy is typically not obtained with this procedure.

Long term indwelling pleural catheter

Placement of a long term indwelling pleural PleurX® catheter (CareFusion Corporation, San Diego, CA, USA), is a generally well tolerated procedure (9,10,15). It is a minimally invasive, outpatient, cost effective method of treatment for pleural effusions and allows for more patient control over the drainage of the effusions (9,15). The indwelling catheter is associated however with a higher degree of complications including clogging of the catheter, increased risk of infection, and pain at the catheter site (14,15). All of these may create the need for additional procedures. In addition to this, pleural catheters do not

Table 1 Advantages and disadvantages of various treatment methods for recurrent pleural effusions

Treatment method	Advantages	Disadvantages
Thoracopic chemical talc pleurodesis	• Minimally invasive, can be outpatient • Direct visualization, immediate and complete drainage • High diagnostic yield of biopsy • High pleurodesis rate • Increased patient satisfaction	• More costly than other methods • Inpatient hospitalization • May require tube thoracostomy following procedure
Tube thoracostomy and talc slurry	• Minimally invasive • Outpatient	• Pain associated with indwelling tube • May require inpatient hospitalization
Thoracentesis	• Minimally invasive • Outpatient	• No pleurodesis achieved following procedure • Frequent need for additional procedures
Long term indwelling pleural catheter	• Minimally invasive • Outpatient	• Chronic indwelling catheter • Higher risk of infection • Need for repeated drainage
Pleurectomy	• High diagnostic yield of biopsy • High pleurodesis rate	• Invasive procedure • Require inpatient hospitalization

Table 2 Comparison of various treatment methods for recurrent pleural effusions

Treatment method	Average cost (14,17)	Symptom relief (14)	Need for further procedures	Pleurodesis rate	Mortality	Morbidity[a] (18)	Diagnostic yield of biopsy	Length of hospital stay [days]
Thoracopic talc pleurodesis[b]	$780	+++	<10% (8)	>90% (8)	<0.5% (8)	2+	+++	0-1 (2)
Thoracopic talc pleurodesis[c]	$780	+++	<10% (8)	>90% (8)	<0.5% (8)	2+	+++	6±4 (16)
Tube thoracostomy & talc slurry	$355	+++	16% (19)	55-90% (12,18)	0%	1+	–	6 (10)
Thoracentesis	$84	++	98% (13)	2% (13)	0%	<1	+	–
Indwelling pleural catheter	$250	+++	23% (19)	42-58% (14)	0% (16)	1+	–	1-3±2 (10,16)
Pleurectomy (17)	$3,500	+++	<1% (18)	99% (18)	10-19% (8)	5+	+++	8-9

++, indicates intermediate level of success; +++, indicates high level of success; [a], indicates morbidity as evaluated on a scale of 1 to 5; [b], indicates video assisted thoracoscopic sugery using local anesthetic and IV sedation; [c], indicates video assisted thoracoscopic sugery with intubation.

facilitate the instillation of any form of chemical for pleurodesis (14,16). Also this method does not allow for obtaining any tissue for diagnosis. Most recurrent pleural effusions are the result of a malignant process, and thus tissue diagnosis if often needed to direct future medical management making this method less ideal for patients.

Discussion/conclusions

There are currently various options for treatment and management of recurrent pleural effusions (*Table 1*). The goals of treatment include methods which involve the least number of repeated procedures, the best patient satisfaction, least amount of pain and anxiety inflicted on the patient, lowest length of stay in the hospital, cost effective, preferably an outpatient procedure and optimally a method which has a high diagnostic yield for tissue diagnosis and a high rate of pleurodesis. Of the various methods described the most ideal in achieving the goals of treatment is non-intubated VATS with talc pleurodesis with local anesthetic and intravenous sedation. VATS with talc pleurodesis is by far the best option for patients and the use of intravenous sedation and local anesthetic reduce the overall cost, length of stay and potential complications associated with the use of intubation and general anesthesia. In patients who undergo the VATS procedure after local and intravenous sedation the average hospital stay is 0-1 days whereas the same procedure with intubated patients has a hospital stay of 6 days on average. Unlike thoracentesis, pleural catheter placements and tube thoracostomy this method allows for direct visualization of the pleural cavity. It also has the highest diagnostic yield for tissue diagnosis. There is a significantly high risk of morbidity and mortality associated with more invasive methods such as a thoracotomy or a pleurectomy (17) than with a VATS with talc pleurodesis. Given the many overall benefits of non-intubated VATS with talc pleurodesis for recurrent pleural effusions, this method stands out as the best treatment modality currently available to patients. Evidence suggests that this procedure should be the standard of care for all appropriate candidates (*Table 2*).

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Nonintubated uniportal video-assisted thoracoscopic surgery for primary spontaneous pneumothorax

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Objective: The objective of the current study was to evaluate the feasibility and safety of nonintubated uniportal video-assisted thoracoscopic surgery (VATS) for the management of primary spontaneous pneumothorax (PSP).

Methods: From November 2011 to June 2013, 32 consecutive patients with PSP were treated by nonintubated uniportal thoracoscopic bullectomy using epidural anaesthesia and sedation without endotracheal intubation. An incision 2 cm in length was made at the 6th intercostal space in the median axillary line. The pleural space was entered by blunt dissection for placement of a soft incision protector. Instruments were then inserted through the incision protector to perform thoracoscopic bullectomy. Data were collected within a minimum follow-up period of 10 months.

Results: The average time of surgery was 49.0 min (range, 33-65 min). No complications were recorded. The postoperative feeding time was 6 h. The mean postoperative chest tube drainage and hospital stay were 19.3 h and 41.6 h, respectively. The postoperative pain was mild for 30 patients (93.75%) and moderate for two patients (6.25%). No recurrences of pneumothorax were observed at follow-up.

Conclusions: The initial results indicated that nonintubated uniportal video-assisted thoracoscopic operations are not only technically feasible, but may also be a safe and less invasive alternative for select patients in the management of PSP. This is the first report to include the use of a nonintubated uniportal technique in VATS for such a large number of PSP cases. Further work and development of instruments are needed to define the applications and advantages of this technique.

Keywords: Uniportal; video-assisted thoracoscopic surgery (VATS); spontaneous pneumothorax

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Introduction

Video-assisted thoracoscopic surgery (VATS) has been reported to offer substantial clinical advantages compared to open surgery for many clinical conditions (1). Regarding primary spontaneous pneumothorax (PSP), several studies have shown that the VATS procedure is as effective as thoracotomy in terms of recurrence and complication rate (2).

In the context of minimally invasive thoracic surgery, uniportal VATS represents one of the most recent evolutions. With the aim of further reducing the invasiveness of VATS, Rocco and colleagues demonstrated that treatment of PSP using uniportal VATS was feasible and, compared with the conventional (3-portal) VATS, resulted in less postoperative pain, paraesthesia, postoperative drainage duration, postoperative stay, and hospital costs (3).

Currently, general anaesthesia with one-lung intubated ventilation is the standard anaesthesia in thoracic surgery. Intubated anaesthesia is often associated, however, with postoperative throat discomfort, including irritating cough, as well as throat pain in some patients. Nonintubated

Table 1 Patient characteristics

Characteristics	Number of patients (n=32)	Percentage (%)
Median age (years)	27.5 (19-36)	
Gender		
Male	28	87.5
Female	4	12.5
Smoking		
Smoking history	2	6.25
No smoking history	30	93.75
BMI (kg/m^2)		
<18	4	12.5
18-25	28	87.5

BMI, body mass index.

anaesthesia can reduce general anaesthesia-related complications; therefore, many investigators have begun to explore its application in general thoracic surgery (4). Two examples of such groups are Dong *et al.* who reported that thoracoscopic wedge resection under nonintubated anaesthesia was both feasible and safe (5), and Chen *et al.*, who reported the safety and feasibility of thoracoscopic resection under nonintubated anaesthesia in 285 patients (6).

The combination of uniportal VATS and nonintubated anaesthesia is potentially a less invasive operation in the management of PSP. This is the first report to include a large number of records on the use of a nonintubated uniportal technique in VATS for PSP.

Materials and methods

Patients

This study was reviewed and approved by the First Affiliated Hospital of Guangzhou Medical University Research Ethics Committee. From November 2011 to June 2013, VATS was performed for PSP in our department using a single-incision and non-rib-spreading approach. The same group of thoracic surgeons and anaesthesiology team performed all of the operations. Data from 32 consecutive patients (28 males and 4 females) who received this operation were analysed (*Table 1*).

Patients were eligible for the procedure if their CT scan demonstrated unilateral apical bullae, if they had an American Society of Anesthesiologists (ASA) grade of I-II and a body mass index (BMI) <25, and had no evident airway secretions or contraindications for epidural puncture in the preoperative anaesthesia assessment.

Surgical technique

Administration of anaesthesia

After establishing intravenous rehydration, an epidural catheter was inserted in the thoracic T6-7 space. With the patient in the supine position, 2 mL of 2% lidocaine was injected through the epidural catheter. If signs of spinal anaesthesia were not present within 5 min, fractionated injection of 12 mL 0.375% ropivacaine was performed. Prior to surgery, an anaesthesia level between T2 and T10 had to be achieved. Propofol and remifentanil were infused for sedation and anaesthesia during surgery, and bispectral index values were maintained between 40 and 60. During the surgery, masked and nasopharyngeal airway assisted ventilation were provided with a fraction of inspired oxygen (FiO_2) concentration of 0.33. The hilum and waist were padded to widen the intercostal space further. To reduce coughing induced by pulling on the lung tissue, and to ensure a steady surgical environment, 6 mL of 2% lidocaine was sprayed on the surface of the lung under thoracoscopic guidance in the chest cavity. The use of lidocaine on the lung surface eliminated the need for blocking of the vagus nerve.

Surgical management

All video-assisted thoracic operations were performed using a Stryker 1288 HD 3-Chip Camera/1288 (Stryker, USA) with a three-chip HD camera system, in addition to endoscopic instruments specially designed by our department. We created a 2 cm incision at the level of the 6th intercostal space in the median axillary line, after which a soft incision protector was placed into the space as the surgical operation channel. A 5 mm 30° video thoracoscope and two laparoscopic instruments (Roticulator™ and Endo Grasp™, USSC-Tyco Healthcare and Endo GIA Universal, Johnson & Johnson, USA) were introduced through this channel.

By deploying the articulating arm, the target bullae were identified and resected with 2-3 firings of blue cartridges. For all procedures, the video thoracoscope lay between the operative instruments, but shifts may have occurred during the procedure. Thus, the relative position was best determined by a geometric approach to the target area. The specimen was usually extracted through an endobag, after which the incision protector was removed, and an 18 Fr

Table 2 Intra- and post-operative conditions of uniportal VATS

Characteristics	Value/number of patients [range]
Mean operation length (min)	49.0 [33-65]
Mean intraoperative blood loss (mL)	20 [10-40]
Mean drainage volume (mL)	36 [20-80]
Mean drainage time (h)	19.3 [15-26]
Mean postoperative feeding time (h)	6
Mean postoperative hospital stay (h)	41.6 [26-47]
Pain scores	
Mild pain	30
Moderate pain	2

VATS, video-assisted thoracoscopic surgery.

chest tube was introduced under direct camera visualization, and placed in the pleural apex. The chest tube was removed after air leak stopped, and an X-ray of the chest demonstrated a well-expanded lung. The patients were observed overnight, and discharged the following morning.

Results

During a telephone interview, all patients provided answers to a questionnaire regarding pain and satisfaction scores. The mean postoperative follow-up time was 14.5 months with a minimum follow-up of 10 months (range, 10-19 months). Neither the signs nor the symptoms of recurrent pneumothorax were observed in any patients.

The median operative time was 49.0 min (range, 33-65 min). The necessity to convert the uniportal VATS procedure to a standard 3-port VATS procedure or a thoracotomy was not encountered. Further, no major complications were observed, and the administration of opiates was not required. The postoperative feeding time was 6 h. The median chest drainage time was 19.3 h (range, 15-26 h). All patients were discharged after a median hospital stay of 41.6 h (range, 26-47 h). Variables contained in the prospective dataset included operation length, intraoperative blood loss, postoperative feeding time, drainage volume, drainage time, postoperative hospital stay, and pain scores (*Table 2*).

Discussion

Currently, VATS is reported to be as effective as thoracotomy, and entails less associated morbidity. In an attempt to reduce complications, conventional VATS has developed to include either smaller working ports and instrumentation, or fewer incisions. Rocco and colleagues first described the uniportal VATS technique as an effective approach to the safe performance of wedge resections for pulmonary lesions (7).

Compared with general anaesthesia performed in a traditional thoracic surgery, nonintubated anaesthesia reduces intubation-related complications, and facilitates timely patient mobility (8). With nonintubated anaesthesia, coughing induced by postoperative throat discomfort is significantly reduced (9). Further, coughing may worsen wound pain, which in turn suppresses the cough reflex, making pulmonary secretions difficult to discharge after surgery. Additionally, nonintubated endoscopic resection may reduce the required dose of intraoperative anaesthetic drugs, which may help protect breathing and digestive functions.

In 4-6 h after non-intubated segmental resection, patients could start eating, drinking, and could get out of bed. The absence of general anaesthesia and double-lung ventilation, in combination with the reduction of postoperative hospital days, could decisively shift the balance in the management of PSP toward uniportal VATS.

At present, nonintubated anaesthesia, combined with uniportal VATS bullectomy, is one of the most minimally invasive surgeries, but only a limited number of reports have been published regarding this procedure. According to the literature (10-15), most previous uniportal VATS were performed under general anaesthesia. Only one procedure, conducted by Rocco *et al.*, was performed while the patient was conscious (16). The procedure described by Rocco *et al.* was performed using a 5 mm 0° thoracoscope, an endostapler, and grip forceps, with which they resected blebs or bullae in the lung apex. In a separate study, Gigirey *et al.* reported some disadvantages including quality of vision; however, problems related to quality of vision are not an issue if a 30° thoracoscope and an incision protector are used (17). Additionally, the absence of any protected channels for introducing the material into the cavity can lead to intercostal nerve injury, as well as increase the need to clean the optical lenses and consequently delay the operative time.

Tsai *et al.* (18) performed a vagus nerve block during nonintubated VATS. In the current study, however, it was not necessary for us to perform this procedure, which raises the risks of damage to adjacent vessels. Instead, we sprayed

Table 3 Comparison of intraoperative and postoperative variables between bullectomy groups

Group	Lead author	Surgical management	Anaesthesia	Number of cases	Operative time (min)	Incision protector	Chest drainage (d)	Postoperative feeding time (h)	Postoperative hospital stay (d)
A	Rajwinder Singh Jutley (3)	3-port VATS	Double-lumen endotracheal tube	16	–	No	3.9±2.1	>12	4.1±1.0
A	Shah-Hwa Chou (19)	3-port VATS	Double-lumen endotracheal tube	35	78.0±4.61	No	2	>12	3.5±0.7
B	Eugenio Pompeo (20)	3-port VATS	Nonintubated	21	78.0±20.0	No	2	6	2.0±1.0
C	Hee Chul Yang (10)	Uniportal	Double-lumen endotracheal tube	27	74.6±22.8	Yes	1	>12	2.3±0.7
C	Michele Salati (11)	Uniportal	Double-lumen endotracheal tube	28	72.3±31.8	No	1	>12	3.8±1.8
C	Orlando Gigirey Castro (17)	Uniportal	Double-lumen endotracheal tube	13	–	Yes	1	>6	2.15
D	Gaetano Rocco (16)	Uniportal	Nonintubated	1	–	No	1	6	1
D	Present study	Uniportal	Nonintubated	32	49.0±13.8	Yes	1	6	1.7±0.3

VATS, video-assisted thoracoscopic surgery.

approximately 6 mL of 2% lidocaine onto the surface of lung. Using the latter method, we found that the cough reflex could be effectively abolished without affecting the heart rate, breathing rate, or blood pressure. Further, we believe that this novel technique is safer than performing a vagus nerve block.

Reports from eight different authors regarding patients who received bullectomy for PSP, including the present report, were divided into four different groups (A-D) for a comparison of duration of chest drainage, postoperative feeding time, and postoperative hospital stay (*Table 3*). Patients in group A received conventional (3-port) VATS under general anaesthesia, and had the longest duration of chest drainage, postoperative feeding time, and postoperative hospital stay of the four groups. Group B patients also received conventional (3-port) VATS, but under nonintubated anaesthesia. Data from group B was similar to that of group A, except for postoperative feeding time, which was significantly reduced and similar to group D patients, who also underwent nonintubated anaesthesia. Group C received uniportal VATS under general anaesthesia. Postoperative feeding time was similar to that of group A, while duration of chest drainage was the same as group D. The postoperative hospital stay of group C patients was also slightly less when compared to group A.

Finally, group D patients underwent a combination of uniportal VATS under nonintubated anaesthesia, Rocco *et al.* reported only one case, and did not use an incision protector. In contrast, we have reported 32 cases, each of which involved the use of a soft incision protector. The mean operative time of group D was comparable to all other groups; however, the combination of the other scores was less than values observed in the other three groups. Specifically, both the postoperative feeding time and hospital stay were less in group D patients than in group A and C subjects, while both duration of chest drainage and postoperative hospital stay were less in group D than in groups A and B.

Passlick *et al.* (21) demonstrated that about a third of all patients who underwent minimally invasive surgery experienced chronic pain. Sihoe *et al*. (22) found that over 50% of patients who underwent VATS for PSP complained of distinct paraesthesia resulting from wound pain. In each of our 32 cases, we chose the use of a soft incision protector instead of a trocar to safeguard the surgical operation channel. We observed moderate chest wall pain in two patients (6.25%), which was a lower rate than previously reported (35%) for the uniportal no-trocar technique (12). It is possible that the use of an incision protector in VATS procedures shields the intercostal nerves from compression due to torqueing of the camera or instruments, and therefore reduces the rate of residual chest wall paraesthesia. It is our opinion that using a smaller soft incision protector could further reduce the intensity of postoperative pain. The incidence of chronic postoperative pain in our uniportal group was less than that of the 3-port group (3). We believe this to be an effect of the potential advantages of using only one intercostal space, as well as a soft incision protector. By reducing the number of ports and using smaller instruments without trocars, the risk of traumatizing the intercostal nerves was decreased. Further, the potential reduction in intercostal nerve trauma was apparent by the fact that the administration of opiates was not necessary during the performance of procedures in the current study, and patients did not require any painkillers after surgery.

We acknowledge that the study was limited by the lack of a control group. Further studies and follow-up are needed to verify the benefits of nonintubated uniportal VATS for PSP. Nevertheless, our initial results indicate that nonintubated uniportal VATS is technically feasible, and may be a safe and less invasive alternative for the management of PSP.

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Non-intubated video-assisted thoracic surgery management of secondary spontaneous pneumothorax

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Abstract: Secondary spontaneous pneumothorax (SSP) is serious entity, usually due to underlying disease, mainly chronic obstructive pulmonary disease (COPD). Its morbidity and mortality is high due to the pulmonary compromised status of these patients, and the recurrence rate is almost 50%, increasing mortality with each episode. For persistent or recurrent SSP, surgery under general anesthesia (GA) and mechanical ventilation (MV) with lung isolation is the gold standard, but ventilator-induced damages and dependency, and postoperative pulmonary complications are frequent. In the last two decades, several groups have reported successful results with non-intubated video-assisted thoracic surgery (NI-VATS) with thoracic epidural anesthesia (TEA) and/or local anesthesia under spontaneous breathing. Main benefits reported are operative time, operation room time and hospital stay reduction, and postoperative respiratory complications decrease when comparing to GA, thus encouraging for further research in these moderate to high risk patients many times rejected for the standard regimen. There are also reports of special situations with satisfactory results, as in contralateral pneumonectomy and lung transplantation. The aim of this review is to collect, analyze and discuss all the available evidence, and seek for future lines of investigation.

Keywords: Thoracic surgery; video-assisted; pneumothorax; anesthesia; epidural; ventilation; mechanical

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Authors' introduction:

Figure 1 is part of our team at the University General Hospital of Alicante, and it is composed by thoracic surgeons (Dr. C. Galvez, Dr. S. Bolufer), anesthesiologists (Dr. J. Navarro-Martinez, Dr. MJ. Rivera, Dr. M. Galiana) and the nurses (Mrs. M. Perez, Mrs. E. Ortuño, Mrs. F. Rey). We began on July 2013 with non-intubated uniportal VATS procedures and we are evolving in the anesthetic care, major procedures and fast-track protocols to achieve the least invasive approach for our patients.

Figure 1 From left to right: (Up) Dr. F. Lirio (Thoracic Surgery Resident), Dr. C. Gálvez (Surgeon), Mrs M. Perez (Nurse), Dr. M.J. Rivera (Anesthesiologist), Dr. J. Navarro-Martínez (Anestesiologist), Dr. S. Bolufer (Surgeon); (Down) Mrs. Fini Rey (Care Assistant), Dr. M. Galiana (Anesthesiologist), Mrs. Eva Ortuño (Nurse).

Introduction

A pneumothorax is defined as an abnormal accumulation of air in the pleural space, and we call it spontaneous in the absence of thoracic trauma. In contradistinction to primary

Figure 2 CT scan of right secondary spontaneous pneumothorax due to underlying severe emphysema with multiple bullas.

spontaneous pneumothorax (PSP) which usually occurs in young healthy males who do not have clinically apparent lung disorders, secondary spontaneous pneumothorax (SSP) is associated with underlying pleural or lung disease, such as chronic obstructive pulmonary disease (COPD) in most cases (*Figure 2*), cystic fibrosis, interstitial lung disease (ILD) or others, and has greater consequences (higher morbidity and mortality) and more challenging management due to the more compromised pulmonary status of these patients, comparing to PSP (1). COPD is the more frequent cause of SSP, and the probability of developing an episode increases proportionally to the deterioration of FEV_1 value and FEV_1 to forced vital capacity (FVC) ratio (2). The global incidence of SSP has been reported as 3.8/100,000, being more likely in men (6.3/100,000), than in women (2/100,000), with a peak incidence at 60-65 years of age. The recurrence rate reaches the 40-56% of all first episodes, with age, pulmonary fibrosis and emphysema as risk factors for recurrence, and can occasionally be lethal (3) increasing the mortality by 3.5 times with each pneumothorax occurrence in COPD (4). All the SSP patients should be admitted to hospital, and most of them need a chest drain, trying to be as conservative as possible in most cases. In those cases of intractable pneumothoraces, or in the case of prolonged air leak, surgical treatment with video-assisted thoracic surgery (VATS) for bullectomy and pleurodesis has shown good results, generally performed under GA and lung isolation with double-lumen endotracheal tube (5). Despite its extended use in many different surgeries, risks of GA and mechanical ventilation (MV) are not negligible, especially in patients with poor performance status (PS) and cardiorespiratory disease. Impaired cardiac function, haemodynamic instability, alveolar barotrauma, volutrauma and atelectrauma with increased risk of pneumonia are described, and also neuromuscular blockade increases atelectasis in the non-operative dependent lung with right-to-left shunt and increased risk of hypoxia and ventilator dependency (6). These risks shouldn't be underestimated in patients with SSP.

Awake procedures in non-intubated patients, avoid GA and ventilator-induced damages, and have shown encouraging results in many surgical procedures such as pulmonary wedge and anatomical resections, pleural effusions, hyperhidrosis, thymectomies and lung-volume reduction surgery (LVRS) (7). In the last years, some groups have reported their results with different approaches under local or regional anesthesia in the treatment of primary and SSP.

The aim of this review is to collect all the experience of different non-intubated VATS (NI-VATS) strategies with local and/or epidural thoracic anesthesia for SSP and analyze their results.

Adverse effects of GA and MV in pulmonary compromised patients

GA is nowadays the first-line gold standard anesthetic strategy in thoracic surgery with single-lung MV. It can be performed with double-lumen tube (DLT) orotracheal intubation or with endobronchial blockers (EB). With the smaller internal diameters of DLTs, plateau pressure and peak inspiratory pressure increase in a 42% and 55% respectively, with the inherent risk of lung damage with high plateau pressures (8). The loss of diaphragm motion with muscle relaxation and displacement by abdominal organs, the loss of intrapleural negative pressure in the operative lung with mediastinal weight release onto the lower lung, and the decrease of functional residual capacity (FRC) of the dependent non-operative lung, which is perfusion favored during lateral decubitus, originates an important disturbance in the ventilation/perfusion (V/Q) matching. With ventilation restriction to the non-operative lung, the perfusion through the operative lung increases the physiological right-to-left shunt, leading to potential intraoperative hypoxemia. The physiological mechanism of hypoxic pulmonary vasoconstriction (HPV), which closes blood vessels in the non-ventilated areas thus redirecting the flow to ventilated areas, protects from this shunt. Volatile anesthetics used in GA have been reported to inhibit this mechanism, whilst other intravenous agents like propofol and thoracic epidural agents have little or no effect on HPV. This shunt fraction can increase if atelectasis develops in the non-

Figure 3 Diaphragm motion in the operative lung during NI-VATS procedures. Keeping diaphragm motion preserves the compliance in the non-operative lung, which in addition to a better perfusion favored by gravity minimizes the disruption in the match of ventilation/perfusion thus decreasing the risk of hypoxemia in patients with pulmonary underlying disease (13). Available online: http://www.asvide.com/articles/496

operative lung, due to extrinsic compression by mediastinum, abdominal organs, and low tidal volumes of protective lung ventilation protocols (9). Oxygen toxicity due to ischemia-reperfusion injury and oxidative stress is another consequence of single-lung ventilation, and should be minimized with the lowest FiO_2 possible (10), and the rational use of PEEP for improving oxygenation trying to avoid excessive lung overdistention. Besides this, MV can produce barotrauma (airway pressure-induced injury), volutrauma (lung inflation-induced injury), atelectrauma (opening-closing cycle) and biological trauma (proinflammatory mediators release), increasing morbidity and mortality. All these deleterious effects of GA and MV should be highlighted in patients with SSP and underlying pulmonary disease because they can fatally influence the postoperative course of the patients, although there is still a paucity of studies assessing the effects of GA in this group of patients.

There are not too many reports of surgery in SSP, but it seems logical that patients with SSP are at a high risk of developing postoperative complications due to their worsened general status and their underlying pulmonary disease, with a postoperative morbidity rate between 15-27.7% in a recent review (11). Many factors like prolonged air leak, elevated $PaCO_2$ level, or severity of the pulmonary disease have been correlated with increased postoperative complications in these patients (12).

Thus, although considered the gold standard for the anesthetic management of thoracic surgery patients, and in spite of being a benign disease, the potential risks of SSP surgery under GA and MV should be taken into account. The scenario in SSP shows to be different from that of PSP in young patients without evidence of pulmonary disease, so searching for new less invasive and aggressive anesthetic strategies becomes essential.

Potential advantages of locoregional anesthesia in awake non-intubated patients with SSP

First of all, keeping diaphragm motion during awake procedures avoiding muscle relaxation (*Figure 3*), preserves the compliance in the dependent non-operative lung, which in addition to a better perfusion by gravity minimizes the disruption in the match of V/Q, compared to GA (14), thus decreasing the risk of hypoxemia in patients with pulmonary disease.

Intravenous anesthetics like propofol, and thoracic epidural agents (bupivacaine, ropivacaine, xylocaine) have shown to affect little or nothing the HPV mechanism, thus reducing the risks of hypoxemia due to right-to-left shunt (15,16). This proves to be safer when dealing with patients with chronic drop of oxygen saturation like severe emphysema or pulmonary fibrosis.

Some meta-analysis showed that thoracic epidural anesthesia (TEA) may potentially decrease cardiac morbidity and mortality after non-cardiac procedures (17,18). Other meta-analysis have shown that epidural anesthesia reduces postoperative morbidity and mortality (19,20) comparing to GA, thus decreasing pulmonary infections to about a third, and overall pulmonary complications to about a half comparing to GA (19). The explanation for this probably relies on earlier mobilization of the patients, adequate pain control for coughing and reduced opiod consumption (21) lead to reduce the risk of secretions retention, atelectasis and pulmonary infection. Of course, avoiding orotracheal intubation and MV seems to reduce postoperative complications such as pulmonary infections, as the traumatic damage to the bronchial and tracheal mucosa is avoided thus diminishing airway inflammation and manipulation of the non-sterile tracheobronchial tree.

Oxygen saturation over 90% can be kept in these spontaneously breathing patients with oxygen support delivered with nasal prongs, facial mask, high-flow oxygen devices or intranasal multi-perforated cannula above the larynx (*Figure 4*). We should be very cautious with sedation because it favors hypercapnia, and in patients with chronic high levels of $PaCO_2$ should

Figure 4 Devices used for oxygen supplementation during spontaneous breathing procedures: nasal prongs, facial mask, high-flow oxygen devices and intranasal multi-perforated cannula.

be kept in mind. The permissive hypercapnia is very common in non-intubated patients, but typically is well tolerated. Monitoring directly pH, PCO_2 and PO_2 through the invasive monitorization using the radial artery is important. In case severe hypercapnia develops, a non-invasive ventilator should be prepared. It is better to avoid sedation as much as possible, letting the patient to communicate with the anesthetic team thus increasing or decreasing depth of ventilation depending on the respiratory parameters and the need of both the surgeon and the anesthesiologist.

NI-VATS with TEA or combined with local anesthesia for SSP

There are not too many reports of NI-VATS procedures under TEA or combined with TEA plus local anesthesia in patients with secondary pneumothorax, and there is a complete lack of clinical trials, so the evidence level reaches at most a level 2- (cohort or case/control studies with high bias risk) or level 3 (non-analytic studies like case reports and case series). This poorness of trials impedes to settle strong recommendations, which are limited to a D degree of the Scottish Intercollegiate Guidelines Network (SIGN) (22). It is important to keep in mind that serious ethical considerations arise when dealing with patients with moderate to severe pulmonary disease if we consider to randomize into two groups with TEA ± local anesthesia or GA in the light of a high respiratory complication rate and great risk for ventilator dependency (6).

There is only one comparative retrospective study, published by Noda *et al.* in 2012 (23). They performed during a 5-year period 57 VATS on SSP patients with air leak of more than 7 days. A total of 42 patients were operated with the standard GA and orotracheal intubation, and 15 underwent surgery with TEA and/or local regimen. There were no specific criteria for selecting patients for the TEA/local arm, but it was applied in patients with poorer PS and more oxygen requirement (P=0.009 and P=0.0002 respectively). With a propensity score matching analysis to minimize differences between the groups, comparable groups of eight patients each with almost identical characteristics were found and there were no statistical differences between them. All procedures in the TEA arm were performed with a catheter at T3-6 level instillating ropivacaine 0.2% in continuous infusion, with lidocaine 1% in the 2-3 ports. Oxygen supplement was administered to keep oxygen saturation above 94%, but there is no explanation about the oxygen delivery system. A Roeder loop and endostaplers were used for treating primary lesions, and no systematical pleurodesis was performed during the surgery. They found an important decrease in the operating room (OR) time in the TEA arm (116.5±5 *vs.* 209.1±77.1 minutes) which proved to be significant in the entire study and the propensity-score matched pairs (P<0.0001 and P=0.006). There were four cases of prolonged air leak (>7 days) in the TEA arm for three cases in the GA arm (P=0.05) but significance disappeared after the propensity-score analysis (P=0.60). Postoperative respiratory complications [pneumonia and acute respiratory distress syndrome (ARDS)] happened during GA in ten cases, but none in the TEA arm (P=0.046) and this difference was kept significant in the propensity analysis (P=0.02). Hospital stay was not significantly different and four hospital deaths were observed in the GA arm (pneumonia in two cases and ARDS in other two cases), without reaching the statistical significance (P=0.25). Authors concluded that TEA could decrease total OR time and postoperative respiratory morbidity, even in more compromised patients, hypothesizing that avoiding barotrauma and the risk for aspiration could benefit this group. This approach proves to be feasible and with an acceptable pattern of morbidity, but additional studies are needed, stated the authors.

There are two case series assessing non-intubated epidural regimens for SSP. Mukaida *et al.* in 1998 (24) reported four cases of intractable SSP with a drainage duration between 22 and 49 days preoperative. All patients were performed a pleurography, but there are no details. Epidural catheter with bupivacaine 0.26%, intravenous sedation with fentanyl and local 1% lidocaine were administered for a 3-port VATS approach and oxygen supplementation with facial mask. Fibrin glue and polyglycolic acid sheet were used to treat the pulmonary leak. There were no hemodynamic disturbances during surgery, and no postoperative complications were reported. There was no recurrence during a 16-month follow-up, so they conclude that TEA NI-VATS surgery for SSP is a safe procedure, and that the fibrin glue and polyglycolic acid sheet technique can control the leak in these patients.

Kiss and colleagues (6) reported in 2014 an observational retrospective series of nine cases of severely dyspnoeic patients excluded from GA, needing thoracic surgery (thoracotomy in six cases and VATS in three cases), five of them with intractable pneumothorax. Different underlying pathologies were registered: idiopathic pulmonary fibrosis in two cases, multiple bilateral pulmonary metastasis in three cases, severe COPD in one case, inflammatory alveolitis in one case, and advanced myopathy in two cases. All patients were high risk of the American Society of Anesthesiologist (ASA 4), and 8 were also grade 4 of the Modified Medical Research Council (MMRC) dyspnea scale, so this is the first report of TEA in which ASA and dyspnea scale are mentioned. Six of the nine patients needed oxygen preoperatively. TEA catheter was inserted between T3-7 levels with lidocaine 20 mg/mL, ropivacaine 7.5 mg/mL, and/or xylocaine 1-2%, and none or only mild sedation with propofol and remifentanyl or only remifentanyl was administered in order to avoid hypoventilation and hypercapnia. High flow oxygen with ventimask at 15 L/min was needed in all the patients to achieve oxygen saturation between 85-100%, and only in one case of severe COPD 2 L/min was administered, being saturation during surgery between 85-97% all the whole procedure. One of the patients with advanced myopathy even needed during surgery her own BiPAP ventilation routine level. All patients received PEEP of 5 cmH_2O for lung re-expansion, and non-invasive ventilation after the surgery to prevent atelectasis in the absence of air leak. Surgical time was 76 minutes and total OR time of 170 minutes, with no need for conversion to GA. Respiratory complications during surgery were only one hypercapnia with 79 mmHg end-tidal CO_2 ($ETCO_2$), and one perioperative hypercapnic coma ($ETCO_2$ 58 mmHg), both of them managed with assisted mask ventilation in the spontaneously breathing patient. All patients resume oral intake at postoperative day (POD) 1, and there was no complication related to TEA. One patient with idiopathic pulmonary fibrosis developed ADRS, dying at POD 25. One patient died at home 2 months after the surgery and postoperative chemotherapy, and seven patients were still alive at 6 months after the procedure. All patients were satisfied with TEA anesthesia. The limitations of the study are its non-randomized and retrospective design, and the small sample of patients. Ethical considerations and the low prevalence of this severely dyspnoeic patients which can improve with surgery are the explanations of the authors. They also make no monitoring of PaO_2, but oxygen saturation was kept in all patients between 85-100%. There was also no specific protocol with TEA, so it was left to the discretion of the anesthesiologist.

In 2005, Sugimoto *et al.* (25) described their experience with two cases of pneumothorax in the native lung after lung transplantation. The risk of pneumothorax is not negligible secondary to bronchial anastomosis stricture thus leading to preferential ventilation in the native one, progression of the underlying disease (emphysema, pulmonary fibrosis, lymphangioleiomyomatosis), or prolonged MV in case of living-donor lobar lung transplantation. They describe a technique with TEA plus local anesthesia in a multiportal VATS approach, controlling the air leak with fibrin glue and polyglycolic acid sheet, with excellent results and no recurrence in a 40 and 23 months follow-up respectively. The potential benefit of non-intubated procedures in these two cases relies on avoiding deleterious effects of MV through a bronchial anastomosis stenosis and a small graft of one lobe.

On the other hand Noda *et al.* (26) reported a successful management of a right pneumothorax in a patient with a previous left pneumonectomy for non-small cell lung cancer (NSCLC), with emphysema and bullas in the right lung. A TEA catheter with ropivacaine 0.2% plus local infiltration of lidocaine 1% were used in a 2-port VATS, resecting the bulla with an endostapler and polyglycolic acid sheets, and spraying fibrin glue over the suture. Oxygen supplement was administered in order to keep saturation above 95% during all the procedure. Patient was discharged on POD 4 and there was no recurrence, concluding that it constitutes a safe strategy for managing pneumothorax in patients with a contralateral pneumonectomy and underlying disease in the affected lung.

We cannot finish this review without mentioning the valuable input of Dr. Pompeo, Mineo and their Awake Thoracic Surgery Research group in two Letters to Editor published in 2012 (27,28). Given their worldwide known experience with awake thoracic surgery procedures, and in response to the report of Noda above mentioned (23), they showed their initial results with 23 SSP. In their series, surgical time between 35 and 90 minutes, and mean hospital stay of 3 days were reported. In a follow-up between 12 and 108 months they had no recurrence of pneumothorax. They also highlighted that mean drop in PaO_2 to inspired fraction of oxygen ratio was markedly lower in patients with underlying severe COPD (34 *vs.* 77 mmHg in normal lungs), and they correlate this with severe trapping of air in COPD patients, which can counteract the effect of atmospheric pressure over the operating lung, due to a PEEP effect and elongation of exhalatory time. They also proved that awake procedures in SSP attenuated release of stress hormones (cortisol), inflammation markers (IL-6) and natural killer cells activation, hypothetizing that, as it preserves more the immune response, could potentially explain the decrease in postoperative infections.

NI-VATS with local anesthesia for SSP

When we analyze the works concerning NI-VATS surgery for SSP performed under local anesthesia with or without sedation, we find only one comparative study, one case series, one case-report and one letter to editor. The lack of scientific evidence is clear and there is a complete lack of clinical trials, so the evidence level reaches at most a level 2- (cohort or case/control studies with high bias risk) or level 3 (non-analytic studies like case reports and case series). It is not possible to settle strong recommendations, which are limited to a D degree of the SIGN (22).

In 1997, Nezu *et al.* (29) published what constitutes the earliest comparative study of NI-VATS surgery for pneumothorax including SSP ever published. They reported 34 cases of persistent or recurrent pneumothorax (primary and secondary) operated on with local anesthesia and sedation. They compared with 38 patients operated under GA, but there are no specified criteria for selecting patients for one or the other regimen, although all the patients in the local group had no adhesions and radiologically localized bullas previous to the operation. They included both primary (PSP) and secondary pneumothorax (SSP). Lidocaine 0.5% in the pleural and intercostal space, and butorphanol tartrate and intravenous diazepam were used to achieve local somatosensory block and mild sedation. With 3-port VATS they performed resection of the bulla with endostapler and fibrin glue aerosolized. Overall success rate was achieved in 94% of the patients, with two cases needing a later open procedure under GA because of anxiety attack and severe adhesions. Respiratory and hemodynamical parameters kept into normal values, with 44.6 minutes of mean surgical time and 4.5 days of mean length of stay. There were three postoperative complications (9.4%): one case of atelectasis solved with conservative treatment, and 2 prolonged air leaks, one of them solved with minocycline pleurodesis and the other stopped spontaneously on 6^{th} day. Only one patient had a recurrence (3.2%), and needed a new surgical procedure. They found statistical differences in surgical time and length of stay favoring patients operated with local anesthesia against GA (44.6±11.6 *vs.* 63.3±20 minutes, $P<0.01$; 4.5±1.3 *vs.* 5.8±1.1 days, $P<0.01$).

The same year, Tschopp *et al.* (30) described their results with a series of 89 patients with recurrent or secondary pneumothorax, where 93 toracoscopies (2-port) and talc pleurodesis with local anesthesia (lidocaine 1%) were performed. For premedicating these patients they used atropine 0.5 mg, midazolam 3-10 mg and petidine 25-100 mg. They didn't resect any lung parenchyma nor any bulla, just applied 3 to 5 mL of talc all over the pleural surfaces. Mean drainage time of 5 days and mean length of stay of 5.2 days were reported. Only mild postoperative complications were described (subcutaneous emphysema, arrhythmia, pneumonia and bronchospasm). Nine patients needed a second procedure, where seven succeeded repeating the same operation, and two needed VATS or thoracotomy. There were six recurrences (6.4%), where three of them succeeded repeating the procedure, two spontaneously and one needed a later thoracotomy. They found bulla size bigger than 2 cm a risk factor for recurrence (40%). They concluded that this approach was safe, cheap and simple for the treatment of complicated pneumothorax.

In 1999, de la Torre Bravos *et al.* (31) in a letter to editor mentioned their experience with two cases treated with local mepivacaine 200 mg and intravenous midazolam 5 mg, with successful results.

Finally, in 2012 Yutaka *et al.* (32) published a case of persistent SSP treated under local anesthesia (lidocaine 1%) with a VATS approach, just using polyglycolic acid sheet, fibrin glue and autologous blood on the air leak. Operative time was 55 minutes and drainage time 5 days and there was no recurrence.

Discussion

The review of scientific evidence about the experience with

Table 1 Results of main reports about non-intubated treatment of secondary pneumothorax

Author [year]	Anesthesia	No. of patients	Morbidity (%)	Respiratory complications (%)¶	Recurrence rate (%)
Nezu [1997] (29)	Local + sedation	32	9.4	–	3.2
Tschopp [1997] (30)	Local + sedation	93	6.4	5.3	6.4
Mukaida [1998] (24)	TEA + local + sedation	4	0	0	0
Noda [2012] (23)	TEA + local	15	26.6	0	–
Kiss [2014] (6)	TEA ± sedation	9	11.1	11.1	0

¶, prolonged air leak excluded from respiratory complications; TEA, thoracic epidural anesthesia.

NI-VATS in the management of SSP, must focus in three main aspects: first of all, what we expect about potential benefits of this less-invasive anesthetic/surgical approach in these deteriorated patients; secondly, the results of the little experience collected through the last two decades, mainly case series and some comparative study; third of all, which ones should be the lines for further research and investigation.

The first issue focuses on elucidating the potential advantages that would make a non-intubated VATS approach better than the conventional one with GA and MV. Our current knowledge about pathophysiology of surgical pneumothorax in a spontaneously breathing patient evidences that it produces both positive and negative effects in the respiratory balance of the patient (33). On the one hand, preserving the diaphragm motion, conserves the pulmonary compliance of the non-operative lung, which is perfusion favored during lateral decubitus, thus the ventilation to perfusion match results less affected, decreasing the risk of hypoxemia. It also reduces the risk of atelectasis in the non-operative lung by keeping diaphragm contraction. The use of propofol and other agents (mepivacaine, ropivacaine) in the thoracic epidural catheter seems to keep the physiological mechanism of HPV, which in conclusion favors perfusion on the non-operative ventilated lung. Avoiding orotracheal intubation and MV clearly diminishes the risk of barotrauma, volutrauma, atelectrauma and the inflammatory response to the aggression of manipulating the airway. Given that COPD patients show a high incidence of bronchial hyperreactivity, avoiding GA and tracheal intubation can prevent from bronchospasm, which in some situations can be lethal for these patients (34-37). Alongside this, the earlier mobilization and restart of oral intake decreases the risk of developing atelectasis and secretions retention, so all of this may explain the reduction in postoperative respiratory complications (20,23). On the other hand, some negative effects of iatrogenic pneumothorax in a spontaneously breathing patient are not negligible. Mediastinum drop above the non-operative lung due to the atmospheric pleural pressure and rebreathing mechanism of expirated air into the dependent lung can produce some degree of hypoxemia, and hypercapnia (38). Oxygen delivery to the patient can counteract these effects by increasing oxygen saturation in the inspirated air in order to elevate oxygen alveolar pressure. Hypercapnia has been called "permissive" because usually seems to be well tolerated by patients and seldom forces to convert to GA. All of those beneficial effects are especially important in patients with severely depressed pulmonary reserve and poor general status, because they might signify the difference between developing or not postoperative complications. NI-VATS experience with other kind of procedures aims at reduction in surgical time but mainly in OR time, thus potentially increasing the OR occupation ratio, and also aims at reducing hospital stay which could have an economical benefit reducing procedure-related costs (39). Finally, Pompeo *et al*. (40) reported no differences identifying emphysema-like changes (ELCs) during surgery for PSP, between the NI-VATS and the GA arms (90% *vs*. 95%; P=0.52), and these findings are in agreement with those reported by Nezu, suggesting that it can even facilitate detection of small blebs/bullae which remained insuflated during spontaneous breathing.

But, which are the results in terms of benefits and risks obtained by surgical groups performing non-intubated VATS procedures for patients with SSP? *Table 1* resumes the main results to date. Best evidence collected proceeds from the only two comparative studies by Nezu *et al*. (29) and Noda *et al*. (23). Significant decrease in operative time was found by Nezu when comparing with the GA arm (44.6±11.6 *vs*. 63.3±20 minutes, P<0.01), but this difference could not be statistically proven when comparing the TEA/local arm

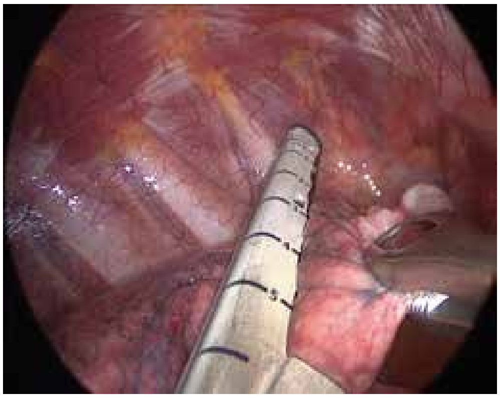

Figure 5 Resecting apical bullous complex with endostapler in a patient with underlying moderate emphysema.

vs. GA arm in the report by Noda in 2012, although they reported a trend for reducing this operative time in the TEA arm (85.9±35.3 *vs*. 111.4±56.1 minutes) not reaching the statistical significance (P=0.12). Significant difference in total OR time favoring the non-intubated arm (116.5±5 *vs*. 209.1±77.1 minutes) both in the entire comparison and in the propensity score-matched comparison (P<0.0001 and P=0.006) was reported in this latter study. Postoperative complications incidence favors the NI-VATS groups in both studies (26.6% *vs*. 30.9% in Noda, and 9.3% *vs*. 10.5% in Nezu) not reaching statistical significance, but in a subanalysis by Noda, they describe significant reduction of respiratory complications which benefits the TEA arm both in the total entire cohort study and in the propensity score-matched analysis (P=0.046 and P=0.02, respectively), even though the TEA patients had poorer PS as shown in *Table 1*. Finally Nezu found a non-negligible reduction in hospital stay in the NI-VATS arm (4.5±1.3 *vs*. 5.8±1.1 days, P<0.01) although not finding differences in the drainage time (3.3±0.9 *vs*. 3.7±1.3 days). A trend toward reducing hospital death in the more affected patients of the TEA arm was mentioned by Noda, despite not reaching significance (0 deaths against 4 deaths in the GA group). Recurrence rate was not increased in the local anesthesia group analyzed by Nezu (3.2%) when compared to the 2.8-9.3% rate in present studies of surgical result in SSP under GA (12,41,42). Globally it seems that NI-VATS can be performed in these patients safely and even decreasing postoperative complications, and it can also save surgical/OR time and hospital stay when comparing to the standard GA regimen. These results support the theoretical benefits previously mentioned and it also seems not to increase the risk for a future recurrence in severely affected patients.

Case series by Mukaida (24) and Kiss (6) show the feasibility and safety of managing high risk patients with a NI-VATS approach without recurrences in the follow-up interval, and reasonable results in terms of postoperative complications with only one ADRS in the study by Kiss in a patient with severe interstitial pulmonary fibrosis and ASA 4 who died on the POD 25. These results constitute a real alternative for patients that normally would be rejected for standard procedures under GA because of high risk.

Some case reports published (25,26) also bring to mind that NI-VATS with thoracic epidural and/or local anesthesia has been anecdotally proven feasible and safe for managing patients with special basal situations that contraindicate or at least increase the risks for complications if GA and one-lung MV are administered, such as lung transplantation or contralateral pneumonectomy, thus providing a new choice with a future potential that must be elucidated.

Specific surgical management of SSP in patients with TEA and/or local anesthesia is not far different from the standard procedures and manoeuvres used for this surgery under GA, highlighting the coincidence in resecting the bullas when possible (*Figure 5*) but trying to seal the leak with fibrin glues/polyglycolic acid sheets in the cases of strong adhesions in order to avoid iatrogenic damage. But surprisingly, barely one of these reports (30) mentions a method of creating a pleural symphysis for preventing recurrences, such as abrasion pleurodesis, apical pleurectomy of chemical pleurodesis with talc, which are recommended in the American College Chest Physicians (5), Respiratory Pathology Spanish Society (3) and British Thoracic Society guidelines (1) of 2001, 2008 and 2010 respectively.

When dealing with potential future lines of research in this field, some ethical issues should be considered. There is evidence that the risk for ventilator dependency in patients with comorbidities is higher in cases of GA (43), and usually SSP patients have poorer PS and cardiopulmonary underlying disease. There is no comparative study of SSP patients undergoing surgery with TEA/local anesthesia against GA which mentions ASA status, but the report by Kiss proved the feasibility and safety of surgery under TEA in ASA 4 patients rejected for GA, in terms of morbidity and recurrence. Also the report by Noda included patients with poorer PS and oxygen requirement in the TEA group, with better results in terms of morbidity and respiratory complications when comparing to patients under GA. It remains unclear whether NI-VATS surgery under TEA/local anesthesia in ASA 3-4 patients could potentially benefit in terms of morbidity and mortality, so a randomized prospective clinical trial would be required to elucidate this dilemma. But as many of these patients are usually contraindicated for GA and because of the encouraging results under NI-VATS surgery, setting up a randomized clinical trial in a real hospital clinical setting results controversial at least.

There is some heterogeneity in the surgical treatment of SSP: some groups tend to treat only the air leak (mainly bullas) with different strategies, plicating the bulla, resection with an endostapler, or applying fibrin glue and polyglycolic acid sheets, in most cases. In the other hand some groups perform pleurodesis to produce pleural symphysis. Finally some groups treat the air leak but also perform pleurodesis with different mechanisms, although criteria for the latter usually lack and is left to the surgeon's decision. This heterogeneity in the surgical management hinders the research, because it adds more variability, and it is also related to the broad period where these studies have been performed, since 1997 till 2014, when the directives in the treatment of SSP have slowly changed. We need homogeneous comparable surgical and anesthetic strategies when comparing TEA/local anesthesia with GA, in order to identify which aspects directly contribute to the results in terms of morbidity, mortality and recurrences. There is no literature of non-intubated uniportal VATS surgery in the treatment of pneumothorax, although our group has performed already three procedures for PSP safely, so more experience is needed to assess the potential benefits of uniportal approach in these patients.

Despite the difficulty, a multicenter international database could be created in order to collect the patients with SSP who finally undergo surgery in the centers performing NI-VATS, including both patients operated with TEA and/or local anesthesia or GA. Although limited for setting strong recommendations, this database may contribute to accumulate data about which patients benefit more of a NI-VATS procedure, risk factors for morbidity and mortality in both groups, and which anesthetic and surgical regimen could benefit more these patients.

Conclusions

NI-VATS with TEA and/or local anesthesia is a feasible and safe alternative for patients with persistent or recurrent SSP with underlying pulmonary disease. The results of the last two decades aim at reduction of surgical and OR times, hospital stay, and decrease in postoperative morbidity and respiratory complications, when compared to GA. It also constitutes an alternative for patients rejected for GA because of their high risk of ventilator dependency. Moreover there is a lack of prospective randomized clinical trials to achieve stronger evidence to make firm recommendations about the surgical treatment in these patients.

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When the doctor becomes the patient, he experiences desolation, affliction and hopelessness. Then he needs the words to keep on fighting: endure, dream, live. To my extraordinary wife, for all. To my beloved family, for peacefulness. To my friends, for support. Thanks to life.

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Surgical pneumothorax under spontaneous ventilation—effect on oxygenation and ventilation

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Abstract: Surgical pneumothorax allows obtaining comfortable surgical space for minimally invasive thoracic surgery, under spontaneous ventilation and thoracic epidural anesthesia, without need to provide general anesthesia and neuromuscular blockade. One lung ventilation (OLV) by iatrogenic lung collapse, associated with spontaneous breathing and lateral position required for the surgery, involves pathophysiological consequences for the patient, giving rise to hypoxia, hypercapnia, and hypoxic pulmonary vasoconstriction (HPV). Knowledge of these changes is critical to safely conduct this type of surgery. Surgical pneumothorax can be now considered a safe technique that allows the realization of minimally invasive thoracic surgery in awake patients with spontaneous breathing, avoiding the risks of general anesthesia and ensuring a more physiological surgical course.

Keywords: Pneumothorax; spontaneous ventilation; one lung ventilation (OLV); lateral position; awake thoracic surgery; minimally invasive surgery; nonintubated thoracic surgery

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Introduction

In the last decades, the widespread use of epidural and local anesthesia techniques has allowed the development of safe minimally invasive thoracic surgery on awake patients in spontaneous breathing (1).

One lung ventilation (OLV) is required in most thoracic open procedure, especially in video-assisted thoracoscopic surgery (VATS), to allow an adequate comfort to surgical procedure (2).

Under general anaesthesia, three ways are usually used to achieve OLV. The classic, most common technique is the use of double lumen tube that allows to isolate either the right or the left lung (3,4).

In alternative, OLV can be achieved using a bronchial blocker or a single lumen tube. Latter options are more easily used to exclude or, respectively, ventilate the right lung because the more favourable angulation of the right bronchus (5).

In awake or sedated patient, the collapse of the operative lung, required for the optimal visualization of the surgical field during open surgery or VATS can't be obtained by double lumen endotracheal tube, bronchial blocker or by single lumen endobronchial tube (6).

Under spontaneous ventilation and thoracic epidural anesthesia, surgical pneumothorax allows obtaining a well-collapsed lung and a comfortable surgical space, without need to provide general anesthesia and neuromuscular blockade (7).

While in the closed pneumothorax, the pleural space enters into communication with the lung air space, in the surgical pneumothorax, defined as open pneumothorax, the air enters the pleural space through the surgically opened chest wall (8).

This iatrogenic event involves some inevitable pathophysiological changes, which modify in a significant manner ventilation, oxygenation and haemodynamic (9,10).

At the same time, spontaneous ventilation, through negative inspiration pressure and maintaining of diaphragmatic mobility, permits to better tolerate some

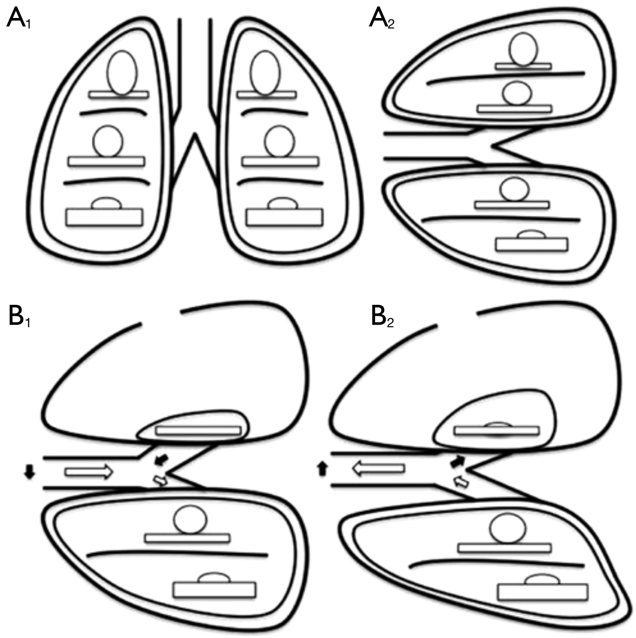

Figure 1 The relationship between ventilation and perfusion. (A) Relationship between ventilation (roundes) and perfusion (rectangles) in different lung zones, in upright (A_1) and lateral position (A_2); (B) relationship between ventilation (roundes) and perfusion (rectangles) in lateral position with surgical pneumothorax, during spontaneous inspiration (B_1) and exhalation phase (B_2). Black arrows show paradoxical ventilation and mediastinal shift.

of the pathophysiological alterations caused by surgical pneumothorax and lateral position (11).

In the next paragraphs we will discuss the main alterations resulting from the surgical pneumothorax and the way in which spontaneous breathing and lateral position affect these changes.

Surgical pneumothorax, hypoxia, and hypoxic pulmonary vasoconstriction (HPV)

As during any kind of OLV technique, during surgical pneumothorax, the excluded and not ventilated lung continues to be perfused. This situation is typically defined as right-left intrapulmonary shunt, condition that involves an increased risk of intraoperative hypoxemia (12).

The pathophysiological mechanism which can protect from undesirable shunt effect is the HPV. Through it, the pulmonary arteries of hypoxic alveoli constrict and divert the blood flow to the arteries of well oxygenated alveoli (13).

Thanks to response of collapsed lung vasculature, ventilation to perfusion ratio alterations are minimized and relatively well tolerated, specially in awake patients, in which this mechanism is well maintained (14).

In fact, some anesthetic drugs, like volatile anesthetics, can inhibit the protective vasomotor response of HPV, exposing a greater risk of hypoxemia while others drugs, such as propofol or drugs used for epidural anesthesia, acting on the sympathetic system, have less inhibitory effect on HPV (15,16).

Awake thoracic epidural anesthesia, and surgical pneumothorax with spontaneous breathing, seems, therefore, to be protective against the risk of hypoxic intrapulmonary shunt.

Simple oxygen administration through a Venturi mask can easily correct a decrease in arterial oxygenation in an awake patient undergoing surgical pneumothorax. Dependent lung has been shown to be able to compensate for decrease in oxygenation (9).

Although administration of oxygen, in association with volume reduction and rebreathing effect, can lead to moderate hypercapnia, this rarely become clinically dangerous (17).

Surgical pneumothorax, hypercapnia, and spontaneous ventilation

In surgical-induced pneumothorax, the negative intra-thoracic pressure, responsible for the physiological phase of inspiration, is lost on the side of the opened hemithorax. Air enters the pleural space through the surgical access on the chest wall, and transmitted atmospheric pressure determines the non-dependent lung collapse allowing an adequate surgical access (18-20).

Pneumothorax produces restrictive ventilatory alterations similar to those of pleural effusion, with reduction in vital capacity (VC), functional residual capacity (FRC), residual volume (RV) and total lung capacity (TLC). Furthermore, the increase in the ratio between airways size and lung volume, increases the expiratory flow and the speed of pulmonary emptying (21).

The loss in tidal volume is not proportional to the size of pneumothorax because it is balanced by the increase in volume of the dependent lung (22). Furthermore, spontaneous breathing in association with the anatomic alterations of the collapsed lung, cause two major adverse effects (23) (*Figure 1*).

First, in the absence of selective intubation devices, during spontaneous ventilation, the dependent lung exhales part of the air volume into the undependent bronchus and relative lung. During inhalation phase, with the same mechanism, part of the air volume just filled undependent lung, will be re-inspired by the dependent lung. This mechanism of ventilatory impairment is known as paradoxical respiration, and may be responsible for hypoxia and hypercapnia in patients undergoing surgical pneumothorax in spontaneous ventilation.

The second alteration consists in oscillation of mediastinum during the respiratory cycle, to and from the dependent hemithorax. In the inspiratory phase, the negative pressure caused by diaphragmatic contraction in the dependent hemithorax determines the attraction of mediastinal structures. During expiration phase the diaphragm back toward the chest, increasing the hemi-diaphragm pressure and pushing the mediastinal structures contralateral. Collapsed hemithorax, due to continuous atmospherical pressure, is unable to contrast the structures displacement during inhalation and exhalation phases. This mediastinal shift can lead to compression of the dependent lung and his potential functional impairment. While general anesthesia, through the diaphragmatic paralysis, worsens the compression exerted by the abdominal organs on the lungs, spontaneous ventilation in surgical pneumothorax condition, better expands the dependent lung, improving ventilation to perfusion matching. In this way, the patients are exposed to fewer alterations of ventilation and oxygenation (24).

Moreover, in awake and spontaneously breathing patients, central nervous mechanisms increase respiratory rate trying to balance the increased carbon dioxide (CO_2) tension due to the decrease in tidal volume (25). The goal during ventilation management of awake or sedated patient undergoing surgical pneumothorax is to maintain spontaneous respiratory activity, with a regular pattern and respiratory rate of 12-20 acts/min. Careful titration of opioid agents had been shown to allow an adequate control of respiratory rate in sedated patients. In case of significant hypercapnia, a modest ventilation in facemask may be required after giving notice to the surgical team (26).

Seriate sampling of arterial blood gas, before and after surgical pneumothorax, providing an adequate monitoring of CO_2 blood level, allows avoiding excessive hypercapnia (27).

Surgical pneumothorax and lateral position

Lateral decubitus position, in addition to being necessary for the surgical procedure, allows the patient significantly better oxygenation than supine position during OLV (28). However, it involves a condition of ventilation to perfusion mismatch: perfusion better occurs in the dependent lung, that behaves as the upright lung base, while the undependent lung, acting as its apex, has a greater ventilation (29-31) (*Figure 1*).

Dependent lung movements are limited by chest position and by rising of abdominal content toward the diaphragm, thus reducing ventilation compliance. At the same time, acting as the base of a lung in standing, dependent lung is better reached by blood pulmonary perfusion. Exactly the opposite occurs in the undependent lung and this implies that ventilation to perfusion ratio decreases in the former and increases in latter (32,33).

Considering the overall effect on the two lungs, in lateral position, VC, RV, and TLC decreases, due to the increasing of the intrathoracic blood volume (34,35).

Furthermore, forced inspiratory flow decreases at 25-75% of VC (36), and forced expiratory volume in one second (FEV_1), forced vital capacity (FVC) and peak expiratory flow decreases by 5-10% compared to sitting posture (37).

Pompeo *et al*. investigated spirometric alteration induced by surgical pneumothorax in awake patients lying in lateral decubitus (9).

They found in relatively normal lung, in interstitial lung disease, and in emphysema, a reduction in FEV_1 respectively of 52%, 49%, and 30%, and in FVC of 45%, 46%, and 34%, proving lower impairment of ventilation in the already altered lungs. The authors suggest that lesser impairment was due to smaller lung collapse occurred in situation of existing ventilatory obstruction and hyperinflation.

Effectiveness of the surgical pneumothorax

Pulmonary, airways, and pleural alterations can affect the optimal lung collapse. Pulmonary emphysema, obstructive pulmonary disease and pleural adhesion, increasing expiratory pressures, can result in a much lower response than conditions with respected physiological tissues elasticity and normal expiratory airway resistance.

The collapse degree also depends on the size of the iatrogenic pleural breach, that participates in the determination of the amount of air that enters the pleural space (9).

Conclusions

Creation of surgical pneumothorax can be now considered a safe technique that allows the realization of minimally invasive thoracic surgery in awake patients with spontaneous breathing. The exact knowledge of the main pathophysiological changes induced by opening of the pleura, allows obtaining the necessary awareness for prompt and safe management of the potential side effects.

The possibility to perform thoracic surgery procedures in awake and spontaneously breathing patients has shown to offer the advantage of avoiding the risks of general anesthesia and ensures a more physiological surgical course. Further detailed investigation is warranted to better define pros and cons as well as optimal indications for these procedurses.

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Urgent awake thoracoscopic treatment of retained haemothorax associated with respiratory failure

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Abstract: A number of video-assisted thoracoscopic surgery (VATS) procedures are being increasingly performed by awake anesthesia in an attempt of minimizing the surgical- and anesthesia-related traumas. However, so far the usefulness of awake VATS for urgent management of retained haemothorax has been scarcely investigated. Herein we present two patients with retained haemothorax following previous thoracentesis and blunt chest trauma, respectively, who developed acute respiratory failure and underwent successful urgent awake VATS management under local anesthesia through a single trocar access.

Keywords: Haemothorax; awake video-assisted thoracoscopic surgery (VATS); nonintubated VATS; respiratory failure; complication; urgent setting

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Authors' introduction:

Figure 1 is a picture including the authors of the article with other representatives of the ATSRG, a multidisciplinary team aimed at accomplishment and promotion of pioneering and comprehensive clinical investigations focused on awake and nonintubated thoracic surgery.

Introduction

Adoption of video-assisted thoracoscopic surgery (VATS) for management of chest trauma and haemothorax is increasing (1) since it can obviate complications associated with thoracotomy and can be employed both for diagnostic or therapeutic purposes in patients with haemodynamic stability (2).

Recently, a number of VATS procedures are being increasingly performed by nonintubated or awake anesthesia in an attempt of minimizing at a further extent the overall surgical- and anesthesia-related traumas. However, so far the usefulness of awake VATS for urgent management of retained haemothorax has been scarcely investigated (3).

Having gained experience with elective awake VATS procedures performed in patients with poor respiratory function due to emphysema (4), interstitial lung disease (5) or pleural effusion (6), we have recently expanded its use to selected patients with retained haemothorax in whom simple chest drainage proved an unsuccessful treatment option leading to the development of acute respiratory failure.

Case 1

A 33-year-old Caucasian male admitted due to acute abdominal pain with peritonitic signs underwent urgent laparotomy and duodenorraphy due to duodenal perforation of unknown origin. The postoperative course was complicated by complex abdominal infection requiring reopening of the skin incision and vacuum-assisted-closure (VAC) treatment; and bilateral pleural effusion. By a right-sided thoracentesis 500 cc of serous fluid were drained. Twelve hours later the patient complained of deteriorating dyspnea and anemia (Hb: 8.0 g/dL). A new chest X-ray showed the presence of massive pleural effusion on the right pleural cavity, which was treated by insertion of a chest tube

Figure 1 Core representatives of the ATSRG. From the left: Drs Benedetto Cristino, Augusto Orlandi, Eugenio Pompeo, Umberto Tarantino, Tiziana Frittelli (General Director of the Policlinico Tor Vergata), Leonardo Palombi, Paola Rogliani, Roberto Massa, Mario Dauri.

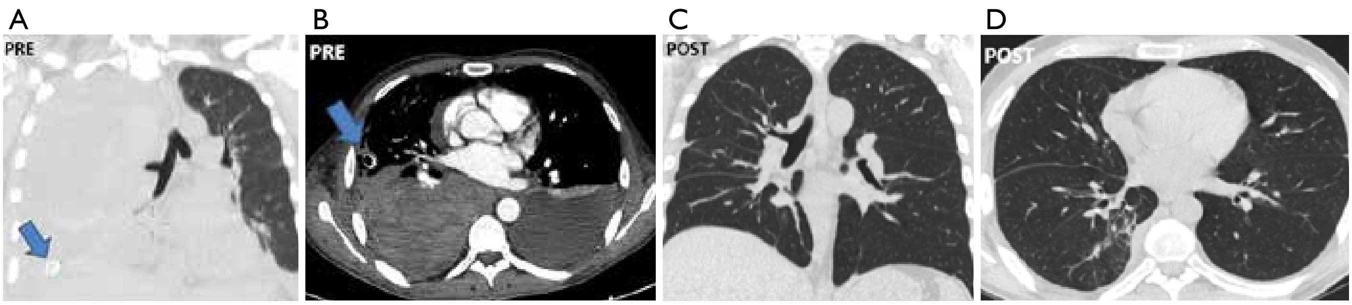

Figure 2 Computed tomography (CT) findings of patient #1. (A) Coronal image showing tension haemothorax causing left-sided mediastinal shifting despite previous insertion of a chest tube (arrow); (B) axial image of the same patient showing right-sided inhomogeneous liquid-solid opacity suggesting clotted haemothorax associated with left-sided pleural effusion and resulting in bilateral lung atelectasis; (C,D) CT of the chest performed 30 days after awake thoracoscopic debridement show complete lung re-expansion with no residual cloths in the pleural cavity.

resulting in evacuation of about 700 cc of blood.

Following an initial mild improvement the patient conditions deteriorated again within 24 h eventually resulting in respiratory failure with room air PaO_2 of 38 mmHg. Repeated blood transfusions maintained Hb concentration to 8.8 g/dL. A chest computed tomography (CT) showed bilateral pleural effusion with a non-homogeneous pattern of density suggesting the presence abundant blood cloths in the right pleural cavity (*Figure 2A,B*). Due to rapidly deteriorating respiratory conditions and the concomitant sepsis, we decided to perform an urgent thoracoscopic exploration of the pleural cavity under sole local anesthesia. The patient was rapidly transferred from the radiology department to the operating room and was placed in a 30° semi-sitting position. Following injection of lidocaine 2% and bupivacaine 0.5% without sedation, a 5-mm 30°-angled camera was inserted through a single 3-cm long skin incision performed by slightly extending the pre-existent chest tube incision. A total of 1,500 mL of blood and cloths were progressively evacuated with the aid of repeated pleural irrigation. During the procedure the patient did not complain chest pain and was able to talk with the surgeons and breathe comfortably with

Table 1 Operative data

Parameters	Case 1	Case 2
PaO_2/FiO_2		
Pre	160	280
Intra	200	280
Post	360	380
$PaCO_2$ (mmHg)		
Pre	34	40
Intra	37	42
Post	40	44
SAP/DAP (mmHg)		
Pre	90/60	100/65
Intra	100/80	130/85
Post	110/70	120/80
HR (b/min)		
Pre	120	100
Intra	105	90
Post	84	80
Dyspnea (Borg score*)		
Pre	10	7
Intra	5	3
Post	2	0

*, Modified Borg dyspnea score. Pre, 5 min before surgery; Intra, during surgical pneumothorax; Post, 60 min post-surgery; SAP, systolic arterial pressure; DAP, diastolic arterial pressure; HR, heart rate.

an oxygen mask. No bleeding site could be identified intraoperatively. At the completion of the procedure which lasted 35 min, one chest tube was inserted in both pleural cavities and the right lung was re-expanded under camera vision, by keeping airtight the chest incision while inviting the patient to breathe more deeply and cough. The postoperative course was uneventful and during the follow-up, a chest CT scan performed at 1 month showed unremarkable findings (*Figure 2C,D*).

Case 2

A 22-year-old patient was admitted at the emergency department following motor-cycle accident. He was conscious and tachipnoic at rest despite additional O_2 delivery via a Venturi mask (FiO_2: 50%). A chest CT scan showed multiple rib fractures and massive pleural effusion on the right haemothorax.

A chest drain was immediately inserted resulting in drainage of 600 mL of blood. Blood gases analysis demonstrated hypoxia (PaO_2: 50 mmHg) and normocapnia. Twenty-four hours later the patient's clinical conditions did not improve meaningfully and a new CT scan suggested the presence of blood cloths occupying 2/3 of the right pleural cavity. Room air blood gases showed a PaO_2 of 45 mmHg and a $PaCO_2$ of 40 mmHg and the patient complained of dyspnea at rest. It was decided to transfer him in the operating theatre and an awake VATS exploration was carried out. The clotted haemothorax was completely evacuated and once revised accurately the hemostasis no active bleeding site could be identified. After surgery the patient oxygenation improved immediately (*Table 1*) and he could be transferred to the ward. The postoperative course was uneventful and the patient was discharged 5 days after the operation.

Discussion

Haemothorax refers to a blood collection within the pleural cavity. The primary cause is sharp or blunt trauma to the chest whereas iatrogenic haemothorax due to thoracentesis occur rarely with a risk between 0.6% and 1% even in critically ill patients (7,8).

Awake VATS has been advocated as an optimal strategy to perform a number of thoracic surgery procedures. Optimal indications are still widely debated but patients with impaired respiratory function and associated co-morbidity are deemed amongst the ideal candidates (9).

To our knowledge this is the first report entailing urgent awake VATS management of clotted haemothorax. So far, Katlic and Facktor (3) only, reported on VATS performed in spontaneously ventilating patients with haemothorax although in this series unconscious sedation and standard 3-ports approach were employed. Moreover, in the Katlic's series it is not mentioned whether these procedures were performed in an elective or urgent setting.

In our first patient, an iatrogenic haemothorax developing following a thoracentesis did not resolve by simple chest drainage probably due to progressive wedging of clots into the tube fenestrations that obstructed the tube and led to progressive tension haemothorax causing acute respiratory failure.

Overall, the short interval time between the onset of respiratory failure and surgical treatment in our two patients has been facilitated by the avoidance of general anesthesia with tracheal intubation underlining the usefulness of creation of fast track pathways that may accelerate lifesaving awake VATS procedures in selected instances.

In addition, we considered the awake anesthesia management as an optimal choice to avoid the need of intensive care unit (ICU) stay and risks of mechanical ventilation that may add meaningfully to the overall surgical risk, particularly in patients with multiple co-morbidity including respiratory failure and concomitant sepsis.

Alternative non-surgical treatment options include intrapleural instillation of urokinase, which has shown to resolve retained haemothorax in up to 92% of patients (10) but was deemed unsuitable to be employed in our two patients since urokinase treatment requires some days to be successful and we needed urgent treatment including exploration of the pleural cavity in search of an active bleeding.

Finally, use of single trocar VATS is currently under active scrutiny as an additional strategy aimed at further minimizing the overall invasiveness of awake VATS (11) and proved optimally suited for treatment of retained haemothorax under local anesthesia as shown by the complete lung re-expansion with no residual cloths observed in our patients 1 month after surgery. Single trocar access permitted us to use the pre-existing incision employed to insert the chest tube thus contributing to reduce potential postoperative chest pain triggering points.

In conclusion, awake VATS was quickly, safely and successfully accomplished according to a fast track path in two patients with retained haemothorax complicated by acute respiratory failure. Further detailed investigation is warranted to support our preliminary findings.

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Awake video-assisted thoracic surgery in acute infectious pulmonary destruction

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Background: Many of thoracic minimally invasive interventions have been proven to be possible without general anesthesia. This article presents results of video-assisted thoracic surgery (VATS) application under local anesthesia in patients with lung abscesses and discusses its indications in detail.

Methods: The study involved prospective analysis of treatment outcomes for all acute infectious pulmonary destruction (AIPD) patients undergoing VATS under local anesthesia and sedation since January 1, 2010, till December 31, 2013. Patients with pulmonary destruction cavity at periphery of large size (>5 cm) underwent non-intubated video abscessoscopy (NIVAS). Patients with pyopneumothorax (lung abscess penetration into pleural cavity) underwent non-intubated video thoracoscopy (NIVTS). Indications for NIVAS and NIVTS were as follows: cavity debridement and washing, necrotic sequestra removal, adhesion split, biopsy. All interventions were done under local anesthesia and sedation without trachea intubation and epidural anesthesia.

Results: Sixty-five enrolled patients had 42 NIVAS and 32 NIVTS interventions, nine patients underwent two surgeries. None of the patients required trachea intubation or epidural anesthesia. In none of our cases with conversion to thoracotomy was required. Post-surgical complications developed after 11 interventions (13%): subcutaneous emphysema (five cases), chest wall phlegmon (three cases), pulmonary bleeding (two cases), and pneumothorax (one case). One patient died due to the main disease progression. In 50 patients NIVAS and NIVTS were done within 5 to 8 days after abscess/pleural cavity draining, while in other 15 patients—immediately prior to draining; both pulmonary bleeding episodes and all cases of chest wall phlegmon took place in the latter group.

Conclusions: NIVAS and NIVTS under local anesthesia and sedation are well tolerated by patients, safe and should be used more often in AIPD cases. Timing of NIVAS and NIVTS procedures was found to be of paramount importance for ensuring complete therapeutic effectiveness.

Keywords: Anesthesia local; lung abscess; non-intubated; thoracic surgery; video-assisted

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Authors' introduction:

Figure 1 is a picture of the authors team from Department of Thoracic Surgery, City Hospital №.1, in Saint-Petersburg, Russia. They are Igor Deynega, Andrey Akopov, Vladimir Egorov, Pavel Ionov from left to right.

Introduction

The history of thoracic surgery started with interventions under local anesthesia. Till the middle of the 60-year of the 20th century almost all lung-related interventions in Russia were done under local anesthesia (1,2).

Later general anesthesia drove out almost completely local one for thoracic surgery use. Surgeons' confidence in the safety of general anesthesia for patients resulted in considerable surgical advancements and made possible such interventions, which previously seemed to be impossible or fatal. However, as surgery develops new tasks and objectives emerge.

Figure 1 Igor Deynega, Andrey Akopov, Vladimir Egorov, Pavel Ionov.

Figure 2 Right lung acute purulent abscess, computerized tomography.

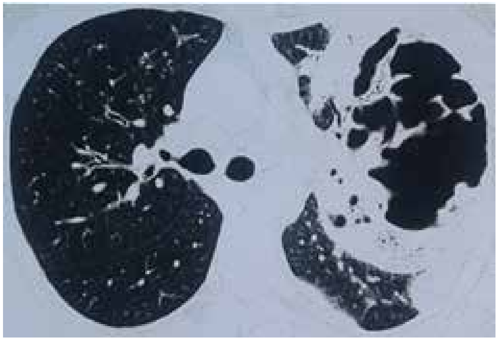

Figure 3 Left lung gangrenous abscess with sequestration, computerized tomography.

Due to wide routine use of minimally invasive thoracoscopic methods our attitude to local anesthesia is again up for review. Such treatment efficacy indices as hospital stay, surgery costs, drainage duration, etc. are currently highlighted (3-8). More surgeries are done in out-patient settings poorly compatible with general anesthesia. Currently many of thoracic minimally invasive interventions have been proven to be possible without general anesthesia.

Our experience includes video-assisted thoracic surgery (VATS) under local anesthesia in patients with acute infectious pulmonary destructions (AIPD). In developed world the number of such patients is still high (9,10). Their treatment is costly and prolonged and general performance is usually poor limiting chances for "major" surgeries (11). For this patient cohort minimally invasive technologies shortening hospital stay are of paramount importance. Our work presents results of VATS application under local anesthesia and discusses its indications in detail.

Methods

The study was approved by the local Institutional Ethics Committee. All the subjects included in the study gave informed consent.

Our study involved prospective analysis of treatment outcomes for all AIPD patients undergoing VATS under local anesthesia and conscious sedation since January 1, 2010, till December 31, 2013. All interventions were without trachea intubation and epidural anesthesia and the team maintained continuous contact with patients during surgery.

We used classification for AIPD given in ESTS-2014 Textbook of Thoracic Surgery (11). Our study enrolled patients with cavernous AIPD forms—acute purulent abscesses and gangrenous abscesses. Acute purulent abscess develops relatively fast purulent meltdown in lung inflammatory foci forming localized cavity (*Figure 2*). Gangrenous abscess results in lung tissue necrosis, which along demarcation process turns into a cavity with near-wall or free lung tissue sequestra exhibiting gradual clearance (*Figure 3*). Patients with these abnormalities underwent non-intubated video abscessoscopy (NIVAS). Destruction cavity at periphery of large size (>5 cm) indicated that in technical sense NIVAS is possible.

Another pathology when general anesthesia-free surgery was indicated was pyopneumothorax. This term implies lung abscess penetration into patient's pleural cavity forming bronchial-pleural connection (fistula) and presence of pus (abscess content) and air in his/her pleural cavity (*Figure 4*). Patients with such complication underwent non-intubated video thoracoscopy (NIVTS).

In this study we did not enroll patients with pleural empyema without destruction cavity in lung tissue.

Figure 4 Localized pyopneumothorax, lower parts of the right pleural cavity, roentgenogram.

Indications for NIVAS and NIVTS were as follows: destruction cavity debridement in lungs or pleural cavity, necrotic sequestra removal, differential diagnosis for specific (tuberculosis, cancer) and non-specific destruction causes.

General surgical contraindications were unstable circulation, acute myocardial infarction, acute cerebral circulation disturbances, and coagulation disorders. Special contraindications for interventions under local anesthesia were significant encephalopathy and patient emotional instability.

Prior to interventions all patients were thoroughly examined including assessment of cardiovascular and pulmonary reserves and general patient performance. Testing for clotting system indices was mandatory. Beside general clinical work-up patients underwent chest X-rays and CT, fiber-optic bronchoscopy. Sputum and exudates were sent for cytology and bacteriology testing.

All patients were provided with similar combined conservative treatments of the following main types: transthoracic drainage of purulent pulmonary cavity; transthoracic drainage for pleural cavity in pyopneumothorax cases; antibiotics; fluid replacement. Purulent cavity was drained at the day of admission as the 1st step followed with intensive conservative treatments.

For NIVAS and NIVTS we used Karl Storz endosurgical video-system in a single port mode placing patients in sitting or semi recumbent position to prevent patients from aspiration their purulent cavity content into the healthy lung. Computerized tomography data was used to find closest location to the chest wall. Patients were sedated with intramuscular injection of Diazepam (conscious sedation), up to a maximum dose of 10 mg/1 hour before VATS. Blood pressure and ECG were monitored during surgery. Oxygen was provided via nasal cannulas.

We used infiltrating local anesthesia with 1% xylocaine or 1% lidocaine injecting the solution via thin needle into soft chest tissues from skin to visceral pleura. Then an abscess was tapped—percutaneous needle aspiration was applied. Once pus and air appeared at the tap site a trocar was passed through a 1.5-cm cut. Cavity content was aspirated. Then the cavity was examined with a thoracoscope. Debridement involved application of antiseptic solutions, mechanical fibrin and sequestra removal. We tried to create conditions facilitating free pus outflow post-surgery detaching adhesions that formed purulent cavity compartments and impeded pus outflow. Cavity walls were biopsied in two or three sites. For hemostasis purposes, if necessary, local hemostatic agents were applied. In NIVTS cases patients, if required, underwent partial pulmonary decortication additionally. Drain 24-28-French tubes were placed into caudal cavity parts. Aminocaproic acid solution was introduced via these drainages.

Central venous catheters were placed for all patients. Arterial catheter was not used. Urine catheter was not placed.

In the post-surgery period passive aspiration was employed. Abscess cavity and pleural cavity was daily washed with antiseptic solutions. For periods of massive exudation the cavity was washed 2 or 3 times daily.

No specific analgesia was provided, no narcotic agents were administered.

Results

Overall, NIVAS and NIVTS were done for 65 patients. There were 51 men and 14 women. Average patient age was 58.4 (24 to 78). Acute purulent pulmonary abscess was noted in 40 patients (62%), gangrenous one—in 25 patients (38%) (*Table 1*). Pyopneumothorax caused by abscess breakthrough into a pleural cavity was found in 29 patients (45%).

In 39 patients (60%) the lesion site was located at the right and in 23 patients (35%)—in the left lung, and 3 patients (5%) had bilateral pulmonary lesions. Mostly lesions were located in posterior upper lobes (31 patients, 48%) and apical segments of lower lobes (25 patients, 38%). In more than a half of the patients pulmonary destruction cavity exceeded 10 cm in the largest diameter, while in 21 of them (32%) the purulent lesion size exceeded 15 cm.

At the time of the admission to hospital American Society of Anesthesiologists (ASA) physical status class were the following: I (none), II (3 patients), III (19 patients), and IV

Table 1 Characteristics of the study population

Characteristics	Data
Number of patients [%]	65 [100]
Sex: male [%]	51 [78]
Average age (years)	58.4
Acute purulent abscess [%]	40 [62]
Gangrenous abscess [%]	25 [38]
Pyopneumothorax [%]	29 [45]
Destruction etiology [%]	
Non-specific	56 [86]
Tumors	4 [6]
Tuberculosis	5 [8]
Physical performance [%]	
ASA 2	3 [5]
ASA 3	19 [29]
ASA 4	43 [66]
Concomitant disorders [%]	
Diabetes mellitus	9 [14]
Drug abuse	13 [20]
Viral hepatitis	25 [38]
HIV+	9 [14]
Timing of VATS [%]	
Prior to abscess/pleural cavity draining	15 [23]
5 to 8 days after draining	50 [67]

ASA, American Society of Anesthesiologists; VATS, video-assisted thoracic surgery.

Table 2 NIVAS and NIVTS manipulations

Manipulation	NIVAS (n=42) [%]	NIVTS (n=32) [%]
Cavity lavage under direct vision	42 [100]	32 [100]
Sequestra and fibrin removal	36 [86]	32 [100]
Adhesion split	22 [52]	20 [62]
Biopsy	42 [100]	32 [100]
Hemostasis	35 [82]	8 [25]

NIVAS, non-intubated video abscessoscopy; NIVTS, non-intubated video thoracoscopy.

(43 patients). The most severe condition was observed in patients with gangrenous abscesses (ASA status IV—21 of 25 patients, 84%) as well as in patients with pyopneumothorax (22 of 29, 76%). Major symptoms were purulent sputum in large amounts of above 100 mL per day and fever in all patients, dyspnea of Modified Medical Research Council (MMRC) Grade 3 to 4—in 49 of 65 patients (75%) as well as fatigue, wasting syndrome, hypotension and tachycardia.

Severe pulmonary disorders (COPD, asthma) were found in 20 patients (31%), coronary failure—in 21 patients (32%), diabetes mellitus—in 9 patients (14%), HIV—in 9 patients (14%), hepatitis B and C—in 28 patients (38%). A total of 46 patients (71%) were current smokers and 13 patients (20%) were drug users.

NIVAS was done in 36 patients (55%), NIVTS—in 29 patients (45%). Six patients with gangrenous abscesses and three ones with pyopneumothorax underwent two surgeries, i.e., in total, enrolled patients had 42 NIVAS and 32 NIVTS interventions. Mean NIVAS time was 11.5 min (range, 7-15 min), NIVTS—13.4 min (range, 10-17 min).

NIVAS description

Purulent abscesses (11 patients) typically presented excessive granulation tissue, massive fibrin deposits; destruction cavity usually was round-shaped. Manipulations in purulent abscess cases were mostly related to biopsy and cavity wall treatment removing fibrin, purulent and necrotic tissue. However, we did not notice prominent adhesions separating such purulent cavity and impeding pus outflow. Gangrenous abscesses (25 patients) presented with an irregular shape cavity, separating adhesions and distinct, hard-to-drain pockets. The cavity walls were usually uneven, covered with necrotic or fibrin covered sites as well as areas of "naked" lung tissue. Its content was of soot-colored, thick, often with foul smell. Near-wall or free locating sequestra were present. In case of NIVAS interventions possibility to remove sequestra and to cut adhesions segregating such purulent cavities was especially important. These manoeuvres are the base for therapeutic NIVAS effects in gangrenous abscess patients.

NIVTS description

Typically there was a large cavity with massive depositions of fibrin easy to remove by simple mechanical curettage. Frequent finding was adhesions segregating the pleural cavity. It was not always easy to locate a lung-pleural fistula. Entire set of VATS manipulations is shown in the *Table 2*.

In none of the cases we saw intrasurgical complications. Also none of the patients required trachea intubation. In none of our cases with conversion to thoracotomy was required. Patients did not present considerable fear of NIVAS and NIVTS under local anesthesia.

Post-surgical complications developed after 11 interventions

Table 3 The range of perioperative complications

Surgery	Pulmonary bleeding [%]	Subcutaneous emphysema [%]	Pneumothorax [%]	Chest wall phlegmon [%]
NIVAS (n=42)	2 [5]	3 [7]	1 [2]	2 [5]
NIVTS (n=32)	0	2 [6]	0	1 [3]
Total (n=74)	2 [3]	5 [7]	1 [1]	3 [4]

NIVAS, non-intubated video abscessoscopy; NIVTS, non-intubated video thoracoscopy.

(13%) (*Table 3*). The bleeding was caused by an attempt of fixed sequestra removal and was stopped with non-surgical methods. Subcutaneous emphysema of chest wall disappeared without treatment. Pneumothorax treatment involved pleural tube placement. In three patients with chest wall phlegmon soft tissues were cut to rib carcass followed with daily dressing replacement and wound debridement. The process was eventually eliminated in two of three patients. One patient died due to the main disease progression.

Timing of NIVAS and NIVTS procedures was found to be of paramount importance for ensuring complete therapeutic effectiveness. In 15 patients NIVAS and NIVTS were done immediately prior to abscess/pleural cavity draining, while in other 50—within 5 to 8 days, after pus was removed and acute inflammatory signs subsided. However, in 5 of 15 (33%) cases operated prior to draining we were unable to implement our surgical plan to its full extent and to provide comprehensive cavity debridement and biopsy. Therefore, later these patients required another surgery. Moreover, both pulmonary bleeding episodes and all three cases of chest wall phlegmon took place in this patient group. In patients with post-draining interventions we managed to fulfill our pre-surgery plans in 91% with no severe complications. Biopsy data was also found to be of higher value in patients with post-draining surgery. In two patients where histology material after first surgery was found to be of poor quality another biopsy at the second NIVAS enabled us to diagnose tuberculosis (one case) and cancer (one case).

Within the 30-day post-surgery one patient with gangrenous abscess died due to inflammation progression and increasing intoxication. Despite his destruction cavity was sufficiently drained we did not succeed in controlling the infectious process in lung tissue caused by pseudomonas aeruginosa and anaerobic microbes due to multiple antibiotic resistance.

Discussion

The grounds for NIVTS and NIVAS under local anesthesia in patients with AIPD were as follows: first, short time of the intervention and, second, rather small range of manipulations to be done during the surgery. Additional rationale for local anesthesia use in AIPD patients is no need for separate contralateral lung ventilation.

The main advantage of the local anesthesia approach according to our results is the method safety. During the surgery regulatory and adaptive central nervous mechanisms still function, thus, respiration and circulation changes during the interventions are adequately compensated (12,13). Also it is important that patients with AIPD are able to cough out their bronchial content as much as possible. Effective coughing and sitting position for interventions prevented infected bronchial content from finding a way into patient's healthy lung. In turn, it diminishes atelectasis risks, which is one of the causes of post-surgical pneumonia. Such complication has never been seen in any of our clinical cases.

During surgery our patients did not complain of considerable discomfort. In general, the method in technical sense is not extremely sophisticated and for majority of thoracic surgeons its learning curve is not steep. Curiously, our anesthetist attitude to local anesthesia interventions—after sufficient experience was gained—became positive. Currently general anesthesia with trachea intubation in patients with infectious pulmonary destructions is only for more traumatic interventions such as full decortication or resections. Other researchers in the field of general anesthesia-free thoracoscopy showed less surgery time, shorter hospital stay and lower treatment costs (3,5,6,14,15). We did not compare cost and duration for VATS-treated patients because since 2009 all thoracoscopic manipulations in AIPD cases were done under local anesthesia and without tracheal intubation. The most important factors when choosing the discussed approach is less operating theater utilization, lower hospital staff involvement, elimination of trachea intubation and related additional risks. One should take into account that this particular patient cohort is different from the general patient population. They are usually of lower social status and their microbial gamut is represented with highly drug resistant bacteria (11,16). AIPD patients should be treated in in-patient settings of specialized units. Every day of their hospital stay implies rather high costs and expenditures. With the aforementioned in mind one can see that applying minimally invasive technologies in such patients is of paramount importance. Also it is quite valuable that such patients have positive attitude to interventions under local anesthesia.

Taking into account the previous discussion and our clinical experience we managed to articulate main indications for NIVAS and NIVTS in AIPD patients. First, such surgery is always both diagnostic and therapeutic. Second, NIVAS and NIVTS interventions should always follow transthoracic draining, pus removal and inflammation subsidence. Although it appears that it is impossible to avoid repeated NIVAS completely. Repeated manipulations are required since there are two types of sequestra—free and fixed or near-wall ones. Attempting for rough removal of the latter might end up in severe bleeding. The question of how to determine if such sequestra are free or fixed and, thus, their removal is fraught with grave consequence is one of paramount importance. And this issue defines time frame for both primary and repeated NIVAS procedures. However, at the moment, regretfully, there is no proper final solution present.

Conclusions

In conclusion, we need to stress that NIVAS and NIVTS under local anesthesia and sedation are well tolerated by patients, safe and should be used more often in AIPD cases. Timing of NIVAS and NIVTS procedures was found to be of paramount importance for ensuring complete therapeutic effectiveness. It is necessary to gain more experience and to promote such interventions to be done in other thoracic surgery clinics to produce evidence-based guidelines for this method and its applications.

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The complex care of severe emphysema: role of awake lung volume reduction surgery

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Abstract: The resectional lung volume reduction surgery (LVRS) procedure entailing nonanatomic resection of destroyed lung regions through general anesthesia with single-lung ventilation has shown to offer significant and long-lasting improvements in respiratory function, exercise capacity, quality of life and survival, particularly in patients with upper-lobe predominant emphysema and low exercise capacity. However mortality and morbidity rates as high as 5% and 59%, respectively, have led to a progressive underuse and have stimulated investigation towards less invasive surgical and bronchoscopic nonresectional methods that could assure equivalent clinical results with less morbidity. We have developed an original nonresectional LVRS method, which entails plication of the most severely emphysematous target areas performed in awake patients through thoracic epidural anesthesia (TEA). Clinical results of this ultra-minimally invasive procedure have been highly encouraging and in a uni-center randomized study, intermediate-term outcomes paralleled those of resectional LVRS with shorter hospital stay and fewer side-effects. In this review article we analyze indications, technical details and results of awake LVRS taking into consideration the available data from the literature.

Keywords: Emphysema; chronic obstructive pulmonary disease (COPD); lung volume reduction surgery (LVRS); awake thoracic surgery; awake VATS; nonintubated thoracic surgery; nonintubated VATS

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Authors' introduction:

Figure 1 is a picture including the authors of the article with other representatives of the ATSRG, a multidisciplinary team aimed at accomplishment and promotion of pioneering and comprehensive clinical investigations focused on awake and nonintubated thoracic surgery.

Introduction

Emphysema, one of the chronic obstructive pulmonary disease (COPD) phenotypes, is an irreversible, progressively debilitating condition, which is estimated to account for about one third of all diagnoses of COPD (1). Due to continuing use of tobacco and biomass fuels as well as to aging populations, emphysema is associated with a global social and economic burden and it is projected to become within 2030 the third leading cause of death (2-4).

In advanced stages, emphysema reduces both lung elastic recoil and mechanical support of peripheral bronchioles eventually leading to early expiratory airway collapse, severe gas trapping and lung hyperinflation.

Standard management of emphysema entails smoking cessation, pharmacological treatment with bronchodilators and anti-inflammatory drugs, supplemental oxygen and rehabilitation.

However, in patients with severe emphysema, medical therapy is poorly effective and interventional treatment including lung volume reduction surgery (LVRS) can be considered.

The standard LVRS procedure, which entails

Figure 1 Core representatives of the ATSRG. From the left: Drs Benedetto Cristino, Augusto Orlandi, Eugenio Pompeo, Umberto Tarantino, Tiziana Frittelli (General Director of the Policlinico Tor Vergata), Leonardo Palombi, Paola Rogliani, Roberto Massa, Mario Dauri.

nonanatomic resection of destroyed lung regions through general anesthesia with single-lung ventilation (resectional LVRS) (5), has shown to offer significant and long-lasting improvements in respiratory function, exercise capacity, quality of life and survival, particularly in patients with upper-lobe predominant emphysema and low exercise capacity (6). Unfortunately, several complications can occur with resectional LVRS leading to mortality and morbidity rates as high as 5% and 59%, respectively (7).

These figures, have led to a reportedly underuse of resectional LVRS and have stimulated investigation towards less invasive surgical and bronchoscopic (8-10) nonresectional methods that could assure equivalent clinical results with fewer morbidity.

In order to overcome the main drawbacks of resectional LVRS, we have developed an original nonresectional LVRS method, which can be performed in fully awake patients (11). Clinical results of this ultra-minimally invasive procedure have been highly encouraging (12) and in a uni-center randomized study, intermediate-term outcomes paralleled those of resectional LVRS with shorter hospital stay and fewer side-effects (13).

In this article we analyze indications, technical details and results of awake LVRS taking into consideration the available data from the literature.

Background

Resectional LVRS

Resectional LVRS was initially proposed by Brantigan and Mueller in 1957 (14). The procedure entailed non-anatomic resection of emphysematous lung tissue performed through staged thoracotomy and was aimed at reducing the overall lung volume to re-configurate the chest wall and diaphragm, and restore radial traction on the bronchi, thereby relieving expiratory flow obstruction. At that time, despite significant subjective benefit occurred in most of patients, the lack of objective benefit documentation and a high mortality rate of 18% (15), led to rapid abandonment of LVRS. Following a dormant phase of 4 decades, LVRS was eventually re-vitalized by Cooper and coworkers (5) who proposed technical refinements including the use of median sternotomy for simultaneous bilateral, staple resection of the lungs. In a first series this method resulted in no mortality and significant improvements in subjective dyspnea, pulmonary function, exercise tolerance and quality of life measures. Thereafter, similar satisfactory results have been reproduced by means of video-assisted thoracic surgery (VATS) LVRS performed either unilaterally (16-18) or bilaterally (19-21).

The large National Emphysema Treatment Trial (NETT) (6) confirmed greater and long-lasting benefit as well as a survival advantage of resectional LVRS when

Table 1 Proposed criteria for awake nonresectional LVRS

Inclusion criteria
Age 40-80 years
Severe, heterogeneous emphysema, at the HRCT
Dyspnea at rest or with minimal physical activity (mMRC score ≥2)
Moderate to severe obstructive defect with FEV_1 ≤50% but >20% predicted
Functional aspects of hyperinflation with RV >170% predicted and total lung capacity >110% predicted on body plethysmography
Resting room PaO_2 >45 mmHg
Impaired exercise capacity but 6MWT distance >150 m
ASA score ≤3
Quit smoking since at least 4 months
Exclusion criteria
BMI <18 and >29
Homogeneous emphysema with no target areas for LVRS, at the HRCT
Need of ventilatory assistance
DLCO <20% predicted on single breath technique
Significant bronchitis with increased inspiratory airway resistance and/or abundant daily sputum production
Resting $PaCO_2$ >55 mmHg
Pulmonary hypertension with mean PA pressure >35 mmHg or peak systolic PA pressure >50 mmHg on Doppler echocardiography
Any comorbid condition that would significantly increase operative risk including unstable, untreated coronary artery disease or ventricular arrhythmia
Neoplastic disease with life expectancy <12 months

LVRS, lung volume reduction surgery; HRCT, high resolution computed tomography; mMRC, modified Medical Research Council dyspnea score; FEV_1, forced expiratory volume in one second; RV, residual volume; PaO_2, arterial oxygen pressure; 6MWT, six-minute walking test; ASA, American Society of Anesthesiology score; BMI, body mass index; DLCO, diffusion capacity for carbon monoxide; $PaCO_2$, arterial carbon dioxide pressure; PA, pulmonary artery.

compared to maximized medical therapy, particularly in patients with upper-lobe predominant emphysema and low exercise capacity. However, in the NETT operative mortality was 5% and overall morbidity was 59% (7). Time spent for postoperative recovery was often prolonged with about 30% of patients being still hospitalized or in rehabilitation facilities 1 month after surgery. As a result, the cost-effectiveness of LVRS has been questioned (22) progressively leading to a generalized underuse of this procedure in recent years (23).

Nonresectional LVRS by awake anesthesia (awake LVRS)

Historical background of nonresectional LVRS with lung plication can be dated back to the Brantigan's work in which both resection and plication of emphysematous lung tissue was already described to achieve an adequate reduction in the lung volume (24).

In 1992, Crosa-Dorado *et al.* (25) proposed multiple fold plications of emphysematous bullae carried out by thoracotomy with the aid of a custom-made folding forceps. In 1998, Swanson and co-workers (26) slightly modified the method proposed by Crosa-Dorado to make it suitable for VATS application. A further original fold plication method has been proposed in 1999 by Iwasaki *et al.* (27).

All the previously mentioned nonresectional LVRS procedures entailed use of general anesthesia with single-lung ventilation.

In 2006, we (11) reported feasibility and early results of an original nonresectional LVRS technique entailing introflexive plication of the most emphysematous lung regions, which was developed by one of the authors (EP) to be ideally performed in spontaneously ventilating awake patients through thoracic epidural anesthesia (TEA). This method respected the basic concepts of resectional LVRS including a reduction of about 30% of the lung volume, suturing performed along a single ideal line and use of stapling devices. Yet, it added potential advantages including avoidance of any loss in lung tissue, peripheral, interrupted suturing which was hypothesized to be more flexible, avoidance of any pleural discontinuation and creation of inlay buttress by the plicated bullous tissue. These technical refinements were aimed at facilitating immediate postoperative re-expansion of the lung and at reducing risks of prolonged air leaks, which accounts as the most frequent side-effect of resectional LVRS.

Selection criteria

Inclusion and exclusion criteria for awake LVRS do not differ significantly from those of resectional LVRS (28) (*Table 1*).

Patients complaining of disabling dyspnea with moderate-to-severe obstructive defect and limited exercise capacity that are not reversed by maximized medical therapy, with radiologic evidence of lung hyperinflation hyperinflation and flat diaphragms on chest X-ray, are potential candidates and must undergo high-resolution computed tomography (HRCT), assessment of static lung volumes by body plethysmography, and of diffusing capacity

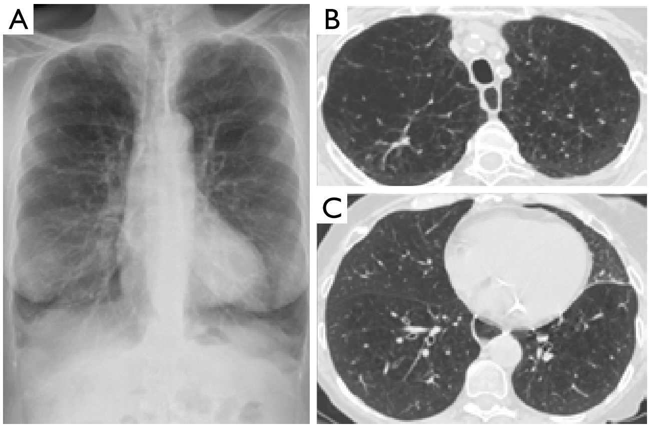

Figure 2 Radiologic features of a good candidate for awake LVRS. (A) Chest X-ray shows signs of lung hyperinflation resulting in flattened diaphragms and chest wall distention. (B,C) HRCT shows on axial scans, heterogeneous severe emphysema with more severe involvement of the upper lobes (B) and relatively better preserved lower/middle lobes (C). HRCT, high-resolution computed tomography.

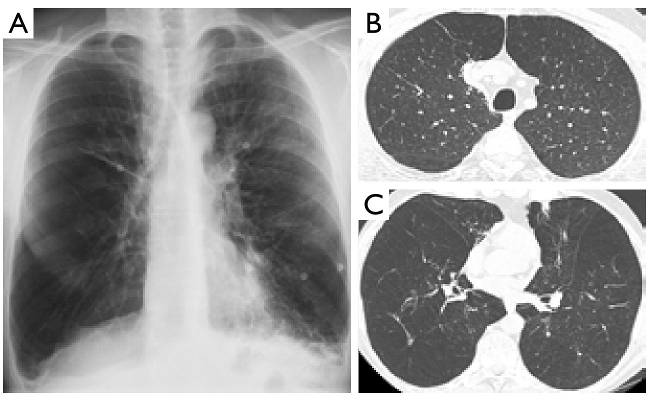

Figure 3 Radiologic features of a moderately good candidate for awake LVRS showing lung and chest wall iperdistention with flattened diaphragm (A) and heterogeneous severe emphysema with more severe involvement of the lower lobes (B,C).

for carbon monoxide (DLCO).

Optimal candidates for awake LVRS disclose increased residual volume (RV) on body plethysmography and heterogeneous, severe emphysema on HRCT. In particular, we have found that as already shown with non-awake LVRS, patients with upper lobe-predominant emphysema are ideal candidates for awake LVRS and those who can achieve the greater magnitude of improvements (*Figure 2*). However, patients with lower-lobe predominant heterogeneous disease also can meaningfully benefit from the awake procedure (*Figure 3*).

On the other hand, the finding that forced expiratory volume in one second (FEV_1) ≤20% predicted and either homogeneous emphysema or DLCO ≤20% predicted, resulted in a mortality rate of 16% following resectional LVRS, has led to consider patients with these characteristics as non-eligible for the operation (29) even though results achieved by the awake LVRS in this patients' subgroup has not yet been reported.

Moderate hypoxemia is commonly found in candidates for awake LVRS and does not represent an exclusion criterion.

Stable abstinence from cigarette smoking is mandatory to minimize operative risks and can help confirm the patient's motivation to undergo the operation.

Specific contraindications for awake LVRS include morbid obesity, unwillingness to undergo an awake surgical procedure, excessive anxious symptoms or HRCT findings showing signs of an obliterated pleural cavity on side chosen for LVRS.

Table 2 Technical differences between intubated and awake anesthesia

Anesthesia characteristics	Non-awake	Awake
Pre-medication	Yes	No
Type	General	Regional*
Ventilation	Mechanical	Spontaneous
Tracheal intubation	Yes	No
Diaphragm paralysis	Yes	No
Consciousness	No	Yes
Amnesia	Yes	No
Coughing reflex	No	Yes
Need of weaning	Yes	No
Need of additional sedation	No	Optional
Need of additional oxygen	Yes	Yes

*Thoracic epidural anesthesia; intercostal or paravertebral blocks.

Anesthesia

The main differences between awake and nonawake anesthesia are summarized in *Table 2*.

Our preferred type of anesthesia for awake LVRS is TEA carried out in fully awake, spontaneously ventilating patients. The objective of TEA is to achieve somatosensory and motor block between the T1-T8 level while preserving diaphragmatic motion.

The epidural catheter is inserted at T4-T5 level. During the procedure, the anesthetic regimen entails continuous infusion of ropivacaine 0.5% and sufentanil 1.66 µg/mL into the epidural space whereas supplemental oxygen is delivered through a Venturi mask to maintain oxygen saturation above 90%.

At end-procedure, the anesthetic regimen is changed to ropivacaine 0.16% plus sufentanil 1 µg/mL at 2-5 mL/h and the epidural catheter is removed on the second postoperative day.

In patients with spinal deformity or coagulation disorders contraindicating the use of TEA, awake LVRS is accomplished through paravertebral (30) or intercostal blocks.

Conversion to general anesthesia is considered in patients showing poor tolerability of an awake procedure or whenever unexpected operative findings or technical difficulty are deemed better manageable by general anesthesia. This is induced by intravenous propofol (1.5-2 mg/kg), fentanyl (0.1 mg) and vecuronium (0.1 mg/kg) and is maintained by fentanyl and vecuronium with a continuous infusion of propofol. A left-sided double-lumen tube is used for single-lung ventilation. Intraoperative conversion from awake to general anesthesia is routinely carried out without changing the patient position and with the aid of a videolaryngoscope and a fiberoptic bronchoscope to facilitate tracheal intubation and obtain a correct position of the double lumen tube, respectively.

After surgery, patients undergoing awake LVRS stay in the recovery room for about 30 min and are then directly transferred to the ward where they can immediately start drinking, eating and walking under physiotherapist assistance.

Surgical technique

The patient position is lateral decubitus as for thoracotomy. The operating table is usually not flexed below the chest to facilitate ventilation of the dependent lung. The video monitor is placed at the head of the table. Surgical access entails placement of four flexible trocars. The camera port is placed in the sixth intercostal space along the midaxilllary line while operating ports for instrumentation are placed in the third and/or fifth intercostal space along the anterior axillary line, and in the fourth intercostal space along the posterior axillary line. A 30°, 10 mm camera is used to optimize vision during spontaneous ventilation. Pleural adhesions, if present, are divided by sharp and blunt dissection.

The goal of nonresectional LVRS is to plicate as much emphysematous tissue as possible. The most destroyed lung regions targeted for plication on the basis of the HRCT imaging are recognized intraoperatively with the aid of instrumental palpation of the lung.

Whenever, the hyperinflation of the lung counteracts the lung collapse induced by creation of the surgical pneumothorax, we employ an endopaddle to push down the lung and improve exposure and surgical manoeuvring.

Subsequently, the apical side of the emphysematous target area is grasped by two ring forceps while pushing downward the tissue in between with a cotton swab. The next step entails simultaneous grasping of both redundant lung edges and peripheral suturing of the plicated area by a 45 mm, non-cutting endoscopic stapler. In a similar manner, two other cartridges are fired in the ventral and dorsal side of the targeted area to perform a linear, interrupted suture line. As a result, the upper lobe volume is reduced by about 50% without any loss in lung tissue and the lung is remodelled to achieve a trapezoidal shape. In patients with lower lobe predominant emphysema, multiple smaller plications are carried out to reduce in a uniform manner the overall lung volume (*Figure 4*).

The main differences between resectional and nonresectional LVRS are detailed in *Table 3*.

Surgical strategy

Simultaneous bilateral LVRS has shown to produce superior benefit than unilateral treatment and is the preferred strategy of treatment in several Institutions (31,32). However, we have reported that in patients with asymmetric emphysema undergoingt unilateral LVRS on the most emphysematous lung, the improvement in FEV_1 compared that achieved by one-stage bilateral treatment (33,34). This is possibly due to mobility of the mediastinum, which can induce interdependence effects leading a single procedure to improve ventilation in both lungs.

Moreover, it has been shown that yearly deterioration in FEV_1 was greater following bilateral than after unilateral LVRS (35). These features summed up to the easier patients' tolerability of unilateral rather than bilateral simultaneous treatment, have led us to prefer a staged bilateral strategy of treatment. In fact, although there are no prospective studies comparing staged *vs.* 1-stage bilateral LVRS, in a previous retrospective analysis by our group, staged bilateral LVRS resulted in more stable improvements in FEV_1, forced vital capacity (FVC), 6-minute walking test (6MWT) and RV

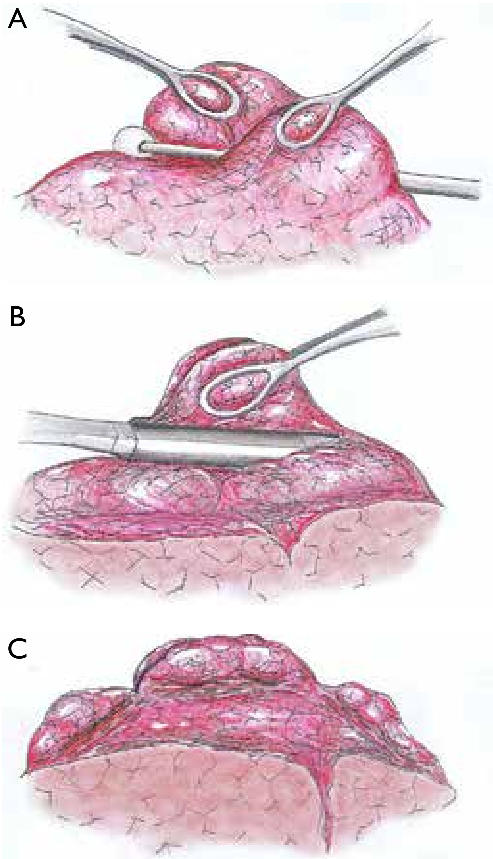

Figure 4 Art drawing illustrating the simple technical steps of the awake nonresectional LVRS method. (A) The most emphysematous lung tissue is grasped and plicated between the ring forceps; (B) plicated tissue is sutured peripherally by non-cutting endostapler; (C) the maneuver is repeated 3 times to achieve lung volume reduction and remodeling with trapezoidal shape to fit easily the apex of the pleural cavity. Reprinted from *the Annals of Thoracic Surgery* (12), with permission.

than 1-stage bilateral LVRS (36).

As a result, our current strategy of treatment entails unilateral awake LVRS performed initially on the most severely emphysematous lung and postponement of the contralateral procedure until when the benefits achieved by the first operation are lost.

In our hands, more than 95% of awake LVRS procedures are performed by VATS whereas we deserve thoracotomy to patients with history of previous major thoracic surgery on side chosen for LVRS, in those with radiologic signs of diffuse, fibrous adhesions as well as whenever unexpected intraoperative findings or complications lead us to consider convertion to thoracotomy the safest choice.

Table 3 Technical differences between resectional and nonresectional LVRS

Characteristic	Resectional	Nonresectional
Tissue resection	Yes, nonanatomical	No
Suture type	Mechanical continuous	Mechanical interrupted
Suture length (mm)	≥225	125
Suture position	Deep	Peripheral
Pleural discontinuation	Yes	No
Buttress	Optional, heterologous	Yes, folded visceral pleura
Remodeling shape	Trapezoidal	Trapezoidal
Volume reduction (one lung) (%)	≥30	≥30

Results

As far as perioperative outcome of awake LVRS is concerned, in a comparative analysis, 66 patients undergoing awake nonresectional LVRS were compared with 66 patients undergoing non-awake resectional LVRS. Prolonged air-leak (>7 days) occurred in 18% of the patients in the awake group *vs*. 40% in the control group (P=0.007) with an overall duration of 5.2 days in the awake group and of 7.9 days in the control group (P<0.0002). As a consequence hospital stay was 6.3 *vs*. 9.2 days, respectively (P<0.0001) (37).

Clinical benefits of awake LVRS are expected to be equivalent to those achievable by resectional LVRS and include improvements in respiratory function, exercise capacity, subjective dyspnea, quality of life measures and survival (38). Other less frequently reported benefits include improvements in oxygenation (39), body weight and nutritional status (40), cardiac function (41,42), cognitive function (43), alveolar ventilation (44), and breathing pattern (45).

So far there exist only a limited number of publications reporting on the intermediate-term results of awake LVRS.

In a 42 patients retrospective series, we reported no 90-day mortality with significant 2-year improvements in 6MWT, FEV_1, FVC, RV as well as in the multidimensional body mass index, airflow obstruction, dyspnea, and exercise capacity index (BODE), which has shown to represent a useful predictor of survival in COPD patients (12).

In a more recent study, 63 patients were randomized to receive unilateral VATS LVRS performed by either the awake nonresectional method in 32 patients or by the non-awake resectional method in 31 patients. Comparative assessment of results between awake and non-awake groups have shown that 1 h after surgery, oxygenation as expressed by the ratio of arterial oxygen tension to fraction of inspired oxygen as well as arterial carbon dioxide tension, were significantly better in the awake group. Mortality and morbidity rates were 0 *vs*. 3.2% and 22% *vs*. 52% (P<0.01); median hospital stay was 6 *vs*. 7.5 days (P<0.04) with 21 *vs*. 10 patients discharged within 6 days (P=0.01). Moreover, at 6 months, FEV_1, which was the clinical primary outcome measure, improved significantly in both study groups (0.28 *vs*. 0.29 L) with no intergroup difference. In addition in both groups, improvements in FEV_1, 6MWT, FVC, RV and physical functioning quality of life measure, lasted more than 24 months. At 36 months, both freedom from contralateral treatment (55% *vs*. 50%; P=0.5) and survival (81% *vs*. 87%; P=0.5) where similar between study groups (13).

Redo LVRS

A particular poor risk sub-cohort that can meaningfully benefit by avoidance of intubated anesthesia is that entailing emphysematous patients who have lost the benefits achieved by a successful LVRS and who develop new target areas in the lung that are amenable of reoperation. In these patients the postoperative functional deterioration usually progresses along several years. As a result, redo-LVRS remains in most of instances the only therapeutic choice since many of these patients are older than 65 years of age and cannot be included in a lung transplantation waiting list.

In a 17 patients series on redo LVRS entailing completion lobectomy in seven patients and intubated resectional or awake nonresectional redo LVRS in five patients each, the mean age was 66 years whereas interval time between the first LVRS procedure and the reoperation was of 55 months. The 90-day operative mortality was 12% and included two patients who underwent one completion lobectomy and one nonanatomic lung resection under non-awake anesthesia.

The mean hospital stay was 9 days and significant improvements lasting for up to 12 months occurred in FEV_1 (P<0.001), FVC (P<0.002), RV (P<0.001), 6MWT (P<0.001), and dyspnea index (P<0.001). Six months after surgery, 11 patients had an FEV_1 improvement of 200 mL or more (46).

Conclusions

LVRS, has been shown to represent a highly effective treatment modality for properly selected patients with severe emphysema although in recent years it remains unexpectedly underused. Decker and co-workers (23) have reported that amongst the Society of Thoracic Surgeons database only 528 patients underwent non-awake LVRS during an 8.5-year period. This figure has led them to highlight the need to invest in future analyses to identify determinants of adjusted surgery-specific quality assessments.

What is arguable is that the Achilles heel of resectional LVRS is not related to doubts on its efficacy but rather to fears of the significant perioperative morbidity that has been associated with this treatment modality and that can meaningfully increase health care costs.

Within the framework of available investigational methods, the awake nonresectional LVRS method, which does not entail use of any expensive device, avoids removal of lung tissue and can be quickly performed in spontaneously ventilating awake subjects, has shown promise in uni-center studies and awaits now to be tested through well designed, multi-institutional controlled trials.

Having matured an experience with several types of thoracic surgery procedures performed through awake anesthesia we can affirm that candidate to LVRS due to emphysema are amongst the patients who can benefit most from an awake anesthesia management. In fact, we have found that perioperative breathing pattern, oxygenation promptness of resumption of daily-life activities, and hospital stay are dramatically better in patients undergoing awake LVRS if compared with those of patients operated on by general anesthesia with single-lung ventilation.

In conclusion, the fear of performing awake LVRS in delicate subjects with severe emphysema and poor pulmonary function is fully understandable as nicely underlined during the discussion about a paper on awake LVRS presented at an international meeting, when one of the moderators affirmed: "It is a little intimidating for some of us to think about having one of these critically ill patients be wide awake while we make holes in their chest and operate on them" (12).

Nonetheless, experience with nonintubated and awake thoracic surgery is increasing worldwide and it is possible that in the near future, a number of thoracic surgeons who will have gained confidence with both non-awake and awake LVRS will rather consider somewhat more intimidating performing LVRS in intubated, non-awake patients.

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A video demonstration of the Li's anastomosis—the key part of the "non-tube no fasting" fast track program for resectable esophageal carcinoma

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Abstract: The main obstacle of fast track surgery for esophagectomy is early oral feeding. The main concern of early oral feeding is the possibility of increasing the incidence of anastomotic leakage. Dr. Yin Li used the Li's anastomosis to ensure oral feeding at will the first day after esophagectomy. This safe and efficient anastomosis method significantly reduced the anastomotic leak rate, the number of post-operative days and stricture. Importantly, the "non-tube no fasting" fast track program for esophageal cancer patients was conducted smoothly with Li's anastomosis. This article was focused on the surgical procedure of Li's anastomosis.

Keywords: Esophageal carcinoma; thoracolaparoscopic esophagectomy; fast track surgery; Li's anastomosis; non-tube no fasting

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Introduction

The fast track (FT) surgical patient pathway, which aims to improve the perioperative treatment of surgery for cancer patients, has been well studied in colorectal (1), gynecological (2), and gastric cancer (3) patients and has significantly reduced the surgical stress and costs (4,5). However, this program for esophagectomy patients is rarely used. The main concern of allowing early oral feeding postoperatively in patients with esophagectomy is the possible increase in the incidence of anastomotic leakage. Based on retrospective studies and surgical technical experience, Dr. Yin Li used the Li's anastomosis to ensure first-day oral feeding at will after an esophagectomy (6), which made the early oral feeding fast track surgical program possible for esophageal cancer patients. More than two years have been passed since the Li's anastomosis together with "non-tube no fasting" fast track program. Until May 2015, about 260 cases have started oral nutrition on postoperative day (POD) 1 at will without a nutrition tube and fasting, which represents the so-called "non-tube no fasting" fast track program.

Indications

This procedure is indicated in all operable esophageal carcinoma patients. We recommend to adopt the fast track surrey program "non-tube no fasting" followed by the Li's anastomosis.

Results

This procedure together with "non-tube no fasting" fast track program has been successfully conducted for more than 2 years by our group. We started a randomized control trial in February 2014, "early oral feeding following thoracolaparoscopic oesophagectomy in patients with esophageal cancer". In interim analyses, between February 2014 and September 2014, 148 continuous patients with thoracolaparoscopic esophagectomy were recruited. Seventy two patients were randomized in "non-tube no fasting" group and 76 patients in late oral feeding group. The anastomotic leakage rate was 2.8% for the "non-tube no feasting" group (6), which is significantly lower than that observed for mechanically stapled anastomosis and fasting for 7 days during the same period in other medical groups (n=92), (2.8% versus 10.9%, P=0.048). The post-operation hospital stay (7.6±2.2 versus 12.1±3.7, P<0.01) is quite short. In our cohort study, from June 2013 to August 2013 (n=30 in each group), the Health-related quality of life (HRQL) mean scores obtained 3 months post operation were significantly better, including those for reflux (14.07±14.86 versus 22.96±17.73, P=0.048) and dysphagia (15.56±15.33 versus 23.70±16.95, P=0.047) compared with the scores for conventional two-layer anastomosis and late oral feeding in other medical group. Additionally, the stricture rate is lower than that observed for conventional two-layer anastomosis at 6 months post operation (15.1±3.7 versus 13.2±3.4 mm, P=0.047). The simply summary of data for studies of Li's anastomosis were shown in *Table 1*.

Conclusions

This safe and efficient anastomosis method significantly reduced the anastomotic leak, the number of post-operative days, reflux, dysphagia and stricture. Importantly, this method ensured at will oral feeding on first day after an esophagectomy. The "non-tube no fasting" fast track program for esophagectomy patients was thus conducted smoothly. A prospective randomized clinical trial (Clinical Trial Registration Number: NCT01998230) is ongoing in our cancer center, with a much larger sample size, to verify our findings and assess the additional potential benefits of early oral feeding after the Li's anastomosis thoracolaparoscopic esophagectomy for esophageal cancer.

Procedure

The operation is performed under general anesthesia. The thoracolaparoscopic esophagectomy and a two-field lymph node dissection were adopted, with a left lateral decubitus position with 30° forerake. The thoracic esophagus was isolated, and the lymph nodes were harvested. Subsequently, the patient adopted a supine position. A 2-3 cm left cervical incision was made. The cervical esophagus was exposed and transected. Then, in the abdominal section, a 4-cm-wide gastric conduit was made by a linear cutting stapler (TLC, Ethicon, USA). The gastric conduit was pulled up to the neck. Finally, the Li's anastomosis was conducted to sew the gastric conduit and the distal esophagus (*Figure 1*).

The Li's anastomosis procedures included the following (*Figure 2*):

(I) We made a 2-3 cm skin incision on the left cervical. The muscle sparing method was utilized in the open tissue space. The distal esophagus and gastric conduit were explored.

(II) The lesser curvature of the gastric conduit was faced forward, and the greater curvature was faced backward. The posterior esophageal wall and posterior wall of the stomach were put together. A row of 4-0 Vicryl (Ethicon) interrupted horizontal mattress sutures were used to sew the two walls. The muscularis layer of the esophagus and the seromuscular layer of the stomach were sewn by four interrupted sutures, including two sutures at each peak and using mosquito forceps as hang lines to define the corners of the layers and obtain an optimal view (sutures were placed at the A1, A2, A3 and A4 positions). These spots were near to the greater curvature of stomach in order to get enough blood perfusion and named as anastomosis inicial spots, short for A, A1-A6. Shown in *Figure 2A*.

(III) A three-leaf clamp was used to fix the gastric conduit and esophageal stump to facilitate the suture procedure. Then, the muscularis layer of the esophagus was cut at the anastomotic side, and the seromuscular layer of the stomach was opened at the anastomotic side. The two layers were sewn with seven to eight stitches of interrupted 4-0 silk suture. Shown in *Figure 2B*.

(IV) The other side of the muscularis layer of the esophagus was opened, the muscular and mucous layers of the esophagus were dissociated by approximately 1.5 cm and the redundant esophagus was removed. Shown in *Figure 2C*.

(V) The gastric mucosa layer was opened, and continuous sutures were used to carry out the mucosa anastomosis for the mucosal layers of esophagus and stomach using 4-0 Vicryl (Ethicon). Shown in *Figure 2D,E*.

(VI) The three-leaf clamp was released, and the anterior muscular layer of the esophagus and the seromuscular layer of the stomach were sewn using 4-0 silk sutures. Shown in *Figure 2F*.

Table 1 Simply summary of data for studies of Li's anastomosis

Study type	Study design	Anastomosis methods	Tube	Oral intake	Patient number	Interval	Inclusion criteria	Anastomotic fistula rate (%)	First flatus	Length of postoperative stay
Prospective study	Single-arm trial (7)	Li's anastomosis	Nasogastric tube	POD1	68	01.2013-08.2013	ESCC, thoracolaparoscopic esophagectomy, age <80 years, adequate organ function, no history of preoperative chemotherapy or radiotherapy	1.5	2.1±0.9	9.2±2.6
Retrospective study	Cohort study	mechanically stapled anastomosis (other group)	Nasogastric tube; naso-intestinal feeding tube	POD7	92	02.2014-09.2014	Adults subject to esophagectomy	10.9 P=0.048	NA	12.1±3.7 P<0.01
		Li's anastomosis	Non-tube	No fasting POD1	72		Adults subject to thoracolaparoscopic esophagectomy for esophageal cancer	2.8	2.4±0.8	7.6±2.2
Prospective study	RCT interim analyses (6)	Li's anastomosis	Non-tube	No fasting POD1	72	02.2014-09.2014	Adults subject to thoracolaparoscopic esophagectomy for esophageal cancer	2.8 P=0.612	2.4±0.8 P<0.001	7.6±2.2 P<0.001
		Li's anastomosis	Nasogastric Tube; naso-intestinal feeding tube	POD7	76			1.5	3.3±0.7	11.7±3.9

POD, postoperative day; ESCC, esophageal squamous cell carcinoma; RCT, randomize controlled trials; NA, not available.

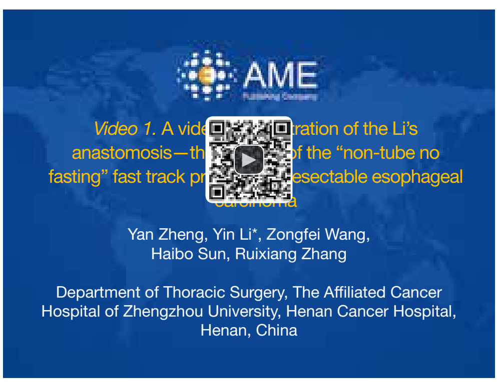

Figure 1 A video demonstration of the Li's anastomosis—the key part of the "non-tube no fasting" fast track program for resectable esophageal carcinoma (8).
Available online: http://www.asvide.com/articles/611

(VII) A linear stapler was used to cut the redundant gastric conduit 1.5-2.5 cm above the anastomosis, shown in *Figure 2G*. Continuous 4-0 Vicryl (Ethicon) sutures were used to enhance the cutting edge. Then, the redundant gastric conduit was embedded into the gastric conduit cavity using forceps and fingers, shown in *Figure 2H,I*. This gastric folding was designed as a valve for anti-acid reflux. The valve was labeled in the *Figure 2H,I* as "V". Finally, the gastric seromuscular layer and the anterior aspect of the esophageal muscle were sewn by intermittent 4-0 Vicryl (Ethicon) sutures together with fundoplication, shown in *Figure 2J*.

(VIII) The mediastinal drainage tube was placed near the anastomosis. The incision was closed with an absorbable suture.

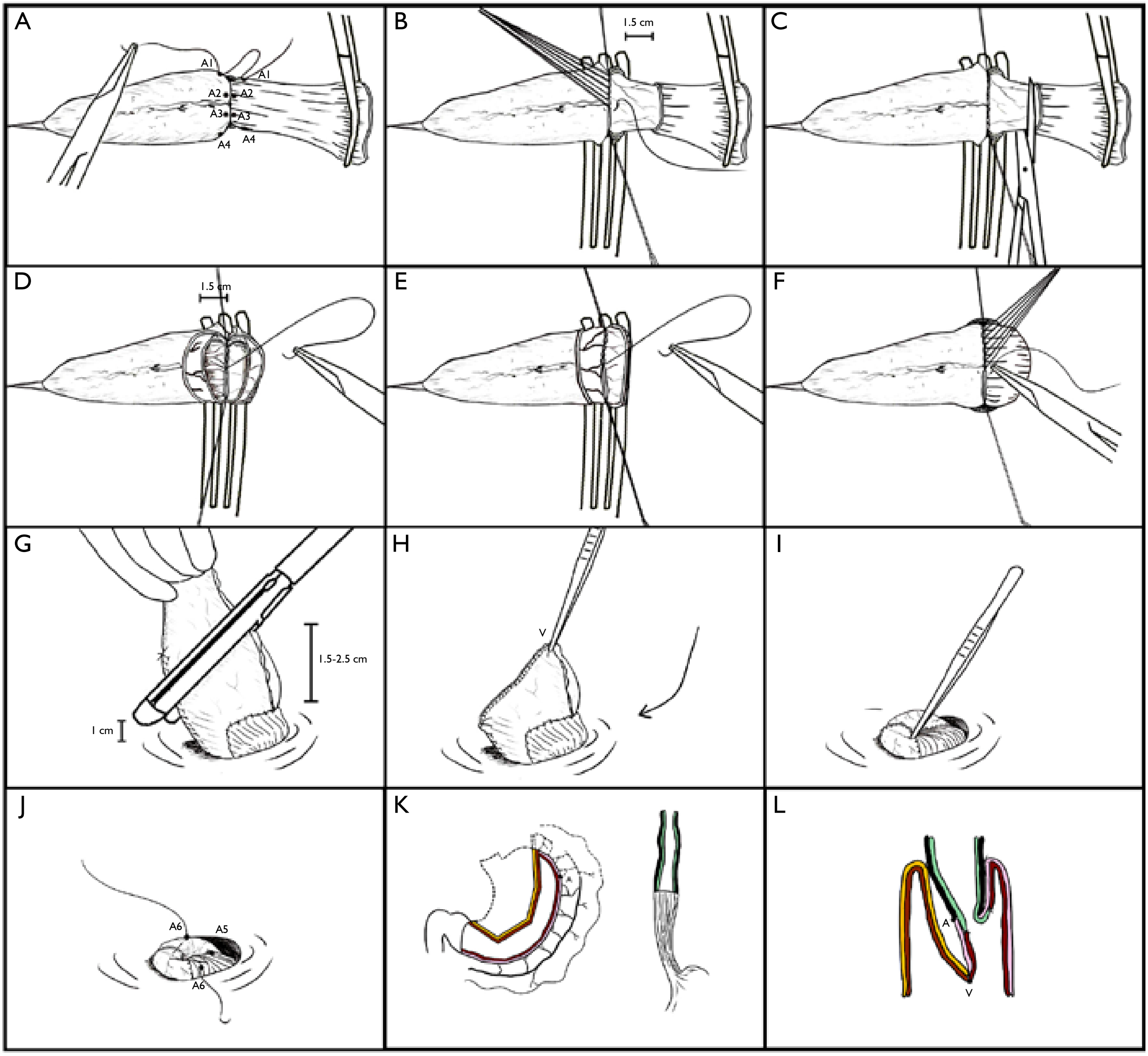

Figure 2 (A) Four interrupted sutures between the muscularis layer of the esophagus and the seromuscular layer of the stomach; (B) three-leaf clamp to fix the gastric conduit and esophageal stump. Open the muscularis layer of the esophagus. Seven to eight interrupted stitches between the muscularis layer of the esophagus and the seromuscular layer of the stomach; (C) esophageal stump was cut off; (D and E) continuous sutures between the mucosal layers of esophagus and gastric mucosa layer; (F) release three-leaf clamp. The anterior muscular layer of the esophagus and the seromuscular layer of the stomach were sewn using interrupted sutures; (G) the redundant gastric conduit was cut by a linear stapler; (H and I) embed the redundant gastric conduit into the gastric conduit cavity by forceps; (J) the gastric seromuscular layer and the anterior aspect of the esophageal muscle were sewn by intermittent two sutures together with fundoplication; (K and L) the simplified profile of Li's anastomosis. A1, A2, A3, A4, A5, A6 (*Figure 2A*), anastomosis site; V, valve.

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None.

Footnote

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

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Anesthetic consideration for nonintubated VATS

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Abstract: In the recent decade, nonintubated-intubated video-assisted thoracoscopic surgery (VATS) has been extensively performed and evaluated. The indicated surgical procedures and suitable patient groups are steadily increasing. Perioperative anesthetic management presents itself as a fresh issue for the iatrogenic open pneumothorax, which is intended for unilateral lung collapse to create a steady surgical field, and the ensuing physiologic derangement involving ventilatory and hemodynamic perspectives. With appropriate monitoring, meticulous employment of regional anesthesia, sedation, vagal block, and ventilatory support, nonintubated VATS is proved to be a safe alternative to the conventional intubated general anesthesia.

Keywords: Anesthesia; thoracoscopy; nonintubated; thoracic epidural anesthesia (TEA); intercostal nerve block; bispectral index

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Introduction

For the conventional idea of video-assisted thoracoscopic surgery (VATS), ventilation control and lung separation/isolation was presumably thought to be vital for the safety and feasibility of the procedure (1). With the advent of modern imaging and monitoring technology, nonintubated VATS has brought a new possibility of breakthrough to this tenet.

In the recent decade, nonintubated VATS has been intensively researched and reported, which has been advocated to be a rising alternative to the conventional intubated VATS with general anesthesia from several perspectives, such as surgical and anesthetic feasibility and safety (2-10), perioperative immunology (11,12), and outcome analysis (13-17).

The aim of this article is to introduce the major anesthetic consideration and the management experience of our group with a problem-based fashion, in the hope of improvement of mutual understanding between surgical and anesthetic personnel, and thus the coordination of the teamwork.

Who and which procedures are suitable for nonintubated VATS?

According the experience of the major research groups, the general patient exclusion criteria includes American Society of Anesthesiologists score 4 and higher, bleeding disorders, sleep apnea, unfavorable airway or spinal anatomy, need for contralateral lung isolation, clinically significant sputum production, bronchiectasis, asthma, extreme of body mass index (BMI), preoperative decompensated heart disease, severe pleural adhesion over targeted hemithorax, and noncompliance to the procedure or patient refusal (5,14).

With the maturation of the technique, Wu and colleagues (18) had evaluated the feasibility of geriatric patients (age ranging from 65 to 87) undergoing lobectomy, which showed comparable safety profile with control group, and opened up the possibility of nonintubated VATS on the old age group.

Initially, nonintubated VATS was tested on simpler diagnostic procedure or management of solitary and peripheral lung lesion (2,9,19,20). With the increasing body of evidence and experience, nonintubated VATS has been extensively promoted and proved safe for treatment of pleural/pericardial effusion, empyema thoracis, bullous emphysema, non-resectional lung volume reduction surgery, spontaneous pneumothorax, biopsy of interstitial lung disease, wedge resection of lung nodules, segmentectomy and lobectomy for lung cancer, mediastinal biopsy and tumor excision (5-8,14,20,21).

What's the anesthetic goals and the corresponding management?

The main difference of the nonintubated VATS from conventional intubated general anesthesia, is to create an iatrogenic pneumothorax, a subsequently collapsed lung to be operated on, and to maintain patients' spontaneous ventilation sufficiently at the same time. Conscious sedation is sometimes required due to emotional stress or prolonged procedure-related discomfort.

Monitoring

In order to handle the physiologic derangement and the complexity of the surgical/anesthetic procedure aforementioned, standard monitoring with pulse oximeter, electrocardiogram, sphygmomanometer, and end-tidal CO_2 should always be in place. In addition, invasive arterial pressure monitor is set for most patients in our group for its versatility on monitoring arterial blood gas, real-time hemodynamic index, and fluid status inclination. For the occasion in which sedation is part of the planning, bispectral index (BIS) is highly recommended for evaluation of sedation level and advanced judgement of anesthetic depth.

Ventilatory

The goal of ventilatory manipulation is to maintain a smooth, non-effort, spontaneous respiratory pattern, aiming respiratory rate over 12 to 20 times/minute for acquiring a satisfactory surgical field with adequately collapsed lung (5).

In awake patients, preoperative communication for reassuring the patients, intraoperative coaching, mental support, verbal communication with medical personnel, and comfortable environment with low-volume music might all contribute to calm the patients down with acceptable respiration (16,22).

In sedated patients of our group, premedication with opioid agent followed by deliberate titration had been proved to control respiratory rate effectively. Meticulous use of nasal airway could be of great benefit if upper airway obstruction raises clinical concerns. If significant hypoventilation should happen, modest assisted ventilation by a mask might be required after notification of the surgical team.

Oxygenation could be facilitated with O_2 supplement by nasal cannula 3-4 liters/minute or by Venturi Mask. Overly hypercapnia should be avoided, a good-quality end-tidal CO_2 trace and serial arterial blood sampling before/after iatrogenic open pneumothorax should mostly suffice for close monitoring.

Analgesia

The target of the analgesia is to block the unpleasant sensation throughout the surgical manipulation. With the temporal sequence, VATS ports are first to be set, which bring about painful sensation from skin to parietal pleura; after ports are set, the manipulation of lung and traction of intrathoracic structures would cause irritation over visceral pleura.

Regional anesthesia had been long reported to be effective for analgesia covering chest cage and parietal pleura (23). Various approaches have been developed and proved feasible, including the current mainstream of thoracic epidural anesthesia (TEA), paravertebral nerve block, and percutaneous or thoracoscopic intercostal nerver block, intrapleural analgesia. In our group practice, we add vagus nerve block and intravenous narcotic to minimize the visceral component of irritating sensation.

Traditionally, before minimal invasive procedure era, thoracotomy was traumatic procedure with large incision, and thus epidural anesthesia was favored for its better quality of postoperative pain control and reduction of respiratory and cardiac complication (23). But with the paradigm shift to VATS, Yie *et al.* (24) had reported Epidural anesthesia holds no superior postoperative analgesic benefits over narcotic-based intravenous patient-controlled analgesia (IVPCA). The optimal postoperative analgesia remains an open issue, other promising modalities such as continuous intercostal-intrapleural analgesia or continuous paravertebral block worth more attention and further investigation (25,26).

Amnesia

Surgery, more or less, could bring forth mental stress to the patients, which might consequently has detrimental effects on patient's physiology (27) and even jeopardize the safety of surgery by panic attack. Sedation with amnesia could offer a stress-free environment even for the relatively vulnerable groups, especially with the prolonged procedure like lobectomy, which makes keeping same position for hours intolerable.

For sedation, our group employs BIS for monitoring sedation level. Empirically speaking, premedication with 50 to 100 mcg fentanyl, followed by propofol with target controlled infusion (TCI), aiming for BIS over 40 to 60, would mostly create a balanced status without significant ventilatory or hemodynamic disorder.

Areflexia

When approaching central intrathoracic lesion, cough reflex is an inevitably encountered problem that requires effective but temporary suppression of the reflex. On the other hand, as an intrinsic protective mechanism, recovery of cough reflex is beneficial on reduction of postoperative respiratory complication.

Pre-operative inhalation of aerosolized lidocaine (28) and ipsilateral stellate ganglion block (29) had been proposed to reach cough control in some extent. In our group experience, Chen and colleagues (5) has routinely performed intraoperative thoracoscopic vagal block, which has been proved effective on cough reflex suppression without causing hemodynamic instability. For more swift procedures, for the sake of decreasing cough suppression duration, incremental intravenous fentanyl is applied in place of vagal block.

Prepare for conversion to general anesthesia

Despite of extra vigilance and preparation aforehand, intraoperative conversion to intubated general anesthesia is inevitable occasionally due to significant bleeding, pleural adhesion, and insufficient anesthesia (5,30). Plan B should always be in hand.

Intubation in lateral decubitus position with VATS instruments in place presents itself as a technical challenge to anesthesiologists. Direct laryngoscopy might stands a chance, but fiberoptic bronchoscopic intubation, video-assisted system, and laryngeal mask airway (LMA) are the trustworthy back-up plan.

How are intraoperative hemodynamic and ventilatory index change?

The hemodynamic and ventilatory index are the core of perioperative monitoring and evaluation. Different protocols would naturally bring out diverse outcomes. During one lung ventilation, heart rate, respiratory rate, PaO_2 and CO_2 elimination will change significantly but they can be kept physiologically adequate.

Generally speaking, the hemodynamic and ventilatory index remained in the acceptable range without causing detrimental hypotension, hypoxemia, hypercapnia, nor acidosis.

Conclusions

Nonintubated VATS has been extensively and safely applied to various surgical procedures involving pleura, lung, and mediastinum. The main challenges for anesthesiologists are coping with the physiologic derangement upon iatrogenic open pneumothorax and balancing the benefits and risks of different anesthesia techniques. With a well-controlled, well-monitored anesthetic combinations of regional anesthesia, sedation, and postoperative pain service, nonintubated VATS has been proved to be safe and feasible amongst a wide variety of patient groups.

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Awake thoracoscopic surgery under epidural anesthesia: is it really safe?

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Thoracoscopic surgeries usually require single-lung ventilation under general anesthesia because of the need to obtain a sufficient working space. In patients with impaired pulmonary function, if the patient can undergo general anesthesia, a more selected collapse of the lung is considered to be beneficial for intraoperative oxygenation. The selective bronchial blockade of the lobe to be resected has been reported by several investigators (1-3). Mukaida and coworkers first reported thoracoscopic surgery for pneumothorax under local and epidural anesthesia in 1998 in high-risk patients contraindicated for general anesthesia (4). They reported that their patients experienced well-managed pain and cough reflex and well-maintained breathing and hemodynamics during the surgery, and demonstrated that thoracoscopic surgeries can be performed safely under epidural anesthesia without tracheal intubation. Subsequently, Pompeo and colleagues conducted a randomized trial comparing the result of awake thoracoscopic resection of solitary pulmonary nodules versus a control group treated under general anesthesia with single-lung ventilation (5). They concluded that the awake thoracoscopic approach was superior to the conventional thoracoscopic approach under general anesthesia in terms of the global in-operating room time, postoperative recovery, need for nursing care and overall hospital stay. Moreover, Mineo's group showed the superiority of the awake thoracoscopic surgery versus conventional thoracoscopic surgery in the treatments of spontaneous pneumothorax (6), metastatic tumors (7), empyema thoracis (8) and emphysematous bulla (9). Moreover, they demonstrated that awake thoracoscopic surgery attenuated the surgical stress responses and had a smaller impact on the postoperative lymphocyte responses when compared with conventional thoracoscopic surgery under general anesthesia with single-lung ventilation (10,11). The awake approach may attenuate the impact on the endocrine and immune systems of the patients compared with the conventional anesthetic option. Based on this background, the use of awake thoracoscopic minor lung surgery has been expanding worldwide (12-15).

Regarding major lung surgery, there have been three studies reported from Taiwan. Chen and coworkers first reported that awake thoracoscopic lobectomy is safe and technically feasible in selected patients with early-stage non-small cell lung cancer (16). They demonstrated that the surgical results of the awake approach were comparable to those of historical controls treated under general anesthesia, while the awake group showed less intubation-associated discomfort and a quicker return to daily activities, including drinking and eating. They also revealed that three (10%) of the 30 subjects in the awake group required conversion to general anesthesia with single-lung ventilation because of persistent hypoxemia, poor pain control or bleeding. They also reported the feasibilities of non-intubated thoracoscopic segmentectomy (17) and lobectomy with the same procedures for geriatric lung cancer patients (18).

Recently, Liu and coworkers conducted a randomized trial comparing the results of awake thoracoscopic surgery, including bullae resection, wedge resection and lobectomy, versus those of a control group treated under general anesthesia with single-lung ventilation in 354 patients treated at a single institution (19). In their study, 174 patients underwent the awake approach, while the remaining 180 patients served as a control group. Seven (4%) of the 174 subjects in the awake group required conversion to general anesthesia with single-lung ventilation because of persistent hypoxemia (n=2), unsatisfactory lung collapse (n=2), diffuse pleural adhesion (n=1), unexpected conversion of the surgical procedure (n=1) and bleeding (n=1). Four (13%) of the 30 patients undergoing lobectomy were converted. The surgical results of the awake group (n=167) excluding the seven conversions were compared with those of the control group (n=180), because this study was not based on an intention-to-treat method. The authors demonstrated that the rates of postoperative complications, including respiratory complications, in the awake group were significantly lower than those of the control group, while there were no mortalities in either group.

Regarding the postoperative fasting time and duration of postoperative antibiotic use (which was dependent on the time when the white blood cells decreased to normal levels), the awake group was superior to the control group. The awake group also showed shorter hospital stays after bullae resection and lobectomy than the control group. Moreover, the authors of that study reported that the awake group was associated with decreased levels of inflammatory cytokines, including tumor necrosis factor-alpha, in the bronchoalveolar lavage fluid and a lower serum high-sensitivity C-reactive protein level after bullae surgery, compared with the control group. This additional study regarding the differences between the pre- and post-operative concentrations of inflammatory cytokines after bullae surgery clearly demonstrated that the awake approach decreased the postoperative complications. Therefore, an additional study should be conducted in all subjects because postoperative complications were compared between the two groups for all subjects, irrespective of the surgical procedures.

However, in this paper, the awake group tended to have an increased intraoperative blood loss during major surgery compared to the conventional group. Although the inclusion of a complicated sub-analysis of minor and major surgeries, the lack of an intention-to-treatment study and the lack of comparisons of the patient characteristics, length of the operation and global in-operating room time decreased the importance of that study, there were several laudable aspects associated with the article. The first is that it was a randomized controlled trial that recruited a relatively large number of patients. The second is that the conversion rate was relatively low at 4%. That shows the experience of the surgical team and their motivation to complete the awake thoracoscopic surgery. The third is the low morbidity rate of 6.7%. Of note, the investigators report a 1.2% incidence of pulmonary infection, which is a remarkably low rate. The smaller number of pulmonary infections may be associated with attenuated surgical stress responses and the preserved function of natural killer cells in patients undergoing awake thoracoscopic surgery (10,11).

Although all of the researchers reported that the least invasive procedures consisting of thoracoscopic surgery under local and epidural anesthesia are safe and feasible (4-9,12-19), collaboration between thoracic surgeons and anesthesiologists is absolutely essential for successful results. Because the frequency of conversions to general anesthesia needing intubation was 10% or more during major lung surgery (16,19), anesthesiologists will need to make provisions for such conversions. For thoracic surgeons, the accumulation of experience by performing minor awake thoracoscopic procedures is very important. Especially in major lung surgeries, including lobectomy, it seems to be difficult to strip the interlobal vessels and treat the incomplete fissures despite inflation of the affected lung. If bleeding from the pulmonary artery occurs, it is extremely difficult to control in such a limited working space. Therefore, a prompt conversion to intubated general anesthesia should be performed without hesitation if such bleeding develops.

In conclusion, this innovative technique consisting of less invasive surgery and anesthesia is associated with a faster postoperative recovery and lower complication rates, compared with conventional thoracoscopic surgery under general anesthesia. However, the safety of major surgery, including lobectomy, performed using this approach is still unclear.

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Nonintubated anesthesia in thoracic surgery: general issues

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Abstract: Anesthetic management for awake thoracic surgery (ATS) is more difficult than under general anesthesia (GA), being technically extremely challenging for the anesthesiologist. Therefore, thorough preparation and vigilance are paramount for successful patient management. In this review, important considerations of nonintubated anesthesia for thoracic surgery are discussed in view of careful patient selection, anesthetic preparation, potential perioperative difficulties and the management of its complications.

Keywords: Awake thoracic surgery (ATS); conversion; general anesthesia (GA)

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Figure 1 Dr. Gabor Kiss.

Introduction

Regional anesthesia for thoracic surgery has been used extensively in the past. In 1950, Buckingham from Kansas City described his experience of 617 thoracic surgery procedures performed under thoracic epidural anesthesia (TEA). He reported no cases of depressed respiration or permanent nerve damage (1). Four years later, Vischnevski from Russia reported a series of more than 600 thoracic surgery procedures under local anesthetic techniques (2). In the last decade, more papers have stressed the advantages of awake thoracic surgery (ATS) compared to thoracic surgery under general anesthesia (GA).

Anesthetic management for ATS is more difficult than under GA, being technically extremely challenging for the anesthesiologist and requiring careful patient selection. The patient must be extensively informed before consenting. Thorough preparation and vigilance are paramount for successful patient management.

Figure 2 Dr. Maria Castillo.

Surgical indications and type of procedures done under ATS

(I) Surgery on the pleural space:
- (i) Drainage of pleural effusion (3);
- (ii) Pleurodesis under TEA, thoracic paravertebral and local anesthesia (LA) (4-6);
- (iii) Pleurostomy under TEA (7);
- (iv) Decortication under TEA or paravertebral block (4,5);
- (v) Treatment of pneumothorax under TEA, including pleurectomy (7,8);
- (vi) Empyema drainage under epidural or paravertebral block (9);
- (vii) Bleb resection (10).

(II) Biopsies:
- (i) Anterior mediastinal mass biopsy (11);
- (ii) Pleural/ lung biopsy under TEA (4-7).

(III) Surgery on the lung:
- (i) Pneumonectomy under TEA (12);
- (ii) Lobectomy via thoracotomy and thoracoscopy under TEA (5,12,13);
- (iii) Bilobectomy under TEA (12);
- (iv) Wedge resection under TEA or LA (5,12);
- (v) Thoracoscopic lobectomy and segmentectomy under TEA (14-16);
- (vi) Lung metastasis resection under TEA (4,17);
- (vii) Lung volume reduction surgery and bullectomy under TEA (4,5,7,18).

(IV) Surgery on the mediastinum:
- (i) Pericardial window (5);
- (ii) Tracheal resection with cervical epidural C7 to T1 (with local anesthetics to blunt the cough response) (19);
- (iii) Thymectomy under TEA (12).

(V) It is important that the surgeons, anesthesiologists and intensivists involved should discuss as a team the strategy for indications and management of ATS.

Pros and cons of ATS compared to thoracic surgery under GA

ATS offers many advantages to the patient. GA may increase the risk of impaired cardiac function with a decrease in myocardial blood flow and left ventricular function (20,21), as well as introduce the possibility of damage induced by mechanical ventilation, such as alveolar barotrauma, volutrauma, and atelectrauma, increasing the risk of pneumonia (22). Neuromuscular blockade during GA increases atelectasis in the dependent lung leading to a right-to-left shunt and increased risk of intraoperative hypoxia (22). GA places the patient at risk for residual neuromuscular blockade (23) and postoperative ventilator dependency (21) with the possibility of multiorgan failure, sepsis, and ICU-induced neuromyopathy or polyneuropathy (7,24). In addition, intubation-related airway trauma to teeth or vocal cords can also occur during intubation (25).

On the other hand, if TEA for ATS is chosen, potential complications are epidural hematoma, spinal cord injury, phrenic nerve palsy and inadvertent high anesthetic level. Predicted risk for neurological complications due to TEA is quoted at 0.07% (26). In contrast, for elective general surgery, the incidence rate of postoperative pulmonary complications was 33.9% and lung-related mortality rate 3.4% in patients with mild-to-moderate COPD (27). The later study only concerns general surgery, but given the fact that higher respiratory complication rates with GA are quoted (27), the risk benefit ratio to reduce pulmonary complications remains in favour of ATS under TEA.

Noda and coworkers in 2012 retrospectively compared the efficacy, morbidity, and mortality of video-assisted thoracoscopic surgery (VATS) awake (ATS) *vs.* GA in the treatment of secondary spontaneous pneumothorax and concluded that ATS patients had a significantly reduced incidence of postoperative respiratory complications, including pneumonia and ARDS. The author hypothesized that avoidance of intraoperative pulmonary barotrauma from mechanical ventilation and preserved deglutition function in ATS patients could be associated with lower prevalence of latent aspiration that could potentially cause pneumonia (28,29). ATS may also reduce stress hormone response (9), attenuate the impact on the immune system, and lower the impact on postoperative lymphocyte response (30) compared with the conventional anesthetic option (28,31-33). Because modern anaesthetic drugs are rapidly metabolized, it can be argued that ATS is unethical because stable dyspnoeic patients should be intubated and would be safer under GA. However, despite short half-lives and the reversibility of modern anesthetics, positive pressure ventilation can significantly increase respiratory complications and cause ventilation-induced lung injury (27,34) compared to spontaneous respiration. Therefore and paradoxically, to offer better chances for recovery, ATS should be the preferred choice in patients with a high risk for ventilator dependency. In case of perioperative panic attacks or cardiorespiratory instability conversion of ATS to GA always remains as the last resort.

Regional anaesthesia techniques may not only provide better haemodynamic stability but also superior postoperative analgesia, reduced thrombotic complications, decreased surgical stress response and fewer side effects, such as nausea and vomiting, when compared to general anaesthesia (6).

Compared with thoracoscopic surgery under GA, ATS also resulted in faster postoperative recovery and lower complication rates (35), and patients can display effective cough minutes after surgery (36).

Patients have no intubation-associated discomfort such as a sore throat and can return more quickly to daily activities, including drinking, eating and walking (7,22).

Several papers conclude that the ATS approach was superior to thoracoscopy under GA in terms of significantly shorter anesthesia and global in-operating room time, less need for nursing care and overall shorter hospital stays with comparable clinical outcomes (4,8,28,37).

There are also cost-cutting arguments in favour of ATS under TEA. For VATS lobectomy awake with TEA, blood loss and surgical duration was comparable with procedures under GA (13,15). In a study on lung volume reduction surgery, ATS under TEA not only resulted in better perioperative outcome and shorter hospital stay (12) but also lower costs since there is no weaning from the ventilator and anesthesia time is reduced (17,38). Given that ATS under TEA patients were spontaneously breathing and ventilator free, nursing labour could be invested for other tasks. Furthermore, in a paper by Klijian and coworkers, a lower mortality rate and less complication for awake VATS were reported (5). Consequently, the use of non-intubated VATS may allow a fast-track protocol avoiding the intensive care unit.

ATS also resulted in high patient satisfaction, especially in patients with severe chronic pulmonary disease who had already experienced long postoperative ICU stays and weaning problems in the past. High patient satisfaction was also due to a better sense of control by patients (7,19).

Patients selection for awake thoracic anesthesia

The literature states no absolute contraindications to GA, which always remains the last resort in case regional anesthesia techniques fail. However, as ATS techniques require more experience, preparation, and vigilance than GA for thoracic surgery, patients must be carefully selected for ATS.

At first, ATS was performed mostly for selected patients classified as ASA I-II and Mallampati grade I-II, with no obesity (body mass index <30), a tumour size of less than 6 cm, and with few comorbidities and good cardiopulmonary function (39). However, indications have been extended to very ill patients. Thoracoscopic surgery for pneumothorax under local and TEA in high-risk patients contraindicated for GA was first described in 1998 by Mukaida *et al.* (40) followed by other papers (7,41).

In one retrospective observational study, high risks patients successfully undergoing ATS had the following severe cardiac and respiratory comorbidities (7): advanced diffuse interstitial lung fibrosis on home oxygen treatment, restrictive chronic respiratory failure on continuous nasal NIV, severe chronic obstructive pulmonary disease with FEV_1 27% and a history of difficult weaning from the ventilator, inflammatory alveolitis, pneumomediastinum, recurrent unilateral or bilateral pneumothorax, pyothorax, multiple bilateral lung metastases, a background of bilateral lung metastasectomy, pleurectomy, undernourishment, atrial fibrillation, severe emphysema with high risk for volu/barotrauma, and two cases of advanced limb girdle myopathy contraindicating muscle relaxants and volatile anaesthetics.

GA can present an ethical dilemma if surgery is the only treatment option for high risk patients with advanced terminal chronic respiratory disease. Under GA, patients with severe respiratory disease carry high risks of ventilator dependency with increased morbidity and mortality (7). In these cases, if the total risk-benefit balance is in favour of surgery to reverse an acute pathology, and in the absence of any contraindications to regional anesthetic techniques, ATS could help avoid early death and could contribute to a reasonable quality of life with comfort and well-being after surgery, even among terminally-ill patients.

ATS can be an option for fragile high-risk patients with dyspnoea at rest to avoid ventilator dependency and to speed up recovery after surgical correction of a reversible pathology. In a retrospective observational study, eight hemodynamically stable patients with acute severe but stable dyspnoea, classified as a maximum grade four of the modified Medical Research Council dyspnoea scale, successfully underwent ATS to reverse the cause for acute dyspnoea (7).

Piccioni and coworkers described two oncology patients with severe dyspnoea (SpO_2 of 85% and 93%, respectively, on room air) undergoing VATS. One patient who had multiple organ and bilateral pulmonary metastases, a large left pleural effusion, and right pulmonary atelectasis underwent VATS on the left thorax. The other patient who was operated on the right thorax presented with right inferior lobe carcinoma, multiorgan metastases, and a large right pleural effusion. According to the authors, thoracic paravertebral block (TPB) provided excellent surgical conditions and postoperative pain control (6).

Whether there is an absolute limit of PaO_2 in arterial blood gas analysis for ATS is unclear. Piccioni and coworkers successfully performed ATS on a 61-year-old man with hypoxaemia, presenting with SaO_2 =93%, pH =7.46, PaO_2 =8.26 kPa (61.9 mmHg), and $PaCO_2$ =4.93 kPa (36.9 mmHg) on room air, and a predicted FEV_1 46% (6).

In another case by the same authors, arterial blood gas analysis on room air showed hypoxaemia and respiratory alkalosis: SaO_2 =88%; PaO_2 =6.39 kPa (47.9 mmHg), $PaCO_2$ =4.39 kPa (32.9 mmHg), and pH =7.51 (6). Pulmonary function tests of the patient revealed a forced vital capacity (FVC) 26% of the predicted value (6).

In order to remain within a margin of safety, it is paramount that patients with severe breathlessness (MMRS 4) have stable cardiovascular and respiratory parameters before ATS (7).

Phrenic nerve paralysis on the non-operated side should be viewed as a contraindication to ATS (7). Patients with suspected difficult intubation in general should not be considered for ATS (6), in case the need for intubation arises emergently during surgery. However, in one paper, a patient with severe breathlessness undergoing ATS had limited cervical mobility with no head extension. In the past, intubation was difficult but successful for cystoprostatectomy and ureterostomy (7). He had bilateral pulmonary metastases and was severely breathless before his planned ATS. Because his risk for ventilator dependency was high and the patient expressed fear of GA, and given that many terminally ill patients at that institution successfully underwent ATS under LA, the patient decided to avoid GA. Thoracoscopy for biopsy by keyhole surgery is a rapid procedure and can easily be done on an awake patient avoiding difficult weaning, ventilator dependency with postoperative complications, and a long hospital stay. In this case of a simple procedure where the benefit of ATS outweighs the risk of a difficult intubation, and considering the patient's wishes, ATS remained an option.

Difficulties in intubation can also be encountered in pregnant patients, yet many clinicians prefer the option of performing cesarean sections under epidural or spinal anesthesia. In a case described by Onodera *et al.*, a 31-year-old female patient in the 9th week of pregnancy underwent chest tube placement for spontaneous pneumothorax with thoracoscopy with local and epidural anaesthesia (33).

Not all patients are willing to tolerate being awake or having surgery with slight sedation. Patients with severe chronic respiratory disease and terminal illness might not want to undergo surgery or accept medical treatment at all. After thorough informed consent about anesthetic risks and options for thoracic surgery, patient refusal for GA also needs to be part of anesthetic decision making (7).

Nakanishi and coworkers raise the issue that surgical difficulties might contraindicate ATS or at least increase the risk of possible conversion to GA. For lobectomy and other major lung surgery, stripping of interlobular vessels and handling of incomplete fissures could be difficult despite inflation of the affected lung. Keeping in mind that bleeding from the pulmonary artery is extremely difficult to control in a limited working space, Nakanishi and coworkers advise that conversion to intubated GA should be performed without hesitation (35). In general, feasibility of ATS may not only depend on the comfort level of the anesthesiologist but also on the experience of the surgeon. This could be a reason for the relatively low number of patients recruited for ATS compared to thoracic surgery under GA, with reports from the literature varying from 8.6 patients per year (17) to 19.7 patients per year (38) at various institutions.

Spontaneous respiration and lung recruitment during ATS

During spontaneous respiration alveoli are opened by negative pleural pressure created by inspiratory muscle contraction (22). This is in contrast to GA with neuromuscular blockade of diaphragm and auxiliary inspiratory muscles, where alveoli are expanded by inflation of a tidal volume with positive pressure ventilation. In addition, during GA intra-abdominal organs push on the paralysed diaphragm, increasing atelectasis thereby reducing lung compliance, increasing pulmonary shunt and pulmonary vascular resistance, and leading to hypoxaemia with an increased possibility of lung injury (42) and delay in patient recovery (22). Therefore, maintaining diaphragmatic motion and creating a negative pleural pressure can decrease detrimental effects of abdominal pressure on the dependent lung.

The open pneumothorax created for the procedure results in a mediastinal shift and compression of the dependent lung and can make spontaneous breathing difficult. However, compensatory maintenance of diaphragmatic tone will tend to reduce the respiratory compromise (6). If necessary, treatment of atelectasis due to mediastinal shift includes application of non-invasive ventilation (NIV). NIV also reduces left ventricular after-load and thereby increases cardiac output.

Given the advantage of gas exchange by physiological expansion of alveoli by negative pleural pressure, even patients dependent on a home treatment with bilevel positive airway pressure (BiPAP) can successfully undergo ATS (7).

As long as patients are breathing spontaneously, they can receive light sedation with short-acting drugs such as propofol, remifentanil, or both with respect to their level of anxiety (7). Dexmedetomidine is another option for sedation.

During ATS, there is never complete lung collapse compared with conditions under GA. Given that patients are awake and breathing spontaneously, the classical lung re-expansion recruitment manoeuvre by manual balloon inflation cannot easily be applied because it is not well accepted by patients. However, at the end of surgery, lung re-expansion can be performed by progressive application of PEEP via NIV. In the absence of air leaks, NIV should also be continued in the recovery room in the immediate postoperative period to prevent atelectasis.

Application of NIV consequently reduces atelectasis, and post-operatively patients will show lower rates of nosocomial infections, decreased ICU and hospital lengths of stay, and decreased morbidity and mortality (43). Lung re-expansion should be monitored with physical examination of the lungs, chest X-rays, or lung ultrasound (44).

Concern is still warranted regarding ATS for patients with severe COPD and its impact on accessory muscles to maintain spontaneous ventilation, because respiratory muscle paralysis and changes in bronchial tone could be induced by regional anesthetic techniques. In a paper by Gruber and coworkers, thoracic epidurals were placed with 0.25% bupivacaine in patients with end-stage COPD undergoing lung volume reduction. The authors concluded that TEA with 0.25% bupivacaine did not adversely affect ventilatory mechanics, gas exchange and inspiratory muscle force (45).

Patient consent

The patient must be thoroughly informed about all possible outcomes of ATS, including the advantages and drawbacks of GA. The patient must be informed that in case of underlying severe chronic respiratory disease, general anaesthesia could lead to difficult or even impossible ventilator weaning.

The patient must understand that the decision to choose ATS is the first option but that conversion to general anaesthesia is always a possibility (6,7).

Premedication

Premedication can be handled in various ways, but it should not be done without the agreement and understanding of the patient, and only given when requested by the patient. Some patients refuse premedication because of underlying chronic respiratory disease and others request it to ease the stress and anxiety of the procedure. In one paper by Kiss and coworkers, three of nine patients did not want premedication (7).

Perioperative monitoring for ATS

Application of standard monitors includes electrocardiogram, pulse oximetry, non-invasive blood pressure measurement, measurement of respiratory rate, and capnography. End-tidal expiratory CO_2 ($EtCO_2$) can be measured with a detector attached to the oxygen mask or nasal cannula, or placed next to or inside one nostril. At least two IV lines should be secured, one for perioperative administration of fluids and another one for intraoperative medications.

It is important that the patient is able to talk throughout the surgery thereby allowing assessment of the patient's breathing, consciousness and comfort level.

Preparation for conversion to GA and emergency intubation

Given the possible pitfalls, caution must be taken with regard to performing ATS without sufficient experience. The critical issue to consider is how to convert ATS to GA if the thorax is still open.

In case of an emergency, quick conversion to GA has to be performed by an experienced and well-prepared team. Planning and coordination between surgeons, anesthesiologists and nursing staff are the keys to success.

Preoperatively, before positioning the patient on the operating table, an additional bed sheet must be positioned under the back of the patient to allow rapid change of positioning during emergency.

Operating room nurses should be reminded before the procedure to keep on stand-by a large surgical drape (example: IOBAN 56 cm × 45 cm incise drape, or a similar product like OPSITE). These drapes are transparent and can be used to cover the incised thorax rapidly in order to keep the wound sterile. Concerning VATS procedures, in a discussion with Professor E. Pompeo from Rome (Italy) one thick silk stitch can close a small VATS incision within a few seconds.

After rapid emergency wound covering with transparent drape by the surgeon, the anesthesiologist keeps the patient's head and neck stable while directing the team to turn the patient back to supine by pulling on the additional bed sheet which is positioned under the back of the patient. This maneuver allows a quick change from the lateral to the supine position while keeping the wound sterile, so that the anesthesiologist can intubate the patient's trachea.

The key to avoiding severe hypoxia is to foresee the problem in advance. The operating room team should practice disciplined coordination when turning the patient supine in order to facilitate immediate intubation and not waste time on surgical manoeuvres.

Quick induction of anesthesia should be performed using a fast acting neuromuscular relaxant such as succinylcholine or rocuronium which can be reversed with sugammadex. The later antagonist is not yet available in the US but is in use in many other countries.

Gonzalez-Rivas *et al.* recommend that in case intubation is necessary, the plan would be to insert a single-lumen endotracheal tube under the guidance of a bronchoscope, followed by insertion of a bronchial blocker without changing the patient's position. Gonzalez-Rivas and coworkers write, depending on the oxygenation status of the patient, that an expert and skilled anaesthesiologist could also achieve a double-lumen intubation in the lateral decubitus position (36). Macchiarini and coworkers even suggest nasotracheal tube intubation but this is debatable because nose bleeding may render further airway management difficult (19).

ATS can be performed in the lateral decubitus position; however, some centers alter the standard thoracotomy technique by performing procedures in a modified supine position. In case emergent intubation would be required, this position would more easily facilitate control of the airway (5).

Surgical and anesthetic reasons for conversion, and ways to avoid it

The risk for conversion depends on the patient's comorbidities as well as the difficulty of the surgery.

Patients must be intubated early when complications begin to emerge in order to reduce the risk of emergency intubation (36).

Reasons for conversions to GA can be due to the anesthesia or to the surgery. Anesthetic causes can include persistent hypoxemia, tachypnoea, poor pain control, and panic attacks (46).

The following lists of surgical difficulties might also trigger the decision to convert to GA: unsatisfactory lung collapse, extensive fibrous pleural adhesions, diffuse pleural adhesions, and bleeding (15,21,46). In an editorial, Nakanishi and coworkers stress that, especially in major lung surgeries, including lobectomy, it can be difficult to strip interlobal vessels and treat incomplete fissures despite lung inflation. The authors warned that bleeding from the pulmonary artery can be extremely difficult to control in a limited working space during ATS. Therefore, a prompt conversion to intubated GA should be performed without hesitation if such bleeding develops (35).

Swift conversion to intubated GA is also recommended in case of significant mediastinal movement and complex hilar dissection, as in cases of silicotic or tuberculous patients (36).

In the literature, conversion rates of an entire patient population undergoing ATS varied in general from 0% (7,47), up to 10% in a paper by Chen and coworkers, who also reported conversion for the subgroup of lobectomies as 13% (15,46).

In the light of elevated conversion rates for lobectomies, Nakanishi and coworkers conclude in an editorial that the safety of major surgery such as lobectomy performed under ATS still remains unclear (35).

Anesthetic complications during ATS

Complications can be classified as problems due to the regional and local anesthetic technique itself as well as respiratory, hemodynamic and neurological events.

During ATS with open pneumothorax, ventilation of the collapsed lung is impaired leading to some measure of hypoxemia, hypercapnia and acidosis, which can cause anxiety and panic attacks.

Except for patients with severe terminal chronic obstructive pulmonary disease tolerating only a low oxygen flow of up to 2 L/min, desaturation can be delayed or even prevented by application of a high-flow oxygen mask (O_2 15 L/min) (7). If O_2 Sat drops below 90%, NIV should immediately be applied to the spontaneously breathing patient to recruit the lungs. In addition, assisted mask ventilation can also correct hypercapnia (7). Patients at risk for perioperative hypercapnic coma may have a history of severe COPD with low FEV_1. Hypercapnic coma can also cause laryngeal oedema which can be treated with supplemental oxygen by facemask (19).

Sore throat leading to panic attack during surgery was once reported by Kiss *et al.* in 2014 in a patient who started to feel the surgeon manipulating inside the thorax. It turned out that xylocaine 1% instead of 2% was given in the TEA. To obtain a dense epidural block, not less than 2% of xylocaine must be administered through the thoracic epidural catheter (7).

Panic attacks can be reduced by reassurance and explanations in a calm surgical environment (5). In the case of VATS, the patient can be allowed to watch the operating video (48). If these steps are unsuccessful, moderate sedation can be given while maintaining spontaneous breathing (7,48).

Mean arterial blood pressure and systolic blood pressure should be kept above 65 and 90 mmHg, respectively. This can be achieved with fluids or vasopressors to compensate for the blood pressure decreases due to the vasodilatory effect of the local anaesthetic administered via epidural. In an observational study no patient required more vasopressors than usually given for the same type of surgery under GA combined with a thoracic epidural (7).

Arterial oxygenation during ATS

Sedation carries the risk of desaturation and atelectasis due to decreased muscle tone of the diaphragm and the intercostal and auxiliary inspiratory muscles. Use of noninvasive BiPAP ventilation via a facemask can help this situation (41). Given that efficient lung reexpansion is difficult or impossible during ATS; postoperative NIV should be performed in the absence of surgical contraindications to decrease postoperative atelectasis.

In one paper, no intraoperative deterioration in arterial oxygenation was observed under ATS with TEA (9). In 2011, Pompeo and coworkers described that perioperative $PaO_2/FiAO_2$ decreased significantly during ATS but remained satisfactory (>300 mmHg), with the intraoperative $PaCO_2$ increase returning to the baseline value 1 h postoperatively (P=0.20). They reported no increase in mortality (18).

Transient permissive hypercapnia during ATS

Transient perioperative permissive hypercapnia (<55 mmHg) has been described in several papers (7,9,18, 22) with no need of conversion to GA.

Dong and coworkers in 2010 studied 22 patients for VATS resection of pulmonary nodules using thoracic epidural and sedation and also local anesthetic block of the vagus nerve block placed intrathoracically to blunt the cough response. PCO_2 increased gradually after incision but returned to normal one hour after wound closure. They reported no hypoxemia (39).

Patients with a background of severe COPD or neuromuscular disease have higher risks for developing perioperative hypercapnia which in most cases can be successfully reversed with assisted ventilation (7). During longer lasting procedures, it is recommended to periodically re-expand the lungs with intermittent NIV in order to limit the risk of hypercapnia.

Coughing during ATS

During ATS, lung manipulation can trigger a cough reflex, which some surgeons want suppressed to improve surgical conditions.

Cough reflex can be minimized by the inhalation of aerosolized lidocaine (41) or application of a spray of lidocaine on the lung surface (16). Other alternatives include a stellate ganglion block (12) or a vagus nerve block placed intrathoracically (15,39). Administration of remifentanil can also help blunt the cough reflex. In order to prevent increased bronchial tone and airway hyper-reactivity, Gonzalez-Rivas and colleagues (36) advise avoidance of epidural anaesthesia-associated sympathetic blockade.

However, with the surgical advantage of suppressing the cough response comes the risk of aspiration and resultant respiratory tract infection. In one paper, surgeons described operating conditions of ATS as good as surgery with GA despite occasional short bouts of coughing (7).

Operative time

In a case series of nine patients, the average duration of ATS surgery under TEA was 76.3 min (SD 23.6 min, range: 46-128 min) (7) proving that epidural ATS can be sustained for surgery lasting for more than 2 hours in patients with severe but stable dyspnoea. In other papers, operating time is quoted as an average of 25.5 min (range: 23-33 min) to 50 min (range: 40-70 min) (9,17).

Postoperative complications of ATS

Patients who underwent ATS with thoracic epidural had faster recoveries and shorter hospital stays (4).

In a study by Liu and colleagues, the ATS group showed shorter hospital stays after bullae resection and lobectomy compared to the GA control group. Liu and colleagues also demonstrated that the rates of postoperative complications, including respiratory complications, were significantly lower in the ATS group than in the control group. In addition, there were no mortalities in either group (46).

Mortality and morbidity of ATS

Several papers conclude that mortality and morbidity up to 6 months for ATS were comparable with thoracic surgery under GA (38) or even lower with fewer postoperative respiratory complications, including pneumonia and acute respiratory distress syndrome (5,12,28).

Surgical results

Several studies conclude that compared to GA, there was no difference in the technical feasibility of ATS for thoracoscopic lobectomies (15), pleural biopsies, decortications (5,9) and wedge resections of lung nodules (4).

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Non-intubated anesthesia in thoracic surgery—technical issues

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Abstract: Performing awake thoracic surgery (ATS) is technically more challenging than thoracic surgery under general anesthesia (GA), but it can result in a greater benefit for the patient. Local wound infiltration and lidocaine administration in the pleural space can be considered for ATS. More invasive techniques are local wound infiltration with wound catheter insertion, thoracic wall blocks, selective intercostal nerve blockade, thoracic paravertebral blockade and thoracic epidural analgesia, offering the advantage of a catheter placement which can also be continued for postoperative analgesia.

Keywords: Awake thoracic surgery (ATS); awake video-assisted thoracoscopic surgery; thoracic epidural anesthesia (TEA); serratus anterior plane block; thoracic paravertebral blockade

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Authors' introduction:

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Figure 1 Dr. Gabor Kiss.

Introduction

Performing awake thoracic surgery (ATS) is technically more challenging than thoracic surgery under general anesthesia (GA), but it can result in a greater benefit for the patient due to avoidance of complications of intubation and prolonged mechanical ventilation, while providing better hemodynamics (1-10) and possibly superior postoperative analgesia.

The absence of GA and its side effects may explain faster postoperative recovery, lower complication rates, reduced stress hormones, and comparable or even reduced morbidity and mortality with comparable surgical results as opposed

Figure 2 Dr. Maria Castillo.

to GA (1,7,11-16).

However, thorough preparation of the patient is an essential part of the anesthetic management and must come before considering the local or regional anesthetic technique. The medical team must know the typical anesthetic complications which could arise during ATS and how to avoid them, and be prepared for conversion to GA and emergency intubation at any time during surgery.

Strict coordination and vigilance are the keys to successful patient management for ATS.

Comparison of each regional anesthesia technique for ATS

The following local and regional anesthetic techniques can be considered for ATS: local wound infiltration (with or without wound catheter insertion), serratus anterior plane (SAP) block, selective intercostal nerve blockade, thoracic paravertebral blockade (PVB) with or without catheter placement, thoracic epidural analgesia (TEA) and lidocaine administration in the pleural space.

Awake video-assisted thoracoscopic surgery has been performed with intercostal blocks and lidocaine infiltration only at the incision site (17-20). Local or wound infiltration proved to be safe but duration of action was limited and depended on the pharmacodynamics of the local anaesthetic agent used (21).

Local anesthesia can also be combined with thoracic epidural anesthesia (TEA) as reported by Mukaida and colleagues for patients with secondary hemothorax undergoing VATS (22).

Administration of lidocaine into the pleural space was used as an anesthetic technique in 34 patients with spontaneous pneumothoraces undergoing awake VATS by Nezu and coworkers (23).

More invasive techniques are SAP block, intercostal nerve blockade, thoracic PVB and TEA, offering the advantage of a catheter placement which can also be continued for postoperative analgesia.

The local anesthesia technique described by Diego Gonzalez-Rivas and coworkers

Single-port thoracoscopic lobectomy in a nonintubated patient was described by Gonzalez-Rivas and coworkers as a technique to reduce surgical access trauma more than in a standard VATS surgical approach. The authors emphasize that with the single-incision VATS technique in a nonintubated patient there is no need for epidural or vagus blockade and no lidocaine spray was used on the surface of the lung.

Thirty minutes before anaesthesia before anesthesia, the patient received intramuscular midazolam and atropine. No epidural catheter, no central venous catheter and no urinary catheter were placed. A laryngeal mask was used to control the airway and for inhalation of oxygen and sevoflurane. A continued target-controlled infusion of remifentanil was administered in order to achieve sedation under spontaneous respiration and avoid excessive patient hyper-reactivity, apnoea or carbon dioxide retention.

Only one intercostal space is opened which explains why the use of local anaesthesia and blockade of a single intercostal space is sufficient for pain control at the beginning and during the surgery. The intercostal space was infiltrated with 5 mL of levobupivacaine (5 mg/mL) which is a long-acting anesthetic agent. Using VATS approach through a single 2.5-cm incision, middle lobectomy and lymph node dissection was completed. Gonzalez-Rivas and coworkers use no trocar and try to avoid pressure on the intercostal nerve during instrumentation in order to reduce the risk of intercostal bundle injury (24,25). With this technique, the total surgical time was 80 min. Postoperatively, the chest tube was removed within the next 16 h and the patient was discharged from hospital after 36 h.

The local anesthetic technique by Hung *et al.*

This is similar to the approach of Gonzalez-Rivas and coworkers and was recently published as a series of cases using only infiltration of several intercostal spaces (from T3 to T8) instead of using an epidural catheter (26).

Thoracic paravertebral anaesthesia for awake video-assisted thoracoscopic surgery

According to a meta-analysis by Davies RG and coworkers, thoracic PVB and epidural analgesia provide comparable pain relief after thoracic surgery. However, PVB has a better side-effect profile (27).

PVB offers the advantage of a unilateral block without bilateral sympathectomy, and a lower incidence of hypotension, urinary retention, and pulmonary complications. PVB can be useful if thoracic anesthesia is contraindicated as in cases of sepsis, coagulation disorders, neurological disorders, or difficult vertebral anatomy where epidural is difficult to perform (28).

Compared to TEA, PVB is relatively easy to learn (28,29). It can be performed using the commonly practiced loss of resistance technique (28), with the assistance of ultrasound (30) or using a nerve simulator (31).

The first description of the use of thoracic PVB as the sole anesthetic for video-assisted thoracoscopy was presented in a paper by Piccioni et al. They described two cases where patients had ATS with PVB without sedation (28). They explained their technique as follows: the patient is in the sitting position. The superior aspects of spinous processes of T3–T6 were marked and after skin anaesthesia with a total of 7 mL lidocaine 1%, needle insertions was performed 2.5 cm laterally to the superior aspects of spinous processes of T3–T6 using a 70-mm, 22-G insulated stimulating needle and peripheral nerve stimulator. The needle was directed to the transverse process, then 'walked' cranially and advanced 1.5-2 cm with the nerve stimulator current set at 2.5 mA (0.3 ms duration and 1 Hz) until the intercostal muscle or sensitive response could still be obtained with a current of 0.5 mA. After aspiration, they administered in one patient 5 mL ropivacaine 1% per segment at four segments and in another patient 4 mL ropivacaine 0.75% at six levels. In general, their blocks took 10-15 min to perform. In both patients the onset of sensory loss to pinprick occurred approximately 15 min after injections and there were no signs of bilateral blockade.

In the operating room patients were placed in the lateral position for surgery and supplemental oxygen was administered at 10 L per minute (28).

A potential complication of thoracic PVB is pneumothorax, however, the incidence is low at 0.5% (32,33). In addition, this is less of a problem if thoracoscopy or thoracotomy with chest tube placement is planned.

Piccioni and coworkers conclude that the use of thoracic PVB as the sole anaesthetic for video-assisted thoracoscopy resulted in adequate unilateral anaesthesia, stable hemodynamics with no complications, and a high level of patient satisfaction (28).

Epidural anesthesia

Complications of epidural anaesthesia include dural puncture, neurological injury and paraplegia. Therefore, PVB is an effective alternative with fewer contra-indications (28). However, if longer duration of surgery should be expected, a thoracic epidural should be the first choice for ATS. In addition, as with the PVB, TEA has the advantage of providing postoperative pain relief for a longer period with boluses or a continuous infusion of local anesthetics compared to an analgesic technique with a single injection. In one paper, TEA provided pain-free surgery for a total operation time of 219 min (5).

Puncture level of the epidural block depends on the surgical incision site but is usually between T3 and T7 and should be discussed with the surgeons. The volume of local anesthesia is titrated to achieve somatosensory anaesthesia between T2 to T12, but depends on the size of the incision and varies with the patient's size and weight.

The choice of the molecule for local anesthesia depends on whether the onset of the TEA block should be rapid, which can be achieved with lidocaine 20 mg/mL. In contrast, ropivacaine 7.5 mg/mL has a slow onset but a much longer half-life. Low concentration LA solutions run the risk that the sensory block is less dense than required and that the patient might feel intrathoracic surgical manipulation, eventually leading to pain or panic attacks (5). In contrast, highly concentrated anesthetics could lead to a motor block of the intercostal muscle and thereby decrease tidal volume. However, as described in a paper by Gruber and coworkers, 0.25% bupivacaine administered in a TEA did not adversely affect ventilatory mechanics and gas exchange and was well tolerated even in severe COPD patients (34).

It is necessary to test the epidural analgesic block either with ice cubes or with a maximal painful tetanic stimulus which can be produced by a neurostimulator before the operation, and surgery should only be allowed once the skin area defined for surgical incision is completely anaesthetized.

Epidural anesthesia can have vasodilatory effects leading to hypotension. Therefore, when mean arterial pressure (MAP) falls below 65 mmHg and/or systolic arterial pressure below 90 mmHg, fluid administration should be started with or without vasoactive drugs. In paper with nine cases for ATS under TEA, phenylephrine or ephedrine was used in 50% of cases to maintain MAP above 65 mmHg and systolic arterial pressure above 90 mmHg (5). Norepinephrine can be used if phenylephrine requirements become elevated.

Serratus anterior plane block

Ultrasound-guided SAP block was first described by Blanco and coworkers in healthy volunteers who obtained an effective block from T2 to T9 lasting 750-840 min by blocking lateral branches of inter-costal nerves (21).

Based on the paper of Dr. Blanco and coworkers, Kunhabdulla NP and coworkers described SAP block with ultrasound guidance in patients with multiple rib fractures. SAP block was followed by catheter insertion for continuous infusion of local anesthetic (35). The authors describe this technique as follows:

The serratus anterior muscle was localized with a high frequency ultrasound probe positioned over the fifth rib in the posterior axillary line in vertical axis and then aligned along the long axis of the rib. The skin was anesthetized with 1% lignocaine and an 18 G Touhy needle was introduced on the surface of the rib under the serratus anterior muscle between the posterior and mid-axillary line. In order to confirm the position of the needle tip, hydro dissection was done with 3 mL of saline and this was followed by an injection of 20 mL of 0.125% bupivacaine. Then a 20 G epidural catheter was advanced through the epidural needle to a depth of 4 cm beyond the needle tip and tunneled subcutaneously to prevent displacement.

Postoperatively, Kunhabdulla and coworkers started a continuous infusion of 0.0625% bupivacaine with 1 mg/mL of fentanyl at 7 mL/h after 4 h (35).

Some clinicians avoid adding opioids in the continous infusion of local anesthetics because of fear of respiratory depression related to obstructive sleep apnea (36).

Supplemental and multimodal analgesia

At the end of surgery, additional analgesics should be given intravenously such as acetaminophen, paracetamol, or tramadol. In case the local anesthetic technique for ATS did not provide full analgesia, ketamine, NSAIDS and opioids can be supplemented depending on the comorbidities of the patient.

When ATS is performed with TEA, use of the epidural can be continued postoperatively as patient-controlled epidural analgesia (5).

Sedation during ATS

The use of short acting agents such as remifentanil administered by total intravenous anesthesia (TIVA) should be the first choice. The advantage of remifentanil is that it has an ultra-short context-sensitive half-time of 3 min. In addition, in case of apnea leading to rapid desaturation, remifentanil can be antagonized by naloxone.

Propofol TIVA can be titrated to the desired sedation level without compromising spontaneous respiration and airway responses. It can be given alone or in conjunction with remifentanil. In several papers, target controlled infusions (TCI) of propofol, TCI remifentanil, and combinations of both have been utilized as a light sedation, resulting in the patients being less anxious yet still remaining responsive during surgery (5).

Titrating levels of propofol plasma concentration can vary from one patient to another and also depends on the experience of the anesthesiologist. Therefore, it is difficult to make a recommendation for plasma concentration to obtain anxiolysis while keeping the patient spontaneously breathing during ATS. In an observational study, the range of propofol TCI plasma concentration in six patients was 0.5-2 μg/mL (Shneider) and remifentanil plasma concentration 0.5-3 ng/mL (Minto) including one patient who had remifentanil only. There was no significant impact on oxygen saturation (5).

Care must be taken in patients with severe COPD where sedation could contribute to or accentuate hypercapnia. If sedation is unavoidable in these patients, ketamine should be used preferentially as it is the only anesthetic that maintains functional residual capacity by preserving inspiratory muscle tone (37).

Finally, dexmedetomidine, an α2-adrenoceptor agonist, also could remain an option for sedation during ATS. It has been approved in the US for perioperative sedation in anesthesia but it has not yet been officially licensed for this use in Europe where its indication is limited to sedation in the Intensive Care Unit. Perioperatively, it decreases sympathetic, neuroendocrine, hemodynamic responses and also anesthetic and opioid requirements during surgery. It preserves respiratory and psychomotoric functions. Side effects consist of moderate cardiovascular depression, with decreases in blood pressure and heart rate (38,39).

Conclusions

Literature has shown that following local and regional anesthetic techniques can effectively be applied for ATS: local wound infiltration, SAP block, selective intercostal nerve blockade, PVB, TEA and lidocaine administration in the pleural space.

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Effects on respiration of nonintubated anesthesia in thoracoscopic surgery under spontaneous ventilation

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Abstract: Thoracoscopic surgery without tracheal intubation [nonintubated video-assisted thoracoscopic surgery (VATS)] is an emerging treatment modality for a wide variety of thoracic procedures. By surgically induced open pneumothorax, the operated lung collapse progressively while the dependent lung is responsible for sufficiency of respiratory function, including oxygenation and ventilation. Encouraging results showed that ventilatory changes and oxygenation could be adequately maintained in major lung resection surgery and in patients with impaired respiratory function. In spite of a relative hypoventilation, mild hypercapnia is inevitable but clinically well tolerated. An understanding the respiratory physiology during surgical pneumothorax, either in awake or sedative status, and an established protocol for conversion into tracheal intubation are essential for patient safety during nonintubated VATS.

Keywords: Thoracoscopy/video-assisted thoracoscopic surgery (VATS); surgical pneumothorax; tracheal intubation; ventilation; oxygenation

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Authors' introduction:

Professor Chen (middle right) and Professor Cheng (middle left) lead the nonintubated thoracoscopic surgery program in National Taiwan University Hospital since 2009 with core team members, Dr. Hsu (left) and Dr. Hung (right) (*Figure 1*).

Figure 1 From left to right: Dr. Hsu, Prof. Cheng, Prof. Chen and Dr. Hung.

Introduction

With advancements of one-lung isolation devices and safer one-lung ventilation (OLV) strategies, thoracic surgery evolves progressively in the past decades while intubated general anesthesia with OLV is regarded as a gold standard (1). However, in a modern era of minimally invasive surgery using a video-assisted thoracoscopic surgery (VATS) approach, a renaissance of thoracic surgery without tracheal intubation (i.e., nonintubated) is increasingly re-evaluated in the past decade in efforts to achieve a smoother perioperative course and to offer an opportunity for surgical treatment in patients, for whom an intubated general anesthesia carry high risks (2,3). Encouragingly, nonintubated thoracoscopic procedures have been reported to be feasible and safe for a variety of thoracic diseases, including lung parenchyma resections for lung tumors (4-15) or interstitial lung disease (16), bullaplasty for pneumothorax (17-20), lung volume reduction surgery for emphysema (21-26), decortication for empyema thoracis (27), and mediastinal tumor excisions (28-30).

Nonintubated thoracoscopic procedures are distinct from conventional intubated general anesthesia, by which patients breathe spontaneously under regional anesthesia techniques with or without conscious sedation (31). While tracheal intubation and lung isolation devices are not necessary, neuromuscular blocking drugs and mechanical ventilator are avoided. Aforementioned avoidance of potential adverse effects of intubated general anesthesia may be translated to offer a more physiological, immunological and neuromuscular recovery after surgery, possibly reduce morbidities and therefore shorten length of hospital stay (32-36).

However, creating a surgical pneumothorax in spontaneously breathing patients is not risk free (37). Patients' oxygenation and ventilation can be impaired because of a loss of lung volume. Therefore, a thorough understanding of pathophysiology of surgical pneumothorax on oxygenation and ventilation is essential to maintain the physiological changes during nonintubated thoracic surgery (36-38). The aim of this review is to look into the factors related to perioperative oxygenation and ventilation during nonintubated thoracic procedures, including surgical pneumothorax, spontaneous breathing, lateral decubitus position, and effects of sedative and analgesic agents on respiratory physiology. Differences in specific patient groups and safety issues related to these physiologic changes are also discussed.

Factors related to oxygenation and ventilation in respiratory physiology

The course of respiration starts with fresh gas enters the lungs with certain rate and volume. The oxygen within fresh gas reaching terminal alveoli diffuses through the alveolar membrane to re-oxygenate the systemic venous blood (i.e., oxygenation). Meanwhile, carbon dioxide contained in systemic venous blood reversely diffuses into alveoli to be exhaled out of body (i.e., ventilation). The fundamental rule of oxygenation and ventilation is the diffusion capacity of an intact alveolar-capillary membrane, where oxygen and carbon dioxide are diffused due to differences of partial pressures of oxygen or carbon dioxide between systemic venous blood and alveoli. To maintain the best of oxygenation, the pulmonary blood flow (Q) and pulmonary ventilation (V) should be matched accordingly. Therefore, any V/Q mismatch can jeopardize pulmonary oxygenation, including low cardiac output, pulmonary thromboembolism, and lung atelectasis or sputum impaction. On the other hand, hypoventilation (a decrease of minute ventilation, which is the product of respiratory rate and tidal volume) can attenuate the elimination of alveolar carbon dioxide, and cause hypercapnia (38,39).

Factors involved in nonintubated VATS

An ideal environment for nonintubated VATS is to create an iatrogenic pneumothorax, a subsequently collapsed lung for adequate surgical exposure. Meanwhile, patients should be maintained in pain-free, stress-free, and effort-less spontaneous ventilation (31,35). To achieve such environment, different regional anesthesia protocols have been applied in nonintubated VATS, including local infiltration (40), intercostal blockades (11), and thoracic epidural anesthesia (34-36). For lengthy procedures such as a lobectomy or a segmentectomy, conscious sedation is usually required due to emotional stress or procedure-related discomfort (6-11).

Factors affecting perioperative oxygenation and ventilation in nonintubated VATS fall into the following categories: surgical pneumothorax, spontaneous breathing, lateral decubitus position, and sedative/analgesic techniques.

Surgical pneumothorax

Surgical pneumothorax starts with the first incision for entry of thoracoscope in the operating hemithorax. By introducing atmospheric pressure into the nondependent pleural cavity, the operated lung collapsed consequently to expose the surgical space (37). Several changes can occur during this process.

Decrease of lung volume

Loss of negative pressure in pleural cavity after surgical pneumothorax causes not only a progressive collapse of the operated lung, but also a decrease of non-operated lung volume because of downward compression of mediastinal tissues by gravity (41). A decrease of total lung volume may lead to hypoventilation.

Decrease of pulmonary perfusion

Surgical pneumothorax can impair the caval blood return because of atmospheric pressure. A decrease of caval venous return leads to low cardiac output and low pulmonary perfusion. However, systemic and pulmonary pressure is usually maintained, probably compensated by an increase of pulmonary vascular resistance from collapsed operated lung and by an intact intrinsic baroreceptor mechanism for a decreasing cardiac output (42). The overall effects of cardiovascular responses to a surgical pneumothorax may therefore be 2-dimensional. An increasing pulmonary vascular resistance of the operated collapsed lung may divert pulmonary blood flow to the dependent lung and improve oxygenation. On the other hand, a decrease of cardiac output may decrease oxygen carrying capacity, resulting low mixed venous oxygen saturation and worsening oxygenation (38,42). It is important to note that use of thoracic epidural anesthesia or sedative drugs may attenuate these intrinsic compensatory mechanisms and should be carefully titrated if adopted (31).

Spontaneous breathing

Preserve of functional residual capacity (FRC) of dependent lung

During conventional intubated general anesthesia, cephalic displacement of diaphragm causes a significant decrease of FRC. Mechanical ventilation with positive end-expiratory pressure is usually required to maintained sufficient ventilation and to avoid of atelectasis of dependent lung. In nonintubated VATS, the patients breathe spontaneously and their diaphragm function and the FRC of dependent lung are less interfered (43,44).

Rebreathing of carbon dioxide and hypercapnia

Without one-lung separation, breathing gases may communicate freely between dependent and nondependent lung during surgical pneumothorax, a phenomenon called "carbon dioxide rebreathing" which leads to hypercapnia (37). While mild to moderate hypercapnia can stimulate the respiratory drive by an increase of breathing rate, use of respiratory depressant agents, such as opioids or sedatives, can aggravate the ventilation and even jeopardize the oxygenation. However, evidences have shown that the degrees of hypoventilation are not clinically significant. The nonintubated VATS procedures are well tolerated by most of patients using a facemask or a nasal cannula to provide supplemental oxygen. In the meanwhile, accumulation of carbon dioxide is usually within the range of "permissive hypercapnia", which is obviously not harmful perioperatively (2,9,23).

Lateral decubitus position

Mostly, thoracic procedures are performed in a lateral decubitus position, which is usually associated with preferential distribution of breathing gases and pulmonary blood flow in the dependent lung because of pulmonary compliance and gravity. During OLV, these preferential distributions contribute to better matching of ventilation and perfusion, leading to a better oxygenation (41,43).

Effects of intravenous or inhaled anesthetics on oxygenation and ventilation

Nonintubated VATS can be performed in fully awake or moderate-to-deep sedative patients (31,35,37). While awake technique offers neurocognitive monitoring and possibility of cooperation from patients to control their respiratory efforts, various depths of sedation are usually required in anxious patients or lengthy procedures. Both intravenous anesthetics (e.g., propofol, midazolam) and inhaled anesthetics through laryngeal airway masks had been reported with successful results (11-13,34-36). Supplemental oxygen through masks is sufficient to maintain satisfactory oxygen saturation in a relative hypoventilation status. However, it is important to note that both intravenous and inhaled anesthetics induce a decrease in FRC and can be respiratory suppressants (44). Careful titration of sedative depths and monitoring of respiratory rate and exhaled partial pressure of carbon dioxide, such as bi-spectral index monitoring and end-tidal capnography, are important to prevent excessive hypoventilation (*Figure 2*) (31).

Effects of regional anesthesia techniques on oxygenation and ventilation

Regional anesthesia had been long reported to be an effective adjuvant to general anesthesia in thoracic surgery. Various approaches, including thoracic epidural anesthesia/analgesia, paravertebral block, intercostal nerve blocks and local wound infiltration, are reported to be effective for analgesia covering chest cage and parietal pleura (45,46). In nonintubated VATS, an effective regional anesthesia to block the unpleasant and painful sensation throughout the surgical wounds are important to prevent patients from emotional irritation, body movement and unfavorable tachypnea after surgical pneumothorax (31). However, the manipulation of lung and traction of hilar structures can cause irritation over visceral pleura, leading to a coughing response and jeopardizing the surgical manipulations (31,36). While visceral afferent transmissions are not blocked

Figure 2 An overview of anesthetic monitorings of patients undergoing sedative and nonintubated thoracoscopic surgery with spontaneous breathing. The sedation level is monitored by an electroencephalography-based bispectral index. End-tidal carbon dioxide and respiratory rate are obtained via a non-invasive capnography connected to a detector in one nostril.

by thoracic epidural anesthesia or intercostal blocks, we add intrathoracic vagal blocks to inhibit the visceral irritations and to minimize unwanted cough responses during nonintubated VATS (*Figure 3*) (6,11,34).

Applying thoracic epidural anesthesia can induce certain degree of motor blockade of respiratory muscles in the thoracic cage, which can lead to around 10% decreases of lung volume, including vital capacity, FRC, forced vital capacity and forced expiratory volume (47,48). Nonetheless, sparing the phrenic nerves, originating for C3-C5 cervical nerve roots, to preserve the diaphragmatic function assures sufficient ventilation despite intercostal muscle paralysis (49). Thoracic epidural anesthesia also induces peripheral vasodilation and functional hypovolemia due to sympathetic blockade (50). On the contrary, intercostal blocks are an effective alternative in place of thoracic epidural anesthesia, which is time-consuming, skill-demanding and requiring more vigilance against potential neurological and cardiorespiratory complications (11).

Oxygenation and ventilation in specific patient groups

Specific patient groups are chosen to elaborate the intraoperative oxygenation and ventilation during nonintubated VATS, including lobectomy for lung cancer patients and a variety of nonintubated VATS procedures for high-risk patients.

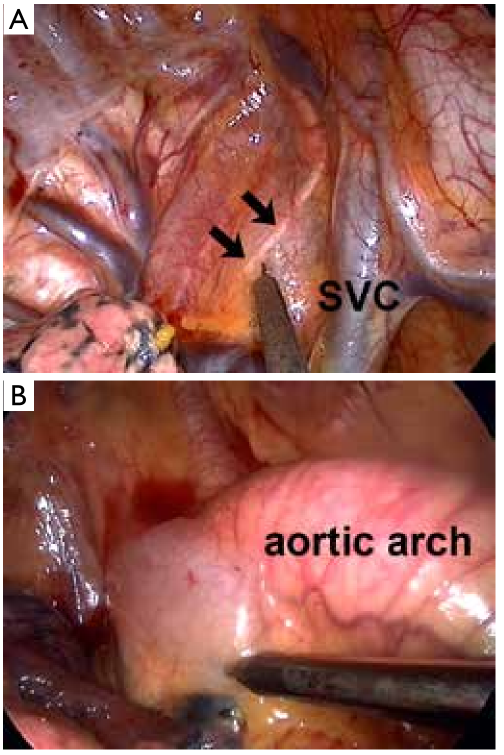

Figure 3 Intrathoracic vagal blocks can be induced under thoracoscopic visions. (A) For right-sided procedures, the vagus nerve (arrows) runs between the SVC and the lower trachea and can be easily identified; (B) for left-sided procedures, the vagus nerve runs in the aortopulmonary window, but no always clearly seen on the video. SVC, superior vena cava.

Lobectomy for lung cancer patients

In our program, we devote to less invasive surgical and anesthetic management for lung cancer patients (51). Lobectomy through VATS approach is currently the standard treatment for early lung cancer (52). In the past five years, we had performed 238 cases of nonintubated VATS lobectomy, in whom thoracic epidural anesthesia was used in 130 patients and thoracoscope-assisted intercostal blocks in 108 patients. We preferred to sedate our patients to induce a relative hypoventilation using incremental opioid and to attenuate cough reflex effectively through intrathoracic vagal blocks (11,31). Our patients underwent nonintubated VATS were mostly female (71%) with short-stature (mean body weight index: 22.9 kg/m^2) and normal lung function (forced expiratory volume in 1 second: 111.7% of predicted). During OLV after surgical pneumothorax, the mean partial pressure of oxygen (PaO_2) was 140.4 mmHg while the mean partial pressure of carbon dioxide was 47.7 mmHg. Although there were 20 patients (8.8%) experienced oxygen desaturation below 90% sometime, simple oxygen supplement through facemasks were sufficient to correct their transient arterial desaturation, except in one patients requiring conversion to tracheal intubation because of persistent low oxygen saturation below 80%.

Nonintubated VATS procedures in high-risk patients

One of the major advantages of nonintubated VATS is to offer surgical opportunities for patients who are too risky for an intubated general anesthesia (19,36,53). Although appealing, sufficiency of respiratory status during surgical pneumothorax is highly concerned, especially in patients with compromised pulmonary functions. To address these issues, Drs. Mineo and Pompeo from Awake Thoracic Surgery Study Group had performed a series of compromised patients for different nonintubated VATS procedures, including pleurodesis for malignant pleural effusion (54), decortication for empyema thoracis (27), thoracoscopic biopsy for pulmonary interstitial disease (16) and lung volume reduction surgery for severe emphysema (23-26). Reported results were also satisfactory that oxygenation could be easily maintained during surgical pneumothorax when patients were kept awake. Asymptomatic hypercapnia were usually noted in patients with severe emphysema but resolved after procedures (23).

Safety issues regarding nonintubated VATS

Coughing

Coughing is a protective reflex against entry of foreign bodies into the tracheobronchial airway. It is usually abolished in an intubated general anesthesia because of neuromuscular blockade. However, it can be triggered from excessive stretch of lung parenchyma or hilar manipulation of bronchial structure during a nonintubated VATS (36). Unexpected coughing during nonintubated thoracic procedures not only impedes the surgical exposure, but also potentially causes life-threatening injuries to intra-thoracic structures (6). In unexpected or intractable cough cases, a conversion to intubated general anesthesia may be required. Therefore, it is mostly advised to manipulate the lung parenchyma and hilar structures gently to avoid of cough reflex during nonintubated VATS, but it is usually inevitable in major and lengthy procedures such as nonintubated lobectomy or segmentectomy (10,26). Methods have been proposed using aerosol lidocaine inhalation (53), stellate ganglion block (55) and intrathoracic vagal nerve block (11,34) to attenuate coughing reflex during nonintubated VATS.

In our experiences, we prefer vagal nerve block to inhibit cough reflex, where infiltration of local anesthetics can be produced at the level of the lower tracheal for right-sided operations and at the level of aortopulmonary window for left-sided operations (*Figure 3*) (11,31,51). The duration of vagal blockade can last more than 3 hours. Repeat dose can be given in prolonged operations. In most cases, the effect of vagal block has worn off after non-intubated VATS. Occasionally, patients undergoing short operations may experience hoarseness in the recovery area, which may suggest residual vagal blockade. It is noteworthy that patients with residual vagal blockade are not recovered sufficiently to protect themselves from aspiration. Oral consumption should therefore be delayed until cough reflex is fully recovered (31).

Conversion to conventional intubated general anesthesia

A thorough plan B for conversion to an intubated general anesthesia should always be prepared in advance for the safety practice of nonintubated VATS (2). Despite of careful patient selection and vigilant monitoring, intraoperative conversion to tracheal intubation is occasionally inevitable, mostly resulting from significant mediastinal movement, persistent hypoxemia, unexpected dense pleural adhesions, and significant bleeding due to vascular injury, or insufficient anesthesia/analgesia (6-11,51). Intraoperative conversion to tracheal intubation in a lateral decubitus position can be a technical challenge to anesthesiologists. While direct laryngoscopy for intubation is feasible, a video-assisted laryngoscope, fiberoptic bronchoscope, or intubating laryngeal mask airway may be more convenient instruments for tracheal intubation in lateral decubitus position. Lung separation can then be achieved using an endobronchial blocker to occlude the operated lung. Otherwise, the patients can also be replaced in a supine position for tracheal intubation in usual manners at the discretion of the caring anesthesiologist (31).

In our practices, when conversion to tracheal intubation is indicated as aforementioned situations occur, the surgical wounds would first be sealed with transparent waterproof dressings after insertion of a chest tube to re-expand the operated lung. Meanwhile, a single lumen tracheal tube will be inserted under the guidance of fiberoptic bronchoscope, followed by insertion of a bronchial blocker without changing the patient's position. Collaboration between surgeon and anesthesiologist is essential for nonintubated VATS, especially in situations of tracheal conversion (11,51).

Conclusions

It is still early to conclude the roles of nonintubated techniques in thoracic surgery. However, encouraging and initial results have broadened our knowledge and experiences in various nonintubated VATS procedures and in a wide variety of patients groups. Hypoventilation during surgical pneumothorax is inevitable, but oxygenation and ventilation during nonintubated VATS are manageable and clinically tolerable. Even so, an understanding of respiratory changes during surgical pneumothorax and a well-prepared conversion protocol are essential to guarantee perioperative safety, especially in sedative patients.

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Nonintubated anesthesia for thoracic surgery

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Abstract: Nonintubated thoracic surgery has been used in procedures including pleura, lungs and mediastinum. Appropriate anesthesia techniques with or without sedation allow thoracic surgery patients to avoid the potential risks of intubated general anesthesia, particularly for the high-risk patients. However, nonintubated anesthesia for thoracic surgery has some benefits as well as problems. In this review, the background, indication, perioperative anesthetic consideration and management, and advantages and disadvantages are discussed and summarized.

Keywords: Thoracic surgery; nonintubated anesthesia; epidural block; anesthesia technique

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In recent years, with the techniques and managements of thoracic surgery increasingly improved, better lung separation and hypoxemia treatment as well as widely-used lung protective strategy have obtained proud achievement (1-3). On the other hand, to fit in with the needs of the fast track and enhanced recovery after surgery, nonintubated anesthesia for thoracic surgery has been intensively researched, reported and advocated (4-8).

Background

There are a lot of studies showing that nonintubated anesthesia for thoracic surgery is superior to the conventional general anesthesia in patients' outcomes. Nevertheless, some patients who are supposed to under nonintubated anesthesia still need intubated during the thoracic surgery (9). In 2004, Pompeo and his coworkers evaluated the feasibility of awake thoracoscopic resection of solitary pulmonary nodules in 30 patients under sole thoracic epidural anesthesia. Comparing to patients with intubated general anesthesia, their results showed that awake technique was safely feasible with better patient satisfaction, less nursing care and shorter in-hospital stay. However, it is important to note that two of the patients in the awake group were converted to intubated general anesthesia because of lung cancer requiring lobectomy via thoracotomy approach (10-12). Therefore, anesthesiologists should emphasize and balance the indication, contradiction, advantages, disadvantages, risks and benefits of nonintubated anesthesia for thoracic surgery, in order to choose better way to perform the anesthesia safely.

Indication

According to recent evidence and experience, several thoracic surgery procedures have been proved suitable for nonintubated anesthesia, such as pleural/pericardial effusion, empyema thoracis, bullous emphysema, non-resectional lung volume reduction surgery, spontaneous pneumothorax, biopsy of interstitial lung disease, wedge resection of lung nodules, segmentectomy and lobectomy for lung cancer, mediastinal biopsy and tumor excision (6,13-22).

The patients under nonintubated anesthesia should have well-evaluation and well-preparation without contraindications and should not reject to receive it. It is worth noting that Wu and colleagues had evaluated the feasibility of geriatric patients (age ranging from 65 to 87) undergoing lobectomy, which showed comparable safety profile with control group. This study opened up the possibility of nonintubated video-assisted thoracoscopic surgery (VATS) on the old age group (23).

Contraindication

The general patients exclusion criteria includes American Society of Anesthesiologists (ASA) physical status 4 and higher, bleeding disorders, sleep apnea, unfavorable airway or spinal anatomy, strict contralateral lung isolation, clinically significant sputum production, bronchiectasis, asthma, extreme of body mass index (BMI), preoperative decompensated heart disease, severe pleural adhesion over targeted hemithorax, and noncompliance to the procedure or patient refusal (6,24).

The implement of anesthesia

Nonintubated anesthesia for thoracic surgery refers to the operation performed under regional anesthetic techniques in spontaneously breathing patients, with or without conscious sedation. Conscious sedation is safe and effective for patients using sedative or dissociative agents such as propofol, midazolam, with or without analgesics such as fentanyl to keep patient tolerate unpleasant procedures while maintaining cardiorespiratory function. That is an induced depressed level of consciousness in which a patient retains the ability to independently and continuously maintain an open airway and a regular breathing pattern, and to respond appropriately and rationally to physical stimulation and verbal commands.

Psychological preparation

Preoperative communication for reassuring the patients, intraoperative coaching, mental support, verbal communication with medical personnel, and comfortable environment with low-volume music might all contribute to calm the patients down with acceptable respiration (25,26).

Monitoring

Standard monitoring with pulse oximeter, electrocardiogram, sphygmomanometer, and end-tidal CO_2 should always be in place. In addition, invasive arterial pressure monitor is often set for its versatility on monitoring arterial blood gas, real-time hemodynamic index, and fluid status inclination. For the occasion in which sedation is part of the planning, bispectral index (BIS) is highly recommended for evaluation of sedation level and advanced judgment of the anesthesia/sedation depth.

Anesthesia techniques

The anesthetic techniques consist of local anesthesia, intercostal nerve blocks, paravertebral blocks, thoracic epidural anesthesia, and spontaneous breathing anesthesia with laryngeal mask airway (LMA). Intravenous narcotics and conscious sedation are often combined with the techniques as above. After intravenous administration of fentanyl 25 to 50 mcg, target controlled infusion of propofol and/or remifentanil is started, aiming for BIS over 50 to 70 (24). Among them, thoracic epidural anesthesia is the most popular and can be enough.

Thoracic epidural anesthesia

The use of thoracic epidural anesthesia in awake thoracic surgery was first proposed in 1950 by Buckingham *et al.* (27,28). Recent studies have reported that thoracic surgery under epidural anesthesia can be easily and safely carried out with less charges and hospital-stay (10,24,29,30). However, it is a novel field to explore and investigate the benefits, risks and disadvantages of thoracic epidural anesthesia in nonintubated thoracic surgery, although the technique has been used in other surgeries for many decades.

Thoracic paravertebral block

Paravertebral block is an alternative technique that may offer a comparable analgesic effect and a better side-effect profile, which is associated with a reduction in pulmonary complications (31). Komatsu *et al.* found that paravertebral block could greatly contribute to enhanced recovery after thoracic surgery owing to effective and fewer side effects in a retrospective observational study (32). Katayama *et al.* suggested that paravertebral block was safe in patients ineligible for epidural block and could contribute to their pain relief following pulmonary resection procedure including VATS (33). However, the study of Messina *et al.* showed that epidural analgesia was more efficient than paravertebral continuous block at reducing pain after thoracic surgery (34).

Percutaneous or thoracoscopic intercostal nerve block

Hung and his colleagues reported that nonintubated thoracoscopic surgery using internal intercostal nerve block, vagal block and targeted sedation was technically feasible and safe in surgical treatment of lung, mediastinal and pleural tumors in selected patients (9). Wurnig *et al.* suggested that pain management by intercostal block was superior during the first 24 h after surgery whereas on the second day after surgery pain control was significantly better achieved by the epidural catheter in relaxed position. A combination of intercostal block and epidural block seems to be an ideal pain management in patients undergoing thoracic surgery (35).

Spontaneous breathing anesthesia with LMA

Cai and his colleagues found that thoracoscopic bulla resection under laryngeal mask anesthesia with low tidal volume high-frequency lung ventilation was safe and feasible and resulted in better patient satisfaction and shorter in-hospital stay than procedures performed under intubation anesthesia with one-lung ventilation (36). Ambrogi *et al.* suggested that thoracoscopic wedge resection of lung nodule was safe and feasible under spontaneous breathing anesthesia with LMA. It is a new technique permitted a confident manipulation of lung parenchyma and a safe stapler positioning without cough, pain, or panic attack described for awake epidural anesthesia, avoiding the risks of tracheal intubation and mechanical ventilation (37). However, it is influenced by surgical personal skills and patients with tenacious pleural adhesions or with nodule unsuitable for VATS resection must be excluded.

Cough control

Preoperative inhalation of aerosolized lidocaine and ipsilateral stellate ganglion block had been proposed to reach cough control in some extent (15,38). Chen and colleagues have routinely performed intraoperative thoracoscopic vagal block, and it has been proved effective on cough reflex suppression without causing hemodynamic instability (16). In some more cases, incremental intravenous fentanyl can be applied in place of vagal block to decrease cough suppression duration (24).

Respiration management

During the whole operation, nasopharyngeal airway and face mask are required for oxygen inhalation, with an oxygen flow of 3-5 L/min. After the pleural cavity is closed and the wound is sutured, the patients are assisted via a face mask in ventilation to inflate the lung tissue.

In sedated patients, premedication with opioid agent followed by deliberate titration had been proved to control respiratory rate effectively. Meticulous use of nasal airway can be of great benefit if upper airway obstruction raises clinical concerns. If significant hypoventilation happens, modest assisted ventilation by a mask may be required after notification of the surgical team. Oxygenation can be facilitated with O_2 supplement by nasal cannula 3-4 L/min or by Venturi Mask. Overly hypercapnia should be avoided; a good-quality end-tidal CO_2 trace and serial arterial blood sampling before/after iatrogenic open pneumothorax should suffice for close monitoring (24,28).

Postoperative analgesia

Thoracic epidural block is still the preferable standard for thoracic surgery analgesia with traumatic procedure. However, some anesthesiologists have some concern for epidural analgesia. Anticoagulant therapy with low molecular weight heparin has been increasingly used in surgical patients, which may make it difficult to safely manage the epidural analgesia. Bang and his colleagues reported a case of epidural hematoma in a 55-year-old male patient who had a thoracic epidural catheter placed under general anesthesia preceding a cardiac surgery. Epidural catheter insertion in a patient anticoagulated with heparin may increase the risk of epidural hematoma (39).

Ding and his colleagues reviewed the updated meta-analysis comparing the analgesic efficacy and side effects of paravertebral and epidural block for thoracotomy, showing that paravertebral block can provide comparable pain relief to traditional epidural block, and may have a better side-effect profile for pain relief after thoracic surgery (29). Recently, the systematic review of Steinthorsdottir *et al.* suggested that thoracic epidural block and especially paravertebral block showed some effect on pain scores for VATS in comparative studies (40). Certainly, a specified catheter for continuous paravertebral block would be more beneficial.

Ishikawa *et al.* have reported that for minimally invasive thoracoscopic surgery, intrapleural analgesia could be one of the good postoperative analgesia for its efficacy, safety, and benefit of easy placement of the catheter (41). Fibla *et al.* showed that the analgesic regimen combining paravertebral block and non-steroid anti-inflammatory drugs (NSAIDs) provided an excellent level of pain control for thoracoscopic surgery through a prospective randomized study (42).

The promising analgesia, including continuous intercostal-intrapleural analgesia or narcotic-based intravenous patient controlled analgesia combining with NSAIDs still need more attention and further study.

Advantages

Nonintubated anesthesia allows thoracic surgery patients to avoid the potential risks of tracheal intubation including the impacts from the manipulation, various anesthetic drugs and mechanical ventilation etc., particularly for the high-risk patients (43).

Liu *et al*. recently compared two groups of patients who received thoracic surgery under epidural anesthesia and those under general anesthesia with double lumen tube, the results showed significant differences in postoperative fasting time, duration of postoperative antibiotic use, and duration of postoperative hospital stay (30).

Mineo and his colleagues studied the quality of life after nonintubated versus intubated VATS talc pleurodesis using case-matched study recruited 391 patients, showing that two groups achieved similar results in pleural effusion and nonintubated VATS got earlier improvement of some quality-of-life domains as well as better mortality, morbidity, hospital stay, and costs (12).

Moreover, Vanni and his coworkers demonstrated that when compared with conventional thoracoscopic surgery under general anesthesia with single-lung ventilation, awake thoracoscopic surgery attenuated the surgical stress responses and had a smaller impact on the postoperative lymphocyte responses (44,45).

Disadvantages

Once mentioned of thoracic surgery just under epidural block, some anesthesiologists will recall the discomfort, irritation, and respiratory depression of the patients and the hustle and frustration of the anesthesiologists during upper abdominal surgery under epidural block decades years ago, even the anesthetics and monitor machines have made great developments. In addition, the thoracic epidural block has been abandoned in lots of hospitals. With heavy labor intensity and various degree of anxiety, anesthesiologists should keep monitoring without distractions and absences.

Some thoracic surgeons also disapprove with the nonintubated anesthesia, because they require that the patient should be unconscious, and are not satisfied with the surgical condition, worry about the position limitation and the possible body movement of the patient (46).

Some patients are not comfortable and even scared about being awake during the surgery, hearing the discussion and noises in the operating room, which may cause mental stress and post-traumatic stress disorder (PTSD). Although there is no related study, a normal human response to such an exceptional situation can for instance be the delayed appearance of unintentional distressing recollections of the event despite the patients' satisfaction concerning the procedure (41,47).

Inexperienced and poorly cooperative surgical team may be the difficulties in performing the nonintubated anesthesia for thoracic surgery. The coordination and cooperation between surgeons and anesthesiologists are very important in operating room. The weak teamwork and poor communication could induce lots of problems even mistakes, seriously endangering the patients' safety.

Hypercapnia can develop during nonintubated thoracic surgery and correlates with the operative time directly. Whereas it is worth noting that clinical study has shown that perioperative hypercapnia without hypoxemia rarely becomes clinically dangerous (13,48). Anyway, airway support and preparation for conversion to intubated general anesthesia should always be in hand in case of respiration depression, insufficient anesthesia and significant bleeding (15,24).

The charge of nonintubated anesthesia is quite lower than that of general anesthesia with double lumen endobronchial tube, and the anesthesiologists in some hospitals may get less economic benefits, for example, in the current bonus distribution system in China.

The advantages and disadvantages of nonintubated anesthesia for thoracic surgery are listed in the *Table 1*.

Future directions

In a modern era of minimally invasive thoracoscopic surgery, we are encouraged that tracheal intubation with double lumen tube or bronchial blocker is no longer regarded as a prerequisite for single lung ventilation in series of reported studies. Nonintubated thoracoscopic surgery is feasible and safe in a variety of thoracic procedures, including pulmonary resection, empyema, and excision of pleural and mediastinal tumors. Although the risks and benefits of this technique are not clear yet, it seems to offer an equally effective and safe alternative for those patients with high risks to intubated general

Table 1 Advantages and disadvantages of nonintubated anesthesia for thoracic surgery

Advantages
Avoiding the potential risks of tracheal intubation
Better results in postoperative fasting time, duration of postoperative antibiotic use, and duration of postoperative hospital stay
Earlier improvement of some quality-of-life domains, better mortality, morbidity, hospital stay, and costs
Attenuated the surgical stress responses and had a smaller impact on the postoperative lymphocyte responses
Disadvantages
Challenge and increased labor intensity to anesthesiologists
Disapproval from some thoracic surgeons
The risk of mental stress and post-traumatic stress disorder for some patients
Problems even mistakes induced by the weak teamwork and poor communication
Hypercapnia, airway support and preparation for conversion to intubated general anesthesia
Less economic benefits in some countries

anesthesia, and the postoperative recovery is faster with less complication rates.

Summary

The psychological preparation and physical evaluation of the patients, the applying of suitable techniques, intraoperative management and communication with surgeons are important for the safety and practicality of nonintubated anesthesia for thoracic surgery. Nevertheless, more evidence and studies are needed to ascertain the risks and benefits of this technique.

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Nonintubated video-assisted thoracic surgery under epidural anesthesia—Encouraging early results encourage randomized trials

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Nonintubated video-assisted thoracic surgery (VATS) that is also defined awake VATS entails thoracoscopic procedures performed by regional anesthesia in spontaneously ventilating, mildly sedated or fully awake patients.

The rationale is the avoidance of side-effects of intubated general anesthesia with single-lung mechanical ventilation, and maintenance of a more physiologic muscular, neurologic, and cardiopulmonary status, in order to minimize the overall surgery- and anesthesia-related trauma, fasten recovery, optimize outcome and possibly reduce costs.

Until a few years ago the main concern against nonintubated VATS was the fear that a surgical pneumothorax could be poorly tolerated under spontaneous ventilation. However, data that have progressively accumulated have contradicted this empiric thought showing that following creation of a surgical pneumothorax, satisfactory oxygenation can be easily maintained for up to several hours (1) and even in subjects with compromised ventilatory function (2).

Reported nonintubated VATS procedures include management of pleural effusion (3), bullectomy for spontaneous pneumothorax (4) and giant bullous disease (5), resection of pulmonary nodules (6) and of primary or secondary lung tumors (7-11); thymectomy (7,12); lung volume reduction surgery (2); and lung biopsy of interstitial lung disease (13). Overall, these early series have suggested patient-friendly and globally minimally-invasive surgical options, which offered an immediate resumption of daily life activities, low morbidity rates and short hospital stay.

Strategies and approaches

There are several differences amongst the various nonintubated VATS programs including anesthesia protocols and surgical details.

Aside from the preference of having a patient fully awake or in conscious sedation on the operating table, the main physiologic difference between all nonintubated VATS strategies and intubated general anesthesia, is that with the latter the diaphragm is pharmacologically paralyzed and ventilation is mechanically driven whereas with the formers, spontaneous ventilation and an efficient contraction of the diaphragm are maintained leading in lateral decubitus to optimal ventilation/perfusion matching in the dependent lung. During nonintubated VATS, the degree of lung collapse achieved by creation of the surgical pneumothorax is usually comparable to that achievable by intubated single-lung ventilation whereas surgical maneuvering may be somewhat more technically demanding due to rhythmic diaphragmatic movement and to the risk of inadvertent stimulation of the coughing reflex. In this respect, the attitude of thoracic surgeons involved in nonintubated VATS has been variable.

Chen and coworkers, first reported on thoracoscopic lobectomy (9) and segmentectomy (10) carried out by an innovative nonintubated VATS protocol which included the use of the bispectral index to monitorize the targeted level of conscious sedation and the block of the vagus nerve by the intrathoracic local injection of lidocaine, which permitted to abolish the coughing reflex for up to 2-3 hours.

In our program we have preferred to employ epidural anesthesia in fully awake and cooperative patients to maintain neurologic vigilance that we consider an ideal way of physiologic monitoring and which allows a constant verbal communication with the surgical staff. On one hand, this can be extremely reassuring inducing a sense of retaining control and a better perception of immediate recovery to the patient. On the other, panic attacks can rarely develop in anxious patients although these can be easily controlled by switching from a typical awake procedure to one under targeted conscious sedation without conversion to intubated anesthesia. In addition we do not employ any measure to abolish the coughing reflex and we simply learned to avoid putting into traction the pulmonary hilum to minimize the risk of coughing although we acknowledge that in some instances the block of the vagus nerve can prove useful.

Thoracic Epidural Anesthesia has been preferred by the majority of the teams performing nonintubated VATS even though intercostal (14) and paravertebral blocks have been also reliably employed and have shown pros and cons. Disadvantages of epidural anesthesia include the risk of hemorrhagic complications including spinal hematoma whereas the old-fashioned fear that epidural anesthesia could lead to impaired compensatory ventilation and bronchial constriction due to adrenergic blockade though not specifically addressed has been largely contradicted by the excellent results repeatedly reported by nonintubated VATS with epidural anesthesia performed in fully awake patients with severe emphysema (2).

In most of instances indications for standard VATS are equally valid for nonintubated VATS. However, in a large series from Taiwan (1), small body-sized female patients with small tracheal caliber have been deemed optimal candidates for nonintubated anesthesia due to higher risks for intubation-related complications.

The main contraindications can be considered an American Society of Anesthesiology score greater than 3, morbid obesity, and an arterial carbon dioxide tension >55 mmHg. Bleeding disorders, and unfavorable spinal deformity are specific contraindications for nonintubated VATS under epidural anesthesia.

Most commonly, a three-ports access has been preferentially employed for nonintubated VATS even though some surgeons have successfully employed the single-port access for talc pleurodesis in management of recurrent pleural effusions (4), to resect isolated pulmonary nodules (15) or very recently, even to perform nonintubated lobectomy (16).

Randomized trials

Until the recent trial reported from China (17), there were only four small randomized studies investigating results of nonintubated VATS, which entailed wedge resection of undetermined pulmonary nodules (6), bullectomy with pleurectomy for treatment of spontaneous pneumothorax (4), lung volume reduction surgery (2) and talc pleurodesis for malignant pleural effusion (3). Three of these studies entailed VATS procedures performed by sole epidural anesthesia in awake patients (2,4,6) whereas one included awake procedures carried out under either epidural anesthesia or intercostals blocks. Common findings emerging from these previous trials included excellent feasibility with low conversion rates (0-7%) as well as shorter hospital stay and lower costs than procedures carried out by intubated general anesthesia. Limitations included the small cohorts and the unicenter designs of these trials, which were all performed by the same surgical team.

For this reason the randomized study recently published by Liu and coworkers in the *Surgical Innovation Journal* (17), is timely and particularly welcome.

This unicenter trial is the largest to be completed so far. It enrolled 354 patients undergoing bullectomy, pulmonary wedge resections and lobectomy who were randomized either to nonintubated VATS with epidural anesthesia (174 patients) or to standard intubated VATS management (180 patients).

Seven patients in the nonintubated group were withdrawn due to by necessity changes in type of anesthesia. Reasons for conversion included pleural adhesions contraindicating the procedure, carbon dioxide retention and hypoxemia, unsatisfactory lung collapse, intraoperative bleeding and need to switch from wedge to lobectomy.

The reported outcomes have been highly satisfactory. In particular, independent by the type of surgical procedure, nonintubated anesthesia resulted in shorter fasting time and duration of postoperative antibiotics. A shorter hospital stay occurred in the groups undergoing nonintubated bullectomy or lobectomy whereas a decreased volume of postoperative pleural drainage occurred in the nonintubated lobectomy group only.

Finally, in patients undergoing bullectomy, nonintubated VATS was associated with a decreased difference between pre-to-postoperative concentration of tumor necrosis factor-α level in the bronchoalveolar lavage fluid.

Limitations of this study include a per-protocol design provided that patients in whom the approach was converted to general anesthesia have been excluded from the outcome analysis; the lack of standardized objective criteria for discharge and of perioperative physiologic data comparisons. On the other hand, unconventional strengths of this trial were the assessment of postoperative antibiotics duration that was calculated on the basis of the presence/

absence of symptoms/signs of pulmonary infection including the serum white blood cells level and of serum/bronchoalveolar lavage levels of inflammatory cytokines.

Future perspectives

I foresee three main paths towards which the next future clinical research on nonintubated VATS may be driven.

The first is a standardization of the indications to perform simple and fast procedures including management of recurrent pleural effusion and of spontaneous pneumothorax for which feasibility of nonintubated VATS has been shown to be excellent whereas intubated general anesthesia with single-lung mechanical ventilation might be deemed an unnecessary luxury as suggested by Katlic and Factor (14). This assumption implies the need for comparative cost-effectiveness assessments and seems to fit pretty well with a general concept coming from the mentors of our mentors and saying that in surgery, unnecessary or redundant maneuvers should be avoided since they are potentially dangerous.

The second path entails surgical procedures performed in patients with impaired respiratory function in whom general anesthesia and one-lung ventilation per se represents a not negligible risk factor. In this respect the experience on awake lung volume reduction surgery for severe emphysema (2) as well as that on awake lung biopsy for interstitial lung disease (13), are promising examples that respectively involve patients with obstructive or restrictive ventilatory defect patterns and that in my opinion merit further thorough investigation.

The third highly promising path is the application of nonintubated VATS to oncologic procedures for which optimal indications are still controversial.

In fact, although metastasectomy (8), segmentectomy (10), lobectomy (7,9), and even pneumonectomy (7) have been shown to be feasible by nonintubated VATS, it is likely that to perform major lung procedures requiring fine vascular dissection, most of thoracic surgeons would still prefer general anesthesia with single-lung ventilation, which provides deeper sedation and an immobile, collapsed lung.

However, it is worth noting that reduced postoperative stress hormone response (18) and a lesser impairment in lymphocytes activity (19) have been both reported in preliminary clinical studies and if confirmed by future investigations with long follow-up might open novel oncologic perspectives including a better self-immunologic defense against cancer spread and higher survival rates.

In addition, complementary combinations of the results achieved in each path might potentially allow to define more precisely optimal indications and add novel perspectives such as the adoption of nonintubated VATS in fast track programs and to increase operability of patients with lung cancer who are currently deemed at high-risk for intubated anesthesia due to an advanced age, associated comorbid conditions or severe ventilatory defects.

Conclusions

In conclusion, research on nonintubated VATS has successfully switched to a new critical phase in which encouraging early results encourage accomplishment of well designed randomized studies and I look forward to learn further interesting insights on this intriguing topic in the near future.

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Non-intubated single port thoracoscopic procedure under local anesthesia with sedation for a 5-year-old girl

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Abstract: Medical thoracoscopy is a feasible procedure for the diagnosis or treatment of thoracic diseases, and it can be performed under local anesthesia without tracheal intubation in cooperative adult patients. However, for younger than school aged patients, even simple procedures require general anesthesia with tracheal intubation. In this case report, we demonstrated the safe performance of a single port thoracoscopic procedure without tracheal intubation in a 5-year-old girl under local anesthesia and sedation. Local anesthesia around the site of a previous chest tube and sedation with intravenous (IV) dexmedetomidine and ketamine were applied. In the aspect of not only minimal injection of local anesthetics but also enhanced visualization of the thoracic structures, the non-intubated single port thoracoscopic surgery under local anesthesia with sedation was a good option for performing a simple thoracoscopic procedure in this 5-year-old patient.

Keywords: Thoracoscopy; non-intubated; single port; local anesthesia; sedation; bispectral index (BIS)

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Introduction

Medical thoracoscopy is a short and simple procedure for the diagnosis or biopsy of thoracic disease (1). In adult patients, it can be easily performed using local anesthetics with or without sedation under the cooperation of the patient (2). However, this is not feasible in pediatric thoracoscopy, which often requires general anesthesia (3). In pediatric patients less than 30 kg, carbon dioxide gas insufflation into the chest cavity through an air-tight port is needed to collapse the lung for operation (4).

In our case, we demonstrated the use of a non-intubated single port thoracoscopic procedure in a 5-year-old girl under local anesthesia with sedation for the management of a chest tube which was inadvertently sutured in the thoracic cavity.

Case report

A girl aged 5 years and 2 months (height 109 cm, weight 18.6 kg) experienced recurrent pneumonia over a 2-year period. Chest radiographs and computed tomographic (CT) scan showed extra lobar pulmonary sequestration in the left lower lung. Her vital signs were stable, and no other anomalies were detected during preoperative evaluation. We resected the lesion through an incision in the left lateral thoracotomy (length, 3 cm) along the fifth intercostal space, under general anesthesia with a single lumen tracheal tube (*Figure 1*). After resection of the sequestrated lung, a 16-Fr chest tube was inserted into the seventh intercostal space. The intercostal space was repaired using a 4-0 absorbable suture. After two days, the chest tube could not be withdrawn. It seemed to have been inadvertently sutured beneath the thoracotomy incision inside the thoracic cavity. At this point, we decided to perform the thoracoscopic procedure through the chest tube insertion site under sedation without tracheal intubation.

Sedation was achieved using Intravenous (IV) dexmedetomidine (1.0 μg/kg) for over 15 min before the injection of local anesthetics, followed by 1 mg/kg of IV ketamine and dexmedetomidine 0.2-1.0 μg/kg/h IV (5). Oxygen at 6 L/min was administered via a pediatric face mask. The patient was monitored during sedation, and the bispectral index (BIS) was maintained between 45 and 65 during the procedure. The thoracoscopic procedure was performed in the right lateral decubitus position (*Figure 2A*). Local anesthesia was achieved around the hole where the chest tube was inserted, using a 2% lidocaine solution.

After the chest tube was pulled and shortened, a 2-mm thoracoscope was inserted through the chest tube site (5.5 mm incision) (*Figure* 2B). The ipsilateral lung was collapsed, during which the patient kept breathing with the contralateral lung. The intercostal suture material penetrating the middle part of the chest tube was found underneath the thoracotomy wound (*Figure 2B*). The suture was intrathoracically cut using 2-mm endoscopic scissor and grasper (*Figure 2C*), and the chest tube was removed. The new 16-Fr chest tube was inserted through the same hole, and anchored outside of the hole.

Figure 1 The extralobar type pulmonary sequestration with aberrant arterial pedicle from descending aorta was resected through a 3 cm thoracotomy incision.

The patient's vital signs were stable during the entire operation (intraoperative mean arterial pressure, 85-90 mmHg; intraoperative heart rate, 90-92 beats/min; and intraoperative SPO_2, 99-100%). Ketamine 0.5 mg/kg (IV) was added as a bolus when involuntary movements or cough reflex occurred. The total operation time was 35 min, and the sedation time was 55 min. The IV dexmedetomidine infusion was discontinued at the end of surgery. After returning to the supine position, she was transferred to the recovery room.

The second chest tube was withdrawn immediately after checking the chest radiography. She was allowed to drink water one hour later, and was discharged after two days. No delayed complications were observed during the follow-up.

Discussion

In thoracoscopic procedures for pediatric patients less than 30 kg, comprehensive visualization of the surgical field is

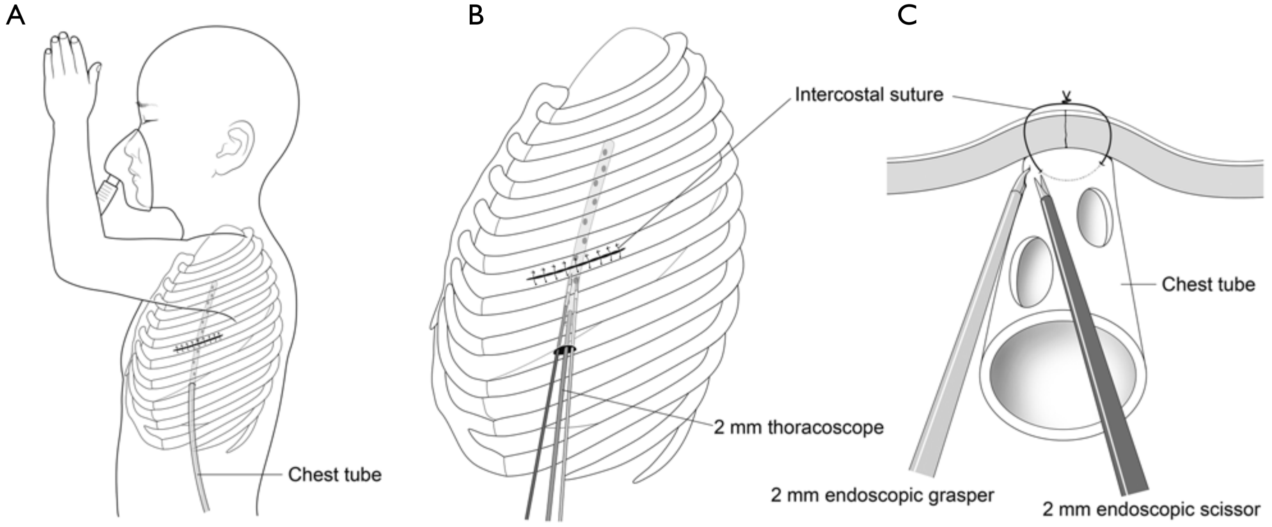

Figure 2 (A) The patient posed in the lateral decubitus position with oxygen supplied by facial mask, in deep sedation status; (B) the chest tube was shortened outside the thoracic cavity, and local anesthetic solution was injected around the chest tube site. A 2-mm-thoracoscope and other instruments were introduced through the chest tube site; (C) intercostal suture penetrated the chest tube underneath the thoracotomy incision. The suture material was cut using 2-mm endoscopic scissor and grasper under thoracoscopy.

quite difficult, even under general anesthesia (3,4). A collapse of the ipsilateral lung is essential for the surgeon to be able to perform a thoracoscopic procedure in thoracic cavities which have limited space. Because there are no appropriate double lumen tracheal tubes, which are used for selective one lung ventilation in adult patients, generally, single lumen tracheal intubation is generally applied in small pediatric patients, with carbon dioxide gas insufflations through air-tight ports into the thoracic cavity to collapse a lung (3,4).

In the present case, a self-ventilating thoracoscopic procedure under local anesthesia with sedation was planned. We considered that the repeat of general anesthesia in a patient who had undergone general anesthesia for the surgery just three days before may be harmful, especially for performing a short and simple procedure, such as cutting a suture material in the thoracic cavity. In addition, the ventilation of two lungs using a single lumen tracheal tube has no benefit in thoracoscopic surgery.

Active negative ventilation and opened thoracic cavity can collapse the ipsilateral lung, maintaining the ventilation of the contralateral lung under local anesthesia with sedation. Previous studies reported non-intubated thoracosopic bleb resections and lobectomies under sedation combined with various local anesthetic methods (1,6-9).

Sedation with IV ketamine and dexmedetomidine was available, and could provide a stable condition for uncooperative pediatric patients during the procedure. Even a simple procedure cannot be performed under local anesthesia without sedation in younger than school-aged patients because of their uncontrollable movement (4). This creates the necessity of deep sedation, which can often cause respiratory depression (3). We chose to combine IV ketamine with IV dexmedetomidine for our patient. Dexmedetomidine has been shown to produce stable sedation without respiratory depression (10), and provides analgesia and hemodynamic stabilization. In addition, it may prevent tachycardia, hypertension, and emergence phenomena associated with ketamine, while ketamine prevents bradycardia and hypotension, which have been reported with dexmedetomidine (11).

The procedure through the single hole from the previous chest tube, that is, the single port procedure was adjustable for an unconscious sedated patient. If possible, less irritation of the wound during the operation is better to maintain sedation. Compared with multiple port surgery, the stimulation of the port site can be reduced in single port surgery.

To the authors' knowledge, this report is the first report of a non-intubated single port thoracoscopic procedure under local anesthesia with sedation in a patient younger than school age. In the present case, non-intubated surgery improved the surgical view in pediatric thoracoscopic surgery, and single port surgery was effective under local anesthesia with sedation. However, our case was of a very short and simple procedure. Prospective randomized trials are required to determine the efficacy of non-intubated single port thoracoscopic surgery under local anesthesia and sedation in cases of complicated and long thoracoscopic procedures for pediatric patients.

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Nonintubated thoracoscopic surgery using regional anesthesia and vagal block and targeted sedation

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Objective: Thoracoscopic surgery without endotracheal intubation is a novel technique for diagnosis and treatment of thoracic diseases. This study reported the experience of nonintubated thoracoscopic surgery in a tertiary medical center in Taiwan.

Methods: From August 2009 through August 2013, 446 consecutive patients with lung or pleural diseases were treated by nonintubated thoracoscopic surgery. Regional anesthesia was achieved by thoracic epidural anesthesia or internal intercostal blockade. Targeted sedation was performed with propofol infusion to achieve a bispectral index value between 40 and 60. The demographic data and clinical outcomes were evaluated by retrospective chart review.

Results: Thoracic epidural anesthesia was used in 290 patients (65.0%) while internal intercostal blockade was used in 156 patients (35.0%). The final diagnosis were primary lung cancer in 263 patients (59.0%), metastatic lung cancer in 38 (8.5%), benign lung tumor in 140 (31.4%), and pneumothorax in 5 (1.1%). The median anesthetic induction time was 30 minutes by thoracic epidural anesthesia and was 10 minutes by internal intercostal blockade. The operative procedures included lobectomy in 189 patients (42.4%), wedge resection in 229 (51.3%), and segmentectomy in 28 (6.3%). Sixteen patients (3.6%) required conversion to tracheal intubation because of significant mediastinal movement (seven patients), persistent hypoxemia (two patients), dense pleural adhesions (two patients), ineffective epidural anesthesia (two patients), bleeding (two patients), and tachypnea (one patient). One patient (0.4%) was converted to thoracotomy because of bleeding. No mortality was noted in our patients.

Conclusions: Nonintubated thoracoscopic surgery is technically feasible and safe and can be a less invasive alternative for diagnosis and treatment of thoracic diseases.

Keywords: Anesthesia; lobectomy; lung cancer; segmentectomy; thoracoscopy; tracheal intubation; wedge resection

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Introduction

Since the introduction of video-assisted thoracoscopic surgery (VATS), it has become a preferred alternative to treat patients with thoracic diseases (1,2). For decades, intubated general anesthesia with one-lung ventilation has been considered mandatory during VATS (3,4). However, complications and adverse effects following tracheal intubation and one-lung ventilation are inevitable, including intubation-related airway trauma, ventilation-induced lung injury, residual neuromuscular blockade, impaired cardiac performance, and postoperative nausea and vomiting (5-10).

To reduce the adverse effects of tracheal intubation and general anesthesia, thoracoscopic surgery without tracheal intubation has been recently employed for management of pneumothorax (11), resection of pulmonary nodules (12-14), resection of solitary metastases (15), lung volume reduction surgery (16), lobectomy, and segmentectomy (17-20). The results achieved for these early surgeries are encouraging.

Although the feasibility of thoracoscopic surgery via nonintubated anesthesia was demonstrated in some reports, most of them are limited to small number of cases. In this study, we reported our experience of 446 consecutive patients undergoing nonintubated VATS in a 4-year period of time to evaluate the feasibility, safety, and indication of this innovative technique in a tertiary medical center in Taiwan. The anesthesia and surgical techniques were also described.

Patients and methods

Study design and patients

The medical records of all patients who underwent nonintubated VATS at National Taiwan University Hospital from August 2009 to August 2013 were retrospectively reviewed. The thoracic surgical team, both surgeons and anesthesiologists, selected the cases upon review of the medical records. Patients considered appropriate for non-intubated thoracoscopic surgery met the same criteria as for intubated single-lung ventilation, including patients with clinical stage I or II non-small-cell lung cancer, metastatic lung cancer, or benign lung tumor. The tumors were peripherally located and smaller than 6 cm in diameter, without evidence of chest wall, diaphragm, or main bronchus involvement. Patients with primary or secondary spontaneous pneumothorax were also suitable for nonintubated thoracoscopic surgery. Patients with American Society of Anesthesiologists (ASA) scores of greater than three, bleeding disorders, sleep apnea, or unfavorable airway or spinal anatomy were contraindicated for nonintubated VATS in our hospital. Patient consent was obtained after explaining the type of anesthesia and the surgical procedure.

The operation methods used had included conventional VATS or needlescopic VATS. All patients were managed by a single thoracic surgical team using the same clinical protocols, care patterns, and perioperative orders.

Anesthetic setting, induction, and maintenance

Anesthetic techniques were described previously (13,14, 17-20). Briefly, all patients were pre-medicated with fentanyl 50-100 μg intravenously. Standard monitoring included electrocardiogram, arterial blood pressure, pulse oximetry, and respiratory rate. The end-tidal carbon dioxide was measured by insertion of a detector into one nostril. A bispectral index sensor (BIS Quatro, Aspect Medical System, Norwood, MA, USA) was applied to the forehead of each patient to monitor the level of consciousness (21). The patients were then sedated with intravenous propofol (Fresfol 1%, Fresenius Kabi GmbH, Graz, Austria) using a target-controlled infusion method (Injectomat® TIVA Agilia, Fresenius Kabi GmbH, Graz, Austria). The level of sedation was set to achieve a bispectral index value between 40 and 60 (21), and incremental intravenous injections of fentanyl 25 μg were given to maintain a respiratory rate between 12 to 20 breaths/min. The patients were placed in the lateral decubitus position. During the procedure, patients spontaneously breathed oxygen through a ventilation mask.

Regional anesthesia was achieved by thoracic epidural anesthesia between 2009 and 2012. From March 2012, we began to use internal intercostal blockade as an alternative for thoracic epidural anesthesia because it is easier and time saving. Thoracic epidural anesthesia was performed by insertion of an epidural catheter at the T5/6 thoracic interspace to achieve a sensory block between the T2 and T9 dermatomes before sedation, and was maintained by continuous infusion of 2% lidocaine. Thoracoscopic intercostal nerve block was produced by infiltration of 0.5% bupivacaine (1.5 mL for each intercostal space) from the third to the eighth intercostal nerve under the parietal pleura, 2 cm laterally to the sympathetic chain, with a 25-G top-winged infusion needle.

During the procedure, patients breathed O_2 through a ventilation mask, keeping oxygen saturation above 90%. An iatrogenic pneumothorax was made by creating incisions through the chest wall for thoracoscopy and the ipsilateral lung collapsed gradually. To inhibit coughing during thoracoscopic manipulation in selected patients, intrathoracic vagal blockade was produced by infiltration of 3 mL of 0.5% bupivacaine adjacent to the vagus nerve at the level of the lower trachea for right-sided operations and at the level of the aortopulmonary window for left-sided operations, under direct thoracoscopic vision. This procedure effectively inhibited the cough reflex for three or more hours and was mandatory for lobectomy and segmentectomy, especially before anatomical dissection of the pulmonary hilum. Repeated bupivacaine infiltration was occasionally needed in prolonged operations.

During wound closure and chest tube insertion, propofol infusion was stopped. After the patient was fully awake, the patient was asked to breathe deeply and cough to re-expand the collapsed lung.

Technique of thoracoscopic surgery

Thoracoscopic lobectomy, segmentectomy, or wedge resection was performed using a 3-port method, as described by McKenna (22). In brief, the patient was positioned in the full-lateral decubitus position, with slight flexion of the table at the level of the mid-chest. The thoracoscope was placed into the seventh or eighth intercostal space in the midaxillary line. A working port was placed in the sixth or seventh intercostal space in an auscultatory triangle, and an anterior 3 cm incision was placed anteriorly in the fifth intercostal space. After collapse of the lung, incomplete fissures, pulmonary vessels, and bronchi were divided with endoscopic stapling devices. The resected specimen was removed in an organ retrieval bag through the utility incision. After staging mediastinal lymph node dissection, a 28-French chest tube was placed through the lowest incision. Rib spreading, rib cutting, and retractor use were avoided in all patients, except when conversion to thoracotomy was required.

Technique of needlescopic VATS

Needlescopic VATS was mainly used for biopsy of undiagnosed peripheral lung nodules. The technique was described previously (13). An incision of about 15 mm in length was made in the sixth intercostal space on the midaxillary line and a 12-mm thoracic port was inserted through the incision. Two or three small skin punctures were made and mini-ports were inserted for the needlescopic instruments (3-mm instruments, Olympus, Tokyo, Japan). Initially, the 10-mm telescope and two mini-endograspers were used to identify the nodule. Once the nodule was identified, it was stabilized using the mini-endograsper. The mini-endograsper in the other mini-port was withdrawn and a needlescope was introduced to visualize the tumor. The 10-mm telescope was then withdrawn and a 45-mm endoscopic stapler was introduced for partial lung resection including the nodule. Resected tissue was placed into a bag inserted through the 12-mm port and was taken out of the thoracic cavity. Upon completion of the procedure, a chest tube was inserted via the 12-mm port.

Anesthetic conversion

The attending surgeon and anesthesiologist decided whether or not to convert nonintubated anesthesia to intubated general anesthesia with one lung ventilation in cases of ineffective analgesia, profound respiratory movement, massive pleural adhesions, persistent hypoxemia (S_PO_2 <80%), unstable hemodynamic status, or intraoperative bleeding requiring thoracotomy. When conversion was indicated, the surgical wounds were sealed with transparent waterproof dressings (Tegaderm Film, 3M Health Care, Neuss, Germany) after insertion of a chest tube to re-expand the lung. A single-lumen endotracheal tube was inserted under the guidance of a bronchoscope, followed by insertion of a bronchial blocker without changing the patient's position.

Postoperative analgesics and care

Postoperative analgesics were administered by patient controlled epidural or intravenous infusion of analgesics. Chest radiography was performed immediate or the next morning. Drinking and meal intake were resumed 2-4 hours after surgery. The chest tube was removed if no air leak was present and drainage was less 200 mL in a 24-hour period.

Data collection and analyses

The data including patient demographics, complications, and the surgical results were collected from the institutional database, anesthesia and surgical notes, and the medical and nursing records.

Results

From August 2009 through August 2013, nonintubated VATS was performed on 446 patients. Among them, 156 patients underwent thoracoscopic intercostal nerve block, vagal block, and targeted sedation for management of their pulmonary diseases. The remaining 290 patients underwent thoracic epidural anesthesia, vagal block, and sedation for nonintubated VATS. The demographic data are reported in *Table 1*. The mean patient age was 56.9 years and 181 patients (40.6%) were male. Four patients received bilateral VATS for lesions in both lungs. Needlescopic VATS was performed in 57 patients (12.8%) for resection of peripheral lung nodules while the remaining patients underwent conventional VATS. The median anesthetic

Table 1 Clinical characteristics of the 446 patients

Variable	N=446
Age (y)[a]	56.9±16.8 [59, 19-90]
Sex (male, %)	181 (40.6)
Smoking (%)	127 (28.5)
Operation methods (%)	
Conventional VATS	389 (87.2)
Needlescopic VATS	57 (12.8)
Operation procedures (%)	
Lobectomy	189 (42.4)
Wedge resection	229 (51.3)
Segmentectomy	28 (6.3)
Pathological diagnosis (%)	
Lung cancer	263 (59.0)
Metastatic cancer	38 (8.5)
Benign lung tumor	140 (31.4)
Pneumothorax	5 (1.1)

[a]Mean ± standard deviation [median, range]; Abbreviation: VATS, video-assisted thoracoscopic surgery.

Table 2 Treatment outcome of nonintubated thoracoscopic surgery

Variable	N=446
Anesthetic side effects (%)	
Vomiting requiring medication	15 (3.4)
Sore throat	7 (1.6)
Headache	6 (1.3)
Operation complications (%)	
Air leaks >5 days	9 (2.0)
Bleeding	2 (0.4)
Pneumonia	3 (0.7)
Conversion to tracheal intubation (%)	16 (3.6)
Lobectomy	11/189 (5.8)
Wedge resection	3/229 (1.3)
Segmentectomy	2/28 (7.1)
Conversion to thoracotomy (%)	1 (0.2)
Mortality (%)	0 (0)

Table 3 Causes of conversion to tracheal intubation

Variable	N=16 (%)
Significant mediastinal movement	7 (43.8)
Persistent hypoxemia	2 (12.5)
Dense pleural adhesions	2 (12.5)
Ineffective epidural anesthesia	2 (12.5)
Bleeding	2 (12.5)
Tachypnea	1 (6.3)

induction time was 30 minutes (range, 15 to 60 minutes) by thoracic epidural anesthesia and was 10 minutes (range, 5 to 30 minutes) by internal intercostal blockade. The operation procedures have included lobectomy in 189 patients (42.4%), wedge resection in 229 patients, and segmentectomy in 28 cases. Most of the patients were diagnosed as non-small cell lung cancer (59.0%).

The operative and anesthetic results are shown in *Table 2*. After the surgery, anesthetic side effects were noted in 28 patients (6.3%), including vomiting, sore throat, and headache. Operation complications were noted in 14 patients (3.1%), including air leaks >5 days, bleeding, and pneumonia. Sixteen patients (3.6%) required conversion to tracheal intubation because of significant mediastinal movement (seven patients), persistent hypoxemia (two patients), dense pleural adhesions (two patients), ineffective epidural anesthesia (two patients), bleeding (two patients), and tachypnea (one patient) (*Table 3*). Conversion to a thoracotomy was required in one patient with blood transfusion due to bleeding during dissection of pulmonary artery. No mortality was noted in this study.

Discussion

Recent reports and our previous studies have suggested that many surgical thoracic procedures are feasible using nonintubated anesthetic techniques, with patients under awake or sedative status (11-20). Our experience of a lot of number of cases with satisfactory results and low conversion rates also showed that nonintubated thoracoscopic lobectomy, segmentectomy, and wedge resection are safe and can be effective alternatives to intubated thoracoscopic procedures.

Concerns might arise with the use of nonintubated anesthesia for pulmonary resection, especially for complicated procedures entailing fine vascular dissection such as lobectomy or segmentectomy. First, prolonged one-lung spontaneous breathing during surgery could lead to hypoxia and hypercapnia. Secondly, cough reflex and unexpected lung movement can be encountered during pulmonary hilar manipulation. Thirdly, conversion to general anesthesia with intubation could be required occasionally (17).

To our surprise, S_PO_2 was maintained at 95% or more during the whole operation in most cases. Hypercapnea was noted in some patients, especially when the surgery was long. Our experience showed that hypercapnia was permissive and did not affect the hemodynamics and surgical procedures, which was comparable to a recently published report by Dr. Dong *et al*. (23).

Cough reflex and unexpected lung movement during manipulation of the pulmonary hilum was hazardous when performing nonintubated lobectomy or segmentectomy. Using intrathoracic vagal blockade, the cough reflex and unexpected lung movement could be effectively abolished, without affecting the heart rate and blood pressure (17).

Although nonintubated thoracoscopic procedures could provide an attractive alternative in managing lung diseases, sixteen patients (3.6%) required conversion to intubated one-lung ventilation because of significant mediastinal movement, persistent hypoxemia, dense pleural adhesions, ineffective epidural anesthesia, bleeding, and tachypnea. Our results suggested that obese patients with body mass index >30 are at a high risk of anesthetic conversion because it usually associated with vigorous spontaneous breathing and significant mediastinal movement. We suggest that proper patient selection, accumulated experience by performing minor non-intubated thoracoscopic procedures, and conversion to intubated general anesthesia without hesitation are mandatory to decrease the risk of emergency intubation and complications, especially at the beginning of the learning curve.

In our cohort, almost two third of the patients were women. We believe that nonintubated thoracoscopic surgery is most applicable in small body-sized female patients. These patients are prone to have small tracheal caliber and are susceptible to intubation-related complications such as sore throat, hoarseness, and subglottic stenosis, especially when double-lumen endotracheal tubes are used. Using the nonintubated technique, we found that the rates of postoperative sore throat were significantly decreased. It is reasonable to suggest that the incidence of hoarseness and tracheal injury could also have been lower, although they were not investigated in this study.

When performing simple thoracoscopic procedures with short operation duration such as wedge resection, previous studies showed awake surgery is feasible and safe (11,12). We did not use awake technique because when the procedures become prolonged or complicated owing to unexpected reasons, conversion to intubated anesthesia with one-lung ventilation is required. Using our nonintubated technique with targeted sedation, major and complicated thoracoscopic procedures such as lobectomy and segmentectomy can be performed without conversion.

Thanks to the avoidance of tracheal intubation and muscle relaxants, the anesthetic side effects were minimal in our patients. Most of our patients resume oral intake and ambulation around two hours after the operation. The rates of postoperative sore throat and vomiting are also lower compared with intubated patients in our previous studies (17,18).

We acknowledge that this study was limited by its retrospective design and the lack of a control group for comparison. Further detailed investigations by prospective controlled designs are needed to elucidate the impact of the different anesthesia protocols on perioperative outcomes, cancer metastasis status, and overall survival.

Conclusions

Our results have suggested that nonintubated thoracoscopic surgery is safe and technically feasible. Avoidance of intubation, mechanical ventilation, and muscle relaxants was reflected in less intubation-associated discomfort, and immediate return to many daily life activities including drinking, eating, and walking. Although the long-term benefits remain unclear, we suggest that it can potentially be an attractive alternative of intubated one-lung ventilated thoracoscopic surgery in managing patients with a variety of thoracic diseases, after prospective, randomized data become available.

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Nonintubated thoracic surgery: a lead role or just a walk on part?

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With the advent of the patient-centered health care concept, thoracic surgeons of the modern era are called to minimize at most the overall invasiveness of their performances, while increasing safety and effectiveness as much as possible. This need has driven an outstanding development of minimally-invasive surgical approaches, which are now the standard to perform a broad spectrum of thoracic operations. A recent and fascinating evolution in this field is represented by the increasing interest toward the use of so-called "non-intubated" anesthesia protocol, which are expected to provide a further improvement in postsurgical outcomes (1-8).

My colleagues and I started to perform this kind of operation in the early 2000's. The basic idea of this emerging surgical practice was that the patients would remarkably benefit from the avoidance of general anesthesia and double-lumen ventilation. This convincement is founded solidly on a large body of observations that the latter method, which is since long time the standard one in thoracic surgery, may cause a series of complex inflammatory changes on the ventilated lung, and even on distant organs (1,7-14). The avoidance of these effects is expected to translate into a lesser morbidity rate and a faster perioperative recovery, especially in the subgroup of patients with chronic respiratory failure. Another theoretical pro was that non-intubated surgery could offer some benefits in terms of oncological outcome, as the reduction in ventilator-related stress and the lesser need of opioids are believed to preserve perioperative anticancer immunosurveillance (15-18).

Therefore, in our early experience, we started to adopt non-intubated videothoracoscopy for removing peripheral lung lesions, mostly metastases and stage I non-small cell lung cancer, in fully awake patients with increased risk for general anesthesia (1). After having taken familiarity with the basic technique, we came to some interesting observations. First, we noted that the collapse of the operated lung (that is, surgical pneumothorax) was well tolerated by almost all patients. Indeed, changes in basic vital parameters were irrelevant, and adequate arterial oxygenation could be maintained with just oxygen administration via a facial mask. The increase in arterial CO_2 was of mild extent, almost always asymptomatic, and usually below the so-called permissive limit (60-70 mmHg). Furthermore, we noted that, despite the preservation of diaphragm contractility, breathing movements of the operated lung were minimal, and even lacking in some instances, without any relevant disturbance to the surgical maneuvers. These observations prompted us to go on with this surgical method, and subsequently we extended the indication to other conditions. These included fibrinopurulent pleural empyema (6) and advanced pulmonary emphysema (7). The latter was deemed to be particularly challenging, due to the extremely severe respiratory impairment, the higher likelihood of pleural adhesions, and the presence of a redundant, hyperinflated lung which could jeopardize the technical feasibility. Even in this field, however, we reported encouraging results. In particular, the employ of a non-resectional lung reduction technique allowed us to fasten the operating time and perform the "awake" operation in an easier and safer way.

At that time, our standard anesthetic protocol was a combination of thoracic epidural anesthesia and the avoidance of intraoperative sedation. This was due to the need of maintaining an effective spontaneous ventilation throughout the operation, while offering an optimal analgesic coverage. When we and other groups felt that the time was right to start performing non-intubated major lung surgeries, however, new concerns came out.

First, this kind of operations takes longer, hence the need of having the patient "comfortably numb" throughout the operation while preserving central airway patency. Second, the surgical maneuvers in proximity of the hilar structures can trigger cough reflex. This was not a concern for minor operation, but could instead negatively affect both the safety and feasibility when performing anatomical resection. The most remarkable improvements in this field, were the introduction of vagal blockade, and the employ of bi-spectral index monitoring during the operation. Both these techniques enormously facilitated non-intubated major lung resections, as they can help prevent cough, and allow to titrate the level of sedation under a real-time measurement. We could never figure out that reaching the goal of performing non-intubated, video-assisted pulmonary lobectomies and segmentectomies would have taken a so short time span.

This said, what about the level of evidence on these topics? Unfortunately, we all are far from the opportunity of recommending against or in favor the routine use of non-intubated thoracic surgery in daily clinical practice. One should never forget what is the basic principle of our profession, that is, patients' safety come first. Is non-intubated thoracic surgery safe enough to be performed electively? And even when assuming an optimistic answer, another question can come out: are non-intubated thoracic operations actually safer than the equivalent procedures performed with general anesthesia? Many published studies so far have reported, at least, a non-superior rate of complications of non-intubated thoracic surgeries versus their conventional counterparts (1,19). Furthermore, it appear that in patients at high-risk for general anesthesia, a certain reduction of some specific complications can be attained (19,20). However, the vast majority of these studies are based on observational or retrospective case series, usually including a small number of patients.

These is an urgent need of more robust studies in this regard. Just to give an idea, when considering the estimated rate of postsurgical death after lung cancer resection in an over 65 patient with low comorbidity status (2.3%), a sample of more than 600 subjects would be necessary to detect, with a sufficient reliability, whether a given surgical or anesthesiological method can attain a 3-fold risk reduction. This simple consideration get amplified when taking into the account minor videothoracoscopic operations, such as talc pleurodesis for pleural effusion (21) or bullectomy/pleuroabrasion for pneumothorax. Indeed, these procedures are much less likely to give any relevant intra- or postsurgical complication, regardless of the kind of anesthesia adopted (21,22). The same reasoning applies when considering other primary outcome measures. These may include patient satisfaction, hospital stay, oncologic results, and cost saving issues. In this regard, some studies showed a certain economical benefit for non-intubated thoracic surgery (21), which was likely attributable to a faster discharge, a shorter operating room time, and a lesser morbidity rate. But are all these advantages reproducible in the real-world scenario? For example, non-intubated thoracic surgery needs adequately trained staff with exposure to a large number of videothoracoscopic operations, so that costs allotted for planning and maintaining a standardized skill level should be included in the future analyses. Dry and wet labs, simulator-based training, increased need of having disposable devices ready for immediate use in the operating theater, are all examples of possible sources of economic expense for a non-intubated thoracic surgery facility.

In this issue of *Surgical Innovation*, a prospective randomized trial of non-intubated major resection for stage I lung cancer is published (23). We are grateful to the authors and the Editor for providing a high-quality study like this. The authors analyzed a series of primary and secondary outcome measures, and found definitively a better performance of non-intubated thoracic surgery in terms of postoperative hospital-stay and some surrogate measures of recovery quality, including feeding time and need of postoperative antibiotics. I also have found to be particularly interesting that, in this study, level of TNF-alpha in the broncho-alveolar lavage fluid was significantly lesser than in patients who underwent conventional surgery. Plasma level of C-reactive protein was also remarkably lower, a finding which is in keeping with our previous report on this topic (17). We hope that this paper will serve as a benchmark for future publications on these topics, and its focus on biological markers of surgical traumatism merits a great consideration.

We are also aware of at least other two randomized controlled trials of non-intubated videothoracoscopy versus conventional operations which are currently underway. One is that from the Taiwan University group, which is one of the leading institutions in this setting. This trial (NCT01533233) is aimed at evaluating safety and oncological outcome after non-intubated videothoracoscopic lobectomy plus mediastinal lymph node dissection in clinical stage I non-small cell lung cancer. The other trial (NCT02109510) is from the Korea University and aims at evaluating several outcomes, including overall perioperative well-being, intraoperative gas exchange, and costs, in the specific subgroup of patients undergoing bullectomy-pleurodesis for spontaneous pneumothorax by either general or non-intubated anesthesia with intercostal nerve block and dexmetodimine/ketamine administration. We are awaiting with enthusiasm the results of both these studies, which will hopefully provide a lot to the current knowledge on these topics.

Some other questions should also be addressed. Which is the best anesthesia regimen to be used for non-intubated operations? Different methods have been proposed in this regard, but there is no definitive consensus on pros and cons profiles between the available techniques. Thoracic epidural anesthesia seems to the more accepted one (24), as it can provide an effective and broad analgesic coverage as well as a series of non-analgesic advantages (25). Other available options are paravertebral block and intercostal nerve block (26). We hope that appropriate randomized, controlled studies will be shortly undertaken to evaluate comparatively the performances of all these techniques and their peculiar features in the specific setting of non-intubated thoracic surgery. For example, the effect of these techniques on respiratory function should be considered. Indeed, low-grade bronchial constriction, a mild cardiovascular impairment or a slight reduction in auxiliary ventilation due to neural block (25,27-29) may have remarkable effect when performing thoracic surgeries on non-intubated subjects, despite being substantially irrelevant when tested in the conventional scenario.

To conclude, perhaps, the question which role should non-intubated thoracic surgery be given is too premature. At the present time, we all have still to think a lot about the movie itself, and have yet to define what the story should tell about. It will be just only when we will be corroborated by the strength of scientific evidence that we will be able to walk on the red carpet of thoracic surgery excellence and innovation.

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Non-intubated thoracic surgery—A survey from the European Society of Thoracic Surgeons

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Background: A survey amongst the European Society of Thoracic Surgeons (ESTS) members has been performed to investigate the currents trends, rates of adoption as well as potential for future expansion of non-intubated thoracic surgery (NITS) performed under spontaneous ventilation.

Methods: A 14-question-based questionnaire has been e-mailed to ESTS members. To facilitate the completion of the questionnaire, questions entailed either quantitative or multiple-choice answers. Investigated issues included previous experience with NITS and number of procedures performed, preferred types of anesthesia protocols (i.e., thoracic epidural anesthesia, intercostal or paravertebral blocks, laryngeal mask, use of additional sedation), type of procedures, ideal candidates for NITS, main advantages and technical disadvantages. Non-univocal answer to multiple-choice questions was permitted.

Results: Out of 105 responders, 62 reported an experience with NITS. The preferred types of anesthesia were intercostal blocks with (59%) or without (50%) sedation, followed by laryngeal mask with sedation (43%) and thoracic epidural anesthesia with sedation (20%). The most frequently performed procedures included thoracoscopic management of recurrent pleural effusion (98%), pleural decortication for empyema thoracis and lung biopsy for interstitial lung disease (26% each); pericardial window and mediastinal biopsy (20% each). More complex procedures such as lobectomy, lung volume reduction surgery and thymectomy have been performed by a minority of responders (2% each). Poor-risk patients due to co-morbidities (70%) and patients with poor pulmonary function (43%) were considered the ideal candidates. Main advantages included faster, recovery (67%), reduced morbidity (59%) and shorter hospital stay with decreased costs (43% each). Reported technical disadvantages included coughing (59%) and poor maneuverability due to diaphragmatic and lung movements (56%). Overall, 69% of responders indicated that NITS procedures will be likely to increase in the near future.

Conclusions: Results of this survey, suggest that NITS is already quite widely adopted by ESTS members to perform simple thoracoscopic procedures. A future expanded adoption of this strategy is also hypothesized.

Keywords: Non-intubated thoracic surgery (NITS); video-assisted thoracic surgery (VATS); awake video-assisted thoracic surgery (awake VATS); survey; regional anesthesia; minimally invasive surgery

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Introduction

Non-intubated thoracic surgery (NITS) that includes in its definition also the so called awake thoracic surgery, is aimed at minimizing the risks of conventional thoracic surgery performed by general anesthesia with single-lung ventilation by summing up potential advantages of video-assisted thoracic surgery (VATS) to those of less invasive anesthesia methods that do not need endotracheal intubation and assure maintenance of spontaneous ventilation.

Several unicenter reports including few randomized trials (1-6) have suggested optimal feasibility and excellent results although indications, advantages, and limits of NITS still need to be more thoroughly elucidated.

Herein we present the results of a first survey conducted amongst the European Society of Thoracic Surgeons (ESTS) members in order to provide insights into the rate of adoption, currents trends and potential future expansion of NITS within a large cohort.

Material and methods

To investigate the interest in NITS within a large cohort of thoracic surgeons, a 14-question-based web-questionnaire has been formulated and e-mailed to members of the ESTS with a link to a web-survey provider where the questionnaire was made available online (Survey Monkey® Inc., Palo Alto, CA, USA) asking to fill in the questionnaire.

Questions entailed either categorized quantitative or multiple-choice answers. Investigated issues included demographics (Questions: 1 name; 2 institution; 3 institution address; 4 preferred contact email), previous experience with NITS (Questions 5-7: *Figure 1*, *Table 1*), the anesthesia protocol employed for NITS (Questions 8,9: *Table 2*), type of procedures performed by NITS (Question 10: *Table 3*), indications, advantages and disadvantages of NITS (Questions 11-13: *Table 4*), personal believe regarding potential future expansion of NITS (Question 14). Non-univocal answers to multiple-choice questions were permitted. In addition, a dedicated note's space was also included in the questionnaire to allow personalized comments to better clarify the answers and implement both the overall interaction with responders and interpretation of the results. The questionnaire was kept available on the web for 2 months.

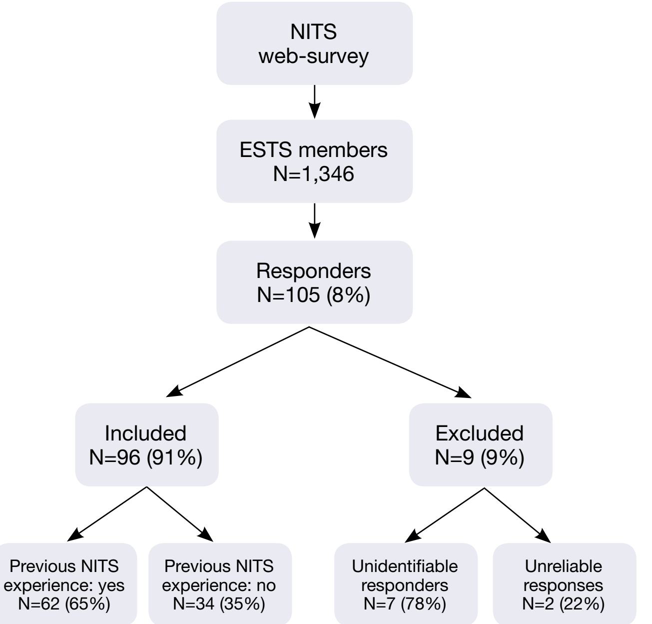

Figure 1 Flow chart summarizing the survey conducts.

Table 1 Questions dealing with responders who declared a previous experience with NITS

Questions	%	N
Q6: When did you start performing NITS?		
Before or up to 2000	39	21
Between 2001-2010	55	30
More recently	6	3
Q7: How many procedures have you performed?		
0-50	67	36
51-100	7	4
101-200	9	5
>200	17	9

NITS, non-intubated thoracic surgery.

Statistical analysis

Once closed the web-survey, all data were initially entered into an Excel database (Microsoft, Redmond, Washington, USA) and the analysis was performed using the Statistical Package for the Social Sciences Windows, version 15.0 (SPSS, Chicago, Illinois, USA).

Responders who did not indicate their name and/or the referring institution as well as those who provided unrelated, clearly unreliable responses were excluded from the data analysis. Instead, responders who provided identification details but did not respond to all questions were included.

Table 2 Questions dealing with anesthesia employed in NITS

Questions	%	N
Q8: Which type of anesthesia have you employed?		
Thoracic epidural anesthesia without sedation	9	5
Thoracic epidural anesthesia with sedation	20	11
Intercostal blocks without sedation	50	27
Intercostal blocks with sedation	59	32
Paravertebral blocks without sedation	9	5
Paravertebral blocks with sedation	9	5
Laryngeal mask with sedation	43	23
Other	15	8
Q9: During NITS procedures you perform, is the patient able to respond and interact actively with the surgical staff?		
Yes	70	38
No	30	16

NITS, non-intubated thoracic surgery.

Descriptive statistics consisted of the median with interval range (IR) for parameter with gaussian distributions (after confirmation with histograms and the Kolgomorov-Smirnov test) or frequencies (%).

Results

The flow diagram of the survey is detailed in *Figure 1*, 62 responders reported a previous experience with NITS. Amongst the 34 responders who negated a previous experience with NITS, 9 affirmed to have already planned to start it in the near future (*Figure 2*).

Fifty-four responders completed the entire questionnaire. Amongst the Institutions of responders who provided clear identification details there were 71 academic hospitals (74%), 16 community hospitals (17%), and 9 private institutions (9%).

Overall, out of 96 responders, 55 were from EC countries whereas 41 from non-EC countries.

The geographical distribution of responders who reported to perform NITS is detailed in *Figure 3*.

Questions dealing with starting time and surgical volume with NITS are included in *Table 1*. The majority of responders reported to have started in performing NITS between 2001 and 2010 whereas a minority affirmed to have already started before the 2000. The median time of beginning was 2004 (IR, 1990-2012).

Table 3 Questions dealing with type of procedures performed by NITS

Question	%	N
Q10: Which type of NITS procedures have you performed?		
Pleural biobpsy/drainage/talcage for recurrent pleural effusion	98	53
Pleural decortication for empyema thoracis	26	14
Mediastinal biopsy	20	11
Sympathectomy	6	3
Pericardial window for effusion	20	13
Blebectomy or blebectomy/pleurectomy for spontaneous pneumothorax	11	6
Bullectomy for bullous/giant bullous emphysema	13	7
Lung volume reduction surgery	4	2
Lung biopsy of interstitial lung disease	26	14
Pulmonary wedge resection of undetermined nodules	9	5
Pulmonary metastasectomy	7	4
Wedge resection of lung cancer	4	2
Segmentectomy	4	2
Lobectomy	2	1
Pneumonectomy	2	1
Excision of mediastinal tumor	2	1
Thymectomy	2	1
Other	20	11

NITS, non-intubated thoracic surgery.

As far as the overall number of NITS procedures performed by each Institution is concerned, the majority of responders reported a number comprised between 0 and 50 whereas 17% reported an overall experience of more than 200 procedures. The median number of procedures performed was 30 (IR, 2-1,200) with a median number of 5 (IR, 1-52) procedures per year.

The preferred types of anesthesia were intercostal blocks with or without sedation, followed by use of laryngeal mask with sedation and thoracic epidural anesthesia with sedation (*Table 2*).

The most frequently performed procedures (*Table 3*) were indicated to be in decreasing order of frequency, thoracoscopic management of recurrent pleural effusion, pleural decortication for empyema thoracis and lung biopsy for interstitial lung disease, followed by pericardial window

Table 4 Questions dealing with indications, advantages and disadvantages of NITS

Questions	%	N
Q11: Which are the ideal candidates for NITS in your opinion?		
Elderly patients	41	22
Patients with poor pulmonary function	43	23
Poor-risk patients due to multiple co-morbidities	70	38
All patients	20	11
Other	11	6
Q12: Which are the main advantages you have found?		
Easier patients' acceptance	28	15
Reduced stress hormone response	9	5
Reduced early immunologic impairment	4	2
Faster recovery	67	36
Reduced morbidity	59	32
Shorter hospital stay	43	23
Decreased costs	43	23
No advantage	7	4
Other	13	7
Q13: Which are the main technical disadvantages you have found?		
Poor maneuverability due to diaphragmatic and lung movement	56	30
Undue patient's movement	41	22
Coughing	59	32
Low oxygen saturation	13	7
Hypercapnia	7	4
Panic attack	20	11
No disadvantage	13	7
Other	7	4

NITS, non-intubated thoracic surgery.

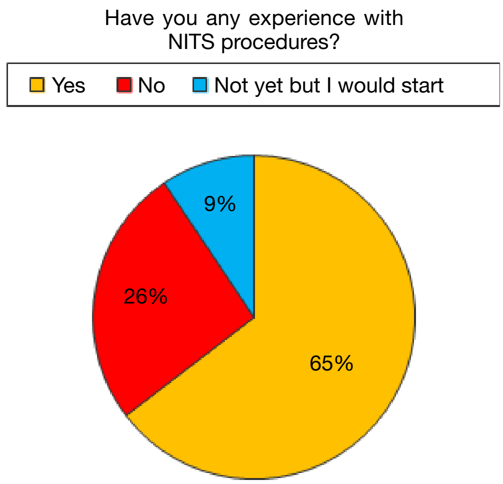

Figure 2 Previous experiences with non-intubated thoracic surgery (NITS) declared by European Society of Thoracic Surgeons (ESTS) members who responded to the questionnaire.

and mediastinal biopsy. More complex procedures such as lobectomy, lung volume reduction and thymectomy have been reported to be performed by a minority of responders.

Questions dealing with indications, advantages and disadvantages of NITS are detailed in *Table 4*. Regarding optimal candidates for NITS, poor-risk patients due to multiple co-morbidities were considered the ideal candidates by most of responders followed in frequency by patients with poor pulmonary function and elderly patients.

Faster recovery, reduced morbidity and lower costs were deemed by most of responders as the main potential advantages offered by NITS whereas coughing, poor maneuverability due to diaphragmatic and/or lung movement, and undue patients movements were reported as the main disadvantages.

At the last question dealing with future perspectives, 69% of responders believed that NITS procedures will be likely to increase in the near future (*Figure 4*).

Discussion

Surveys are now quite commonly employed to collect primary quantitative data from healthcare professionals in order to gather valid, reliable, and discriminatory data (7,8). This survey represents the first overview of the current trends and believes on NITS within the ESTS population and may represent a good platform to start cooperative investigational efforts to provide insights into the most debated and unresolved issues.

Overall, the number of responders who demonstrated an interest in NITS included an adequate representative of University, community and private hospitals across European and extra-European countries.

The rate of thoracic surgeons who expressed an interest in NITS accounted for 74% of responders and the number of surgeons who declared to perform NITS procedures was unexpectedly high provided that NITS entails non-standardized strategies and so far the majority of publications came from few research teams. In addition, 9% of responders admitted no experience but declared to have planned to start it in the near future. It is also worthy of note that on

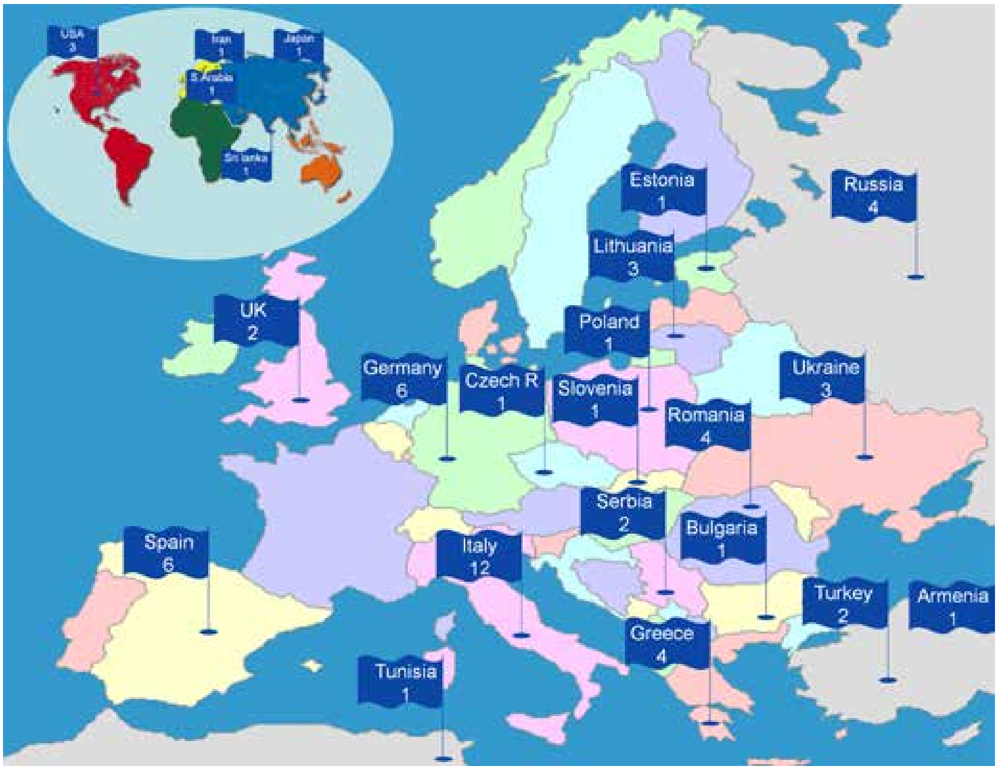

Figure 3 Geographical distribution of European Society of Thoracic Surgeons (ESTS) members who declared to perform non-intubated thoracic surgery (NITS) and provided identification details.

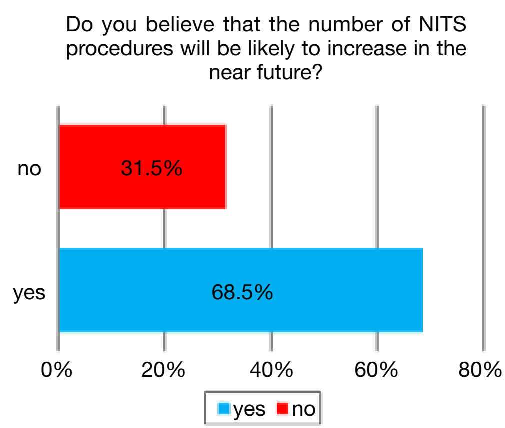

Figure 4 Bar graph detailing in percentages that the answers to the 14th question.

the final question related to a potential future expansion of NITS, about 70% of responders believed that the number of NITS procedures will be likely to increase in the near future. This perception can be considered highly satisfactory and contributes to encourage further investigation on this topic.

Starting time and volume

Regarding the starting time of individual experiences, 39% of responders affirmed to have already matured an experience with NITS reporting a median experience of 9 years. Overall, 67% of responders indicated a median number of 30 procedures only whereas only 17% of them reported an experience of more than 200 procedures. These findings are in line with the prevalence of literature reports on this topic indicating few centers which are relevantly dedicating their research activity to NITS (1-3,5,6) but on the same time they disclose a satisfactorily diffuse interest on these strategies.

Anesthesia methods

Among the various anesthesia protocols, which have been proposed, the present survey indicated that intercostals block with mild sedation is currently preferred by most of responders. The reasons leading to this preference are conjectural and may include the technical simplicity of this type of anesthesia and the fact that most of responders limited their experience to quick and simple VATS procedures, which are optimally suited to be performed by intercostals block only. On the other hand, surgeons who performed also more technically demanding procedures have usually preferred thoracic epidural anesthesia, which is somewhat more technically demanding but is supposed to assure superior thoracic analgesia (1,2).

Surgical procedures

In recent years, NITS has been increasingly employed to perform thoracic surgery procedures including management of recurrent pleural effusion (3,9), of spontaneous pneumothorax (4,10) and giant bullous disease (11), resection of pulmonary nodules (1,12), lung metastases (13) and lung cancer (2,5,6); pleural decortication (14), thymectomy (15), lung volume reduction surgery (16) and even tracheal resection (17) and bronchial sleeve lobectomy (18).

In this survey most of responders indicated that simple procedures including thoracoscopic management of recurrent pleural effusion, pleural decortication for empyema thoracis and lung biopsy for interstitial lung disease were those most frequently carried out by NITS whereas only few surgeons affirmed to perform more demanding procedures such as lobectomy, lung volume reduction surgery and thymectomy. This finding reinforces the hypothesis that for several simple procedures such as management of recurrent pleural effusion or pneumothorax, use of general anesthesia and one-lung ventilation is an unnecessary and not-risk-free option (3) provided that they can be safely and reliably performed by more simple anesthesia methods.

Ideal candidates

The empiric fear that a surgical pneumothorax is poorly tolerable by spontaneously ventilating, awake patients has been contradicted by several literature reports showing that adequate ventilation and satisfactory oxygenation can be assured throughout the procedure in most of operated patients and even in those with severely impaired respiratory function (16,19,20).

These findings seem in line with the survey responses on question dealing with optimal candidates for NITS. In fact, the majority of responders indicated that multiple comorbidity, poor pulmonary function and advanced age should be considered as the main eligibility criteria for NITS. This result is notable and if confirmed by future investigation might eventually lead to widen the rate of surgical candidates at least to a part of the patients who are currently considered unfit for surgery due to associated comorbid conditions or poor pulmonary function. Finally, in is also worthy of note that 20% of responders consider NITS as a suitable treatment option to be employed in all patients.

Advantages and disadvantages

As far as the main advantages and disadvantages of NITS were concerned, most of responders indicated faster recovery, reduced morbidity, shorter hospital stay and lower costs as the main potential advantages of NITS. This result suggests the existence of a relative consensus with literature findings of smoother and quicker postoperative recovery achieved by NITS as compared with results of intubated-thoracic surgery. Further potential advantages could also be related to a reduced postoperative stress hormone response and a lesser impairment in lymphocytes activity, which have been anecdotally reported (21,22) but await confirmation from future investigations.

On the other hand, coughing, poor maneuverability due to diaphragmatic and/or lung movement, and undue patients movements were indicated as the main disadvantages. These findings suggest that overall, as compared with intubated-anesthesia, factors that affect negatively the achievement of an immobile operative field and that can thus render more technically demanding surgical maneuvering, are considered as the major drawbacks of NITS.

Hence, standardization of technical refinements that can abolish the occurrence of inadvertent coughing and patients undue movements (6) will be required to promote a more diffuse acceptance and adoption of NITS strategies.

Limitations

The main limitation of this survey relates to a relatively low response rate. However, it must be taken into account that at least in some instances, one representative of a single Institution responded to the questionnaire on behalf of the whole group that may include several ESTS members. Although we cannot present this figure, it is clear that the crude response rate underestimated the real one. Moreover, the questionnaire was constructed to preferentially retrieve information from surgeons who already had an experience with NITS or who were in anyway interested in the topic. Accordingly, we believe that the survey results are meaningful since they indicated a much wider rate of adoption of NITS than that inferable by solely taking into consideration the available literature on this topic. In addition, when taking into consideration other similar surveys performed among the same population, the response rates varied considerably depending both on the topic and the questionnaire characteristics.

In a survey published by Internullo and coworkers (7) investigating attitudes of ESTS members regarding pulmonary metastasectomy, the response rate was of about 30% whereas more recently in another survey accomplished by Ruffini and coworkers (8) on thymic neoplasms, there were 44 reliable responders whereas the overall response rate was not reported.

Our response rate is lower than that reported by Internullo *et al*. even though NITS must be still considered a not standardized option when compared with procedures such as pulmonary metastasectomy and resection of thymic tumors, which are almost universally accepted and commonly carried out within the standard thoracic surgery practice.

We acknowledge that overall, survey results must not be taken as consensus statements or recommendations. Nonetheless, they may represent a good platform to start further multi-institutional collaborative efforts aimed at providing more definitive insights into the several issues still awaiting an answer.

Conclusions

This survey, suggests that NITS is already quite widely adopted among ESTS members and is mainly employed to perform simple VATS procedures. A future increase in the number of procedures performed by NITS has been foreseen by the majority of responders suggesting that the rationale underlying these strategies is deemed valid and this research field is of general interest.

We hope that future multi-institutional and multi-disciplinary cooperative investigation conducted either within and outside the ESTS will better explore indications, methods and results of NITS to eventually allow the drawing of reliable consensus statements.

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Nonintubated thoracoscopic lung resection: a 3-year experience with 285 cases in a single institution

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Objective: Tracheal intubation with one-lung ventilation is considered mandatory for thoracoscopic surgery. This study reported the experience of thoracoscopic lung resection without endotracheal intubation in a single institution.

Methods: From August 2009 through July 2012, 285 consecutive patients were treated by nonintubated thoracoscopic surgery using epidural anesthesia, intrathoracic vagal blockade, and sedation for lobectomy, segmentectomy, or wedge resection in a tertiary medical center. The feasibility and safety of this technique were evaluated.

Results: The final diagnosis for surgery were primary lung cancer in 159 patients (55.8%), metastatic lung cancer in 17 (6.0%), benign lung tumor in 104 (36.5%), and pneumothorax in 5 (1.8%). The operative methods consisted of conventional (83.2 %) and needlescopic (16.8%) thoracoscopic surgery. The operative procedures included lobectomy in 137 patients (48.1%), wedge resection in 132 (46.3%), and segmentectomy in 16 (5.6%). Collapse of the operative lung and inhibition of coughing were satisfactory in most of the patients. Fourteen (4.9%) patients required conversion to tracheal intubation because of significant mediastinal movement [5], persistent hypoxemia [2], dense pleural adhesions [2], ineffective epidural anesthesia [2], bleeding [2], and tachypnea [1]. One patient (0.4%) was converted to thoracotomy because of bleeding. No mortality was noted in our patients.

Conclusions: Nonintubated thoracoscopic lung resection is technically feasible and safe in selected patients. It can be a valid alternative in managing patients with pulmonary lesions.

Keywords: Anesthesia; tracheal intubation; lobectomy; lung cancer; thoracoscopy; segmentectomy; wedge resection

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Introduction

Since the introduction of the double-lumen endotracheal tube, intubated general anesthesia with one-lung ventilation has been considered mandatory in both open and video-assisted thoracoscopic surgery (VATS) (1). However, adverse effects of intubated general anesthesia occur after the operation and they include intubation-related complications, ventilator-induced lung injury, impaired cardiac performance, and postoperative nausea and vomiting (2-5). In order to reduce the adverse effects of tracheal intubation and general anesthesia, thoracoscopic surgery without tracheal intubation has been recently employed for management of pneumothorax (6-8), resection of pulmonary nodules (9-12), resection of solitary metastases (13), lung volume reduction surgery (14), and even performing lobectomy (15). The results achieved for these early surgeries are encouraging.

Although the feasibility of thoracoscopic surgery via nonintubated anesthesia was demonstrated in some reports, most of them are limited to small number of cases. In this study, we reported our experience of 285 consecutive patients undergoing nonintubated VATS or nonintubated needlescopic VATS in a 3-year period of time to evaluate the feasibility, safety, and indication of this innovative technique.

Patients and methods

Study design and patients

The medical records of all patients who underwent nonintubated VATS at National Taiwan University Hospital and National Taiwan University Hospital Yun-Lin Branch, a 3,200-bed tertiary medical center, from August 2009 to July 2012, were retrospectively reviewed. The thoracic surgical team, both surgeons and anesthesiologists, selected the cases upon review of the medical records. Patients considered appropriate for nonintubated VATS met the same criteria as for intubated VATS. Patients with American Society of Anesthesiologists (ASA) scores of greater than 3, bleeding disorders, sleep apnea, or unfavorable airway or spinal anatomy were contraindicated for nonintubated VATS in our hospital. Patient consent was obtained after explaining the type of anesthesia and the surgical procedure.

During this period of time, nonintubated thoracoscopic lung resections were performed in 285 patients, including wedge resection, segmentectomy, and lobectomy. The operation methods used were conventional VATS or needlescopic VATS. All patients were managed by a single thoracic surgical team using the same clinical protocols, care patterns, and perioperative orders.

Anesthetic setting, induction, and maintenance

Anesthetic techniques were described previously (10,11,15). Patients were pre-medicated with fentanyl 50-100 µg intravenously (IV) and were continuously monitored electrocardiographically, along with pulse oxymetry, respiratory rate, blood pressure, body temperature, and urine output. Monitoring of central venous pressure was optional. Thoracic epidural anesthesia was performed by insertion of an epidural catheter at the T5/6 thoracic interspace to achieve a sensory block between the T2 and T9 dermatomes, and was maintained by continuous infusion of 2% lidocaine. End-tidal carbon dioxide ($ETCO_2$) was continuously monitored by insertion of a detector into one nostril. The patient was then asked to turn him or herself into the lateral decubitus position. Sedation was then started by intravenous infusion of propofol (10 mg/mL) using a target-controlled infusion method, with incremental fentanyl injection to maintain the patient in a mildly sedated, but communicable and cooperative level (Ramsay sedation score III), responding to commands only (16).

During the procedure, patients breathed O_2 through a ventilation mask, keeping oxygen saturation above 90%. An iatrogenic pneumothorax was made by creating incisions through the chest wall for thoracoscopy and the ipsilateral lung collapsed gradually. To inhibit coughing during thoracoscopic manipulation in selected patients, intrathoracic vagal blockade was produced by infiltration of 2 mL of 0.25% bupivacaine adjacent to the vagus nerve at the level of the lower trachea for right-sided operations and at the level of the aortopulmonary window for left-sided operations, under direct thoracoscopic vision. This procedure effectively inhibited the cough reflex for 3 or more hours and was mandatory for lobectomy and segmentectomy, especially before anatomical dissection of the pulmonary hilum. Repeated bupivacaine infiltration was occasionally needed in prolonged operations. During the thoracoscopic procedure, the respiration rate was 12-20/min.

During wound closure and chest tube insertion, propofol infusion was stopped. After the patient was fully awake, the patient was asked to breathe deeply and cough to re-expand the collapsed lung. The epidural catheter was used for postoperative pain control during the following days.

Technique of thoracoscopic surgery

The detailed surgical setting and procedures performed in our group were described before (10,15). Thoracoscopic lobectomy, segmentectomy, or wedge resection was performed using a 3-port method, as described by McKenna (17). In brief, the patient was positioned in the full-lateral decubitus position, with slight flexion of the table at the level of the mid-chest. The thoracoscope was placed into the seventh or eighth intercostal space in the midaxillary line. A working port was placed in the sixth or seventh intercostal space in an auscultatory triangle, and an anterior 3 cm incision was placed anteriorly in the fifth intercostal space. After collapse of the lung, incomplete fissures, pulmonary vessels, and bronchi were divided with endoscopic stapling devices. The resected specimen was removed in an organ retrieval bag through the utility incision. After staging mediastinal lymph node dissection, a 28-French chest tube was placed through the lowest incision. Rib spreading, rib cutting, and retractor use were avoided in all patients, except when conversion to thoracotomy was required. Conversion from nonintubated anesthesia to intubated general anesthesia or from thoracoscopic surgery to thoracotomy was decided by the attending surgeon and anesthesiologist. Conversion from nonintubated to intubated anesthesia was performed when epidural anesthesia was ineffective, hypoxemia persisted (S_PO_2 <80%), hemodynamic status was unstable, or intraoperative bleeding requiring thoracotomy. When conversion was indicated, the surgical wounds were sealed with transparent waterproof dressings (Tegaderm Film, 3M Health Care, Neuss, Germany) after insertion of a chest tube to re-expand the lung. A single-lumen endotracheal tube was inserted under the guidance of a bronchoscope, followed by insertion of a bronchial blocker without changing the patient's position.

After the operation, chest radiography was performed immediate or the next morning. Drinking and meal intake were resumed 2-4 hours after surgery. The chest tube was removed if no air leak was present and drainage was less 200 mL in a 24-hour period.

Technique of needlescopic VATS

Needlescopic VATS was mainly used for biopsy of undiagnosed peripheral lung nodules. The technique was described previously (10). Briefly, of Two sets of independent video-thoracoscopic equipment and monitors (HD Endoscopy System, Karl Storz, Tuttlingen, Germany), one for needlescopic videothoracoscopy and the other for 10-mm videothoracoscopy, were used simultaneously to save time switching scopes (18,19). An incision of about 15 mm in length was made in the sixth intercostal space on the midaxillary line and a 12-mm thoracic port was inserted through the incision. Two or three small skin punctures were made and mini-ports were inserted for the needlescopic instruments (3-mm instruments, Olympus, Tokyo, Japan). Initially, the 10-mm telescope and two mini-endograspers were used to identify the nodule. Once the nodule was identified, it was stabilized using the mini-endograsper. The mini-endograsper in the other mini-port was withdrawn and a needlescope was introduced to visualize the tumor. The 10-mm telescope was then withdrawn and a 45-mm endoscopic stapler was introduced for partial lung resection including the nodule. Resected tissue was placed into a bag inserted through the 12-mm port and was taken out of the thoracic cavity. Upon completion of the procedure, a chest tube was inserted via the 12-mm port.

Data collection and analyses

The data including patient demographics, complications, and the surgical results were collected from the institutional database, anesthesia and surgical notes, and the medical and nursing records.

Results

From August 2009 through July 2012, nonintubated thoracoscopic lung resection was performed on 285 patients. The demographic data of the patients are shown in *Table 1*. The mean patient age was 59.2 years and 107 patients (37.5%) were male. Conventional VATS was performed in 237 patients (83.2%), while needlescopic VATS was performed in 48 patients. One patient received bilateral VATS for lesions in both lungs (11). Operation procedures included lobectomy in 137 patients (48.1%), followed by wedge resection and segmentectomy.

The operative and anesthetic results are shown in *Table 2*. The mean duration of anesthesia induction was 34.3 minutes. Fourteen (4.9%) patients required conversion to tracheal intubation because of significant mediastinal movement [5], persistent hypoxemia [2], dense pleural adhesions [2], ineffective epidural anesthesia [2], bleeding [2], and tachypnea [1] (*Table 3*). Conversion to a thoracotomy was required in one patient with blood transfusion due to bleeding during dissection of pulmonary artery. After the surgery, anesthetic side effects were noted in 23 patients (8.1%) including vomiting, sore throat, and headache. Operation complications were noted in 11 patients (3.9%) including air leaks >5 days, bleeding, and pneumonia. No mortality or major complications were noted.

Discussion

Since the introduction of thoracoscopic surgery, intubated general anesthesia with one-lung ventilation has been considered mandatory for lung resection. To avoid intubation-related or mechanical ventilation-associated complications, thoracoscopic surgery without endotracheal intubation has recently been tried in selected patients. However, the number of patients in the published reports is small (2,6-15). This is the first report of nonintubated thoracoscopic lung resection applied in large number of patients. Our results showed that nonintubated VATS is feasible and safe for lobectomy, segmentectomy, and wedge resection.

Some concerns might arise with the use of nonintubated epidural anesthesia for pulmonary resection, especially for patients with compromised respiratory function. First, prolonged one-lung breathing during surgery could

Table 1 Clinical characteristics of the patients.

Variable	N=285
Age [y][a]	59.2±12.3 [60,19-89]
Sex (male)	107 (37.5%)
Smoking (%)	75 (26.3%)
Operation methods	
Conventional VATS	237 (83.2%)
Needlescopic VATS	48 (16.8%)
Operation procedures	
Lobectomy	137 (48.1%)
Wedge resection	132 (46.3%)
Segmentectomy	16 (5.6%)
Pathological diagnosis	
Lung cancer	159 (55.8%)
Metastatic cancer	17 (6.0%)
Benign lung tumor	104 (36.5%)
Pneumothorax	5 (1.8%)

[a]Mean ± standard deviation (median, range); VATS = video-assisted thoracoscopic surgery.

Table 2 Treatment outcome of nonintubated thoracoscopic lung resection.

Variable	N=285
Anesthetic side effects (%)	
Vomiting requiring medication (%)	12 (4.2%)
Sore throat (%)	6 (2.2%)
Headache	5 (1.8%)
Operation complications (%)	
Air leaks >5 days	6 (2.1%)
Bleeding	2 (0.7%)
Pneumonia	3 (1.1%)
Conversion to tracheal intubation (%)	14 (4.9%)
Lobectomy	10/137 (7.3%)
Wedge resection	3/132 (2.3%)
Segmentectomy	1/16 (6.3%)
Conversion to thoracotomy (%)	1 (0.4%)
Mortality (%)	0 (0%)

Table 3 Causes of conversion to tracheal intubation.

	N =14
Significant mediastinal movement	5 (35.7%)
Persistent hypoxemia	2 (14.3%)
Dense pleural adhesions	2 (14.3%)
Ineffective epidural anesthesia	2 (14.3%)
Bleeding	2 (14.3)
Tachypnea	1 (7.1%)

lead to hypoxia and hypercapnia in patients with already compromised respiratory function. Secondly, epidural anesthesia-associated sympathetic blockade could lead to increased bronchial tone and airway hyperreactivity. Thirdly, lung movement and inadequate lung collapse would make hilar dissection more difficult. Fourthly, conversion to general anesthesia with intubation could be required occasionally (15).

To prevent respiratory failure, we selected patients with good cardiopulmonary reserve during the learning curve of this cohort. In most of the patients, S_PO_2 was maintained at 90% or more during the whole operation. Hypercapnea was noted in some patients, especially when the surgery was long. Our experience showed that hypercapnia was permissive and did not affect the hemodynamics and surgical procedures, which was comparable to a recently published report by Dr. Dong et al. (12).

Increased bronchial tone and airway hyper-reactivity during manipulation of the pulmonary hilum was a major obstacle when performing nonintubated lobectomy or segmentectomy. Using simple intrathoracic vagal blockade, we found that the cough reflex could be effectively abolished, without affecting the heart rate, breathing rate, and blood pressure (15).

Although non-intubated thoracoscopic lung resection could provide an attractive alternative in managing patients with lung diseases, they should be cautious until judicious evaluation of the benefits and risks is complete. Fourteen patients (4.9%) in the nonintubated group required conversion to intubated one-lung ventilation because of significant mediastinal movement, persistent hypoxemia, dense pleural adhesions, ineffective epidural anesthesia, bleeding, and tachypnea. We suggest that proper patient selection, accumulated experience by performing minor non-intubated thoracoscopic procedures, and conversion to intubated general anesthesia without hesitation are mandatory to decrease the risk of emergency intubation and complications, especially at the beginning of the learning curve.

In our cohort, almost two third of the patients were women. We believe that nonintubated thoracoscopic surgery

Table 4 Comparison among different nonintubated anesthesia techniques and the applicable thoracoscopic procedures [modified from works of Dr. Tseng et al. (10)].

Anesthetic techniques	Pleural diseases[a]	Wedge resection	Lobectomy or segmentectomy
Local anesthesia + IV sedation	+	+	–
Epidural anesthesia + IV sedation	+	+	–
Epidural anesthesia + IV sedation + vagal blockade	+	+	+

[a]Including pleural biopsy and management of pneumothorax and empyema; +, Technically feasible; –, Technically infeasible; IV, intravenous.

is most applicable in small body-sized female patients. These patients are prone to have small tracheal caliber and are susceptible to intubation-related complications such as sore throat, hoarseness, and subglottic stenosis, especially when double-lumen endotracheal tubes are used. Using the nonintubated technique, we found that the rates of postoperative sore throat were significantly decreased. It is reasonable to suggest that the incidence of hoarseness and tracheal injury could also have been lower, although they were not investigated in this study.

Many of our patients presented with an undetermined solitary pulmonary nodule when undergoing thoracoscopic surgery. A previous study showed that wedge resection of benign lung nodules can be performed by awake thoracoscopic surgery (9). One of the major concerns of the awake technique is that when the frozen section shows malignancy, the procedure must be converted to intubated general anesthesia for subsequent lobectomy. Using our nonintubated technique, both the diagnosis of the pulmonary nodules and curative resection of the lung cancer can be performed under the same type of anesthesia. Our technique extends the indication of nonintubated anesthetic technique to a wider application. A comparison among different types of nonintubated anesthesia techniques and applicable thoracoscopic procedures is provided in *Table 4*.

The anesthetic side effects were minimal in this patient cohort. In a previous study of intubated one-lung ventilation for thoracoscopic lobectomy, 40% of patients required medication for control of vomiting and 37% had a sore throat (15). In this study, the rates were 4.2% and 2.2%, respectively. We attribute these results to the avoidance of tracheal intubation and muscle relaxants.

We acknowledge that this study was limited by its retrospective design and the lack of a control group for comparison. Nonetheless, the low conversion rate from nonintubated to intubated anesthesia and the low complication rate indicate that nonintubated VATS can be safely performed in selected patients.

Conclusions

Nonintubated thoracoscopic lung resection is safe and technically feasible. Avoidance of intubation, mechanical ventilation, muscle relaxants, and routine use of perioperative epidural anesthesia in these patients was reflected in less intubation-associated discomfort, and immediate return to many daily life activities including drinking, eating, and walking. Nonintubated thoracoscopic surgery is a less invasive surgery than traditional thoracoscopy due to the combination of less thoracic trauma and less invasive anesthesia. Although the long-term outcome and benefits remain unclear, we believe that it can be a valid alternative of one-lung ventilated thoracoscopic surgery in managing patients requiring lung resection.

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Analysis of feasibility and safety of complete video-assisted thoracoscopic resection of anatomic pulmonary segments under non-intubated anesthesia

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Objective: To explore the feasibility and safety of complete video-assisted thoracoscopic surgery (C-VATS) under non-intubated anesthesia for the resection of anatomic pulmonary segments in the treatment of early lung cancer (T1N0M0), benign lung diseases and lung metastases.

Methods: The clinical data of patients undergoing resection of anatomic pulmonary segments using C-VATS under non-intubated anesthesia in the First Affiliated Hospital of Guangzhou Medical University from July 2011 to November 2013 were retrospectively analyzed to evaluate the feasibility and safety of this technique.

Results: The procedures were successfully completed in 15 patients, including four men and eleven women. The average age was 47 [21-74] years. There were ten patients with adenocarcinoma, one with pulmonary metastases, and four with benign lung lesions. The resected sites included: right upper apical segment, two; right lower dorsal segment, one; right lower basal segment, two; left upper lingular segment, three; left upper apical segment, one; left upper anterior apical segment, two; left upper posterior segment, one; left lower basal segment, one; left upper posterior and apical segments, one; and left upper anterior and apical segments plus wedge resection of the posterior segment, one. One case had intraoperative bleeding, which was controlled with thoracoscopic operation and no blood transfusion was required. No thoracotomy or perioperative death was noted. Two patients had postoperative bleeding without the need for blood transfusions, and were cured and discharged. The pathologic stage for all patients with primary lung cancer was IA. After 4-19 months of follow-up, no tumor recurrence and metastasis was found. The overall mean operative length was 166 minutes (range 65-285 minutes), mean blood loss 75 mL (range 5-1,450 mL), mean postoperative chest drainage 294 mL (range 0-1,165 mL), mean chest drainage time 2 days (range 0-5 days), and mean postoperative hospital stay 5 days (range 3-8 days).

Conclusions: Complete video-assisted throacoscopic segmentectomy under anesthesia without endotracheal intubation is a safe and feasible technique that can be used to treat a selected group of IA patients with primary lung cancer, lung metastases and benign diseases.

Keywords: Video-assisted thoracoscopic surgery (VATS); segmentectomy; lung cancer

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Introduction

Lung cancer is the most common cancer worldwide, accounting for about 15% of cancer cases around the world, and 28% of cancer deaths (1). Lung cancer is also associated with the highest morbidity and mortality among all malignant conditions in China (2). Surgical resection by thoracotomy or thoracoscopy is the preferred treatment for early-stage non-small cell lung cancer (3). Since the early 1990s, video-assisted thoracoscopic surgery (VATS) has been rapidly developed and widely applied in the world, involving almost all areas of general thoracic surgery. Compared with thoracotomy, VATS enables a smaller incision without removing or stretching the ribs open, sparing respiratory muscles from injures and thus minimizing the loss of lung function. Moreover, with a smaller incision, patients will suffer less pain postoperatively and expectorate more easily, reducing the incidence of postoperative pulmonary infection and complications as well (4). Thoracoscopic lobectomy is a representative application of thoracoscopic surgical techniques in thoracic surgery.

With the development and extensive application of imaging techniques such as high-resolution computed tomography (HRCT) and low-dose spiral computed tomography (CT), the detection rate of small lung nodule of unknown nature has been increasing. Lung resection is considered to be applicable for early lung cancer (T1N0M0), small metastases and localized benign lesions (such as bronchiectasis and tuberculosis) (5-8). Compared with lobectomy, segment resection better preserves lung functions while removing small nodules (9). With the intensified aging population, some patients are often complicated with cardiovascular diseases that make them unable to tolerate lobectomy, and therefore segmental resection has also been considered for the treatment of patients with primary lung cancer and poor cardiopulmonary function (3).

For now, general anesthesia with one-lung intubated ventilation is the standard anesthesia in thoracic surgery. Intubated anesthesia is, however, often associated with postoperative throat discomfort, including primarily irritating cough, and throat pain in some patients. On the other hand, non-intubated anesthesia can reduce general anesthesia-related complications, and many investigators have therefore begun to explore its application in general thoracic surgery. Dong *et al.* reported that thoracoscopic wedge resection under non-intubated anesthesia was feasible and safe (10). Chen *et al.* reported the safety and feasibility of thoracoscopic resection under non-intubated anesthesia (lobectomy, lung resection and wedge resection) in 285 patients (11). Hung *et al.* reported segmental resection under non-intubated anesthesia in 21 patients, finding that the technique preserved maximum normal lung tissue while reducing the loss of lung functions, and general anesthesia-related adverse reactions (12). This study summarizes 15 patients undergoing C-VATS resection of anatomic pulmonary segments under non-intubated anesthesia in our department.

Subjects and methods

Clinical data

Patients undergoing C-VATS resection of anatomic pulmonary segments from July 2011 to November 2013 were enrolled. All patients received pre-operative chest high-resolution thin-slice enhanced CT scans and pulmonary function tests. For those suspected of lung cancer, additional upper abdomen CT, head MRI, whole body bone scintigraphy or whole body PCT examination was needed to exclude distant metastases. Patients were eligible when they had an ASA grade of I-II, BMI <25 and no evident airway secretions or contraindications for epidural puncture in preoperative anesthesia assessment (11). All operations were performed by the same group of thoracic surgeons and anesthesiologist team. The primary outcome measures included the operative time, intraoperative blood loss, hospital stay, chest drainage, chest tube duration, and type of lung resection.

Indications for segmental resection

The indications for segmental resection included: (I) a lung mass close to the hilum in which wedge resection is not possible; (II) history of lung lobe resection, leading to the consideration of an additional primary lesion; (III) past history of other malignancies and lung solitary tumors, for which differentiation with primary lung cancer is not possible via intraoperative frozen sections; (IV) multiple pulmonary ground-glass shadows, for which atypical adenomatous hyperplasia (AAH), adenocarcinoma *in situ* (AIS) or minimally invasive adenocarcinoma (MIA) may be suspected; (V) a complication with any cardiopulmonary disease that makes lobectomy intolerable; and (VI) peripheral early lung cancer ≤2 cm in diameter.

Surgical methods

Administration of anesthesia: with established intravenous rehydration, an epidural catheter is inserted in the thoracic T6-7 space. In the supine position, 2 mL of 2% lidocaine is injected through the epidural catheter. If signs of spinal anesthesia are not present in five minutes, fractionated injection of 12 mL 0.375% ropivacaine is administered. Before surgery, the anesthesia level should reach between T2 and T10. Propofol and remifentanil are infused for sedation and analgesia during surgery, with the BIS values maintained between 40 and 60. During surgery, masked and nasopharyngeal airway assisted ventilation is given with an inhaled oxygen concentration FiO_2 of 0.33. Monitors are mounted on both sides along the patient's head, which generally lies on the opposite side to the operating site, with the hilum and waist padded to further widen the intercostal space. The operator stands in front of the patient, the first assistant on the patient's back side, and the second assistant handles the thoracoscope. The first port is generally made in the 7th or 8th intercostal space at the anterior axillary as the observation port. It should be noted that, in case that the diaphragm is too high or unclear on the X-ray images, this port should be positioned at a higher intercostal space to avoid injuring the abdominal organs. The second port is usually in the 7th intercostal space at the posterior axillary line and the third port close to the lesion, which form a triangle on the chest wall. All of them are treated with soft incision protectors to serve as the surgical operation channels. All video-assisted thoracic operations are performed using Stryker 1288 HD 3-Chip Camera/1288 with a three-chip HD camera system and specially designed endoscopic instruments in our department. After insertion of the thoracoscope from the first port, full chest exploration is conducted to determine whether there is evidence that the lesion is unresectable, such as pleural metastasis or other sign of metastases. Local vagus nerve block is achieved with 2 mL of 2% lidocaine under thoracoscopic guidance in the chest cavity, followed by spray of appropriate amount of the same concentration on the surface to reduce coughing that may induced by pulling of the lung tissue, ensuring a steady operation environment.

The thoracoscopic lung resection is done following the basic principle for lobectomy, in the order of arteries, bronchi, veins, and lung parenchyma in general. For resection of upper segments in the left upper lung, the veins are treated first because the superior branch of the superior pulmonary vein is anterior to, and blocks part of, its anterior branch, and thereby it should be first transected. The use of staplers and vascular clips is at the discretion of the operator depending on the vessel sizes during the surgery. According to the experience of the surgeons in our department, the use of hemolok and titanium clips should be avoided when clamping blood vessels. That is mainly because their application may affect the appropriate operation of other equipment such as stapler. (For example, a clip being caught in the stapler may prevent it from being successfully triggered.). Although in the event that vessels are well exposed, a stapler can be used to directly close or ligate and cut them off, there are still many factors that may affect those operations to such an extent that vessels are excessively pulled and injured when the stapler passes through them. In such cases, the tip of a linear stapler can be guided through the stapler guiding catheter to safely pass the posterior part of a vessel to successfully cut it off. The same method can be used to cut off bronchi, with satisfactory results. After the vessels and bronchi at the lesion segment are resected, the lung segment is in an atelectasis state. The anesthesiologist is instructed to maintain low volume low pressure ventilation to help determine the intersegmental plane. In addition, when the veins around the segment and in the surrounding segments to be preserved are well exposed, they can also be used to help identify the intersegmental plane. Mediastinal lymph node assessment is an essential component in thoracoscopic segmental resection for non-small cell lung cancer. Systemic lymph node dissection is performed following the segmental resection. Frozen sections of the segmental bronchus stumps and lymph nodes are sent for pathological tests. When positive intersegmental or interlobular metastases are present, switch to lobular resection is always preferred as long as the patient's physical conditions allow. If there is so little residual tissue following the resection that the high mobility makes lung torsion likely, Gossot *et al.* suggests connecting with the adjacent lobes via TA to reduce the postoperative complication (10). During surgery, if SpO_2 drops to below 90%, mask assisted ventilation is needed to improve oxygenation. If blood gas analysis shows an arterial carbon dioxide partial pressure of ≥80 mmHg, the operation needs to be suspended followed by mask-assisted gas exchange. If the ventilation does not improve in this way, endotracheal intubation is required (9). Chest tube drainage is routinely used after the surgery. When there is no leakage and thoracic fluid volume is less than 200 mL per day, removal of the drainage can be considered.

Specific methods of segmental resection

(I) Resection of right upper posterior apical segments: the

Table 1 Basic characteristics of patients

Characteristics	Number of patients (n=15)	Percentage
Median age (years)	47 [21-74]	
Gender		
Male	4	27
Female	11	73
Smoking history		
No smoking history	15	100

Table 2 Postoperative pathology

Pathological type	Number of patients (n=15)	Percentage
Primary bronchogenic carcinoma		
Adenocarcinoma	10	66.7
Metastasis		
Lung metastasis of breast cancer	1	6.7
Benign disease		
Pulmonary sclerosing hemangioma	1	6.7
Bulla	1	6.7
Proliferation of fibrous connective tissue	1	6.7
Arteriovenous fistula	1	6.7

apical and posterior segments can be treated separately, but they are usually removed at the same time. The posterior ascending aorta anterior to the upper lobular bronchus is treated before the bronchi. The upper lobe is pulled forward to expose the posterior mediastinum. The pleura of the upper lobe bronchus close to the mediastinum are opened using coagulation hook, "peanut" gauze or a combination of both. A 45-mm endoscopic stapler is used to open the posterior part of the oblique fissure to help expose the ascending aorta, and the artery is transected. With combined use of the cautery hook, right-angle clamp and ultrasonic scalpel, the surrounding soft tissue is separated until the apical segmental bronchus is fully exposed. The apical artery is located posterior to it. A cutting stapler is used to close the bronchus while the posterior arteries are properly protected. After transection of the segmental bronchus, the apical artery is revealed. The upper lung lobe is pulled backwards to expose the apical vein anterior to the hilum, which is then closed and cut. When eventually cutting the lung parenchyma, the anesthetist is instructed to maintain low-pressure ventilation so that the boundary line between ventilated and non-ventilated areas can be followed as the cutting line.

(II) Resection of the upper segment in the right lower lung: with combined use of the coagulation hook and ultrasonic scalpel, the pleura around the hilum in the right lower lung are divided and the oblique fissure opened using a stapler. The pulmonary arteries are gradually exposed. After the upper segmental artery is divided and cut, the posterior bronchus is revealed, separated, stapled and cut. The inferior pulmonary ligament is transected through to the inferior pulmonary vein. Gauze is used to expose the superior segmental vein upwards from the inferior pulmonary vein, and the former is then cut with a vascular clamp or stapler.

(III) Resection of the basal segment in the right lower lung: the anterior part of the oblique fissure is opened to expose the basal segment artery, which is transected and closed. The segmental bronchus is separated from the deep structure of the artery. The anesthesiologist is instructed to help identify if the basal segment bronchus is closed off by ventilation. The inferior pulmonary ligament is transected through to the inferior pulmonary vein. With the inferior lobe is pulled up, the surrounding tissue of the inferior pulmonary vein is divided using the cautery hook and peanut gauze. The basal segment vein is exposed and transected.

(IV) Lingular segment of the left upper lung: the lingular artery is separated and transected to reveal the upper lobular bronchus and lingular segmental bronchus. The latter is clamped, and low ventilation is used to identify its closure before transaction. The superior pulmonary vein is separated until its lowermost branch is exposed. If the lingular segmental vein can be located, it is transected before the intersegmental pulmonary tissue is handled. Otherwise, the lingular segmental vein can be treated until the lingular segmental tissue is fully separated.

Results

The procedures were successfully completed in 15 patients, including four men and eleven women. The average age was 47 [21-74] years. The patient characteristics are listed in *Table 1*. Pathological examination showed ten patients with adenocarcinoma, one with pulmonary metastases, and four with benign lung lesions (*Table 2*).

Segmental resections were successful in all patients without switching to thoracotomy or lobectomy. The

Table 3 Thoracoscopic resection of lung segments

Sites	Number
Left	
S4 + S5	3
S1 + S3 + PS2	1
S1	1
S2	1
S7 + S8 + S9 + S10	1
S1 + S3	2
S1 + S2	1
Total	10
Right	
S1	2
S6	1
S7 + S8 + S9 + S10	2
Total	5

Note: S1, apical; S2, posterior; S3, anterior; S4 + S5, lingular; S6, superior; S7, medial basal; S8, anterior basal; S9, external basal; S10, posterior basal.

resected sites included: right upper apical segment, two; right lower dorsal segment, one; right lower basal segment, two; left upper lingular segment, three; left upper apical segment, one; left upper anterior apical segment, two; left upper posterior segment, one; left lower basal segment, one; left upper posterior and apical segments, one; and left upper anterior and apical segments plus wedge resection of the posterior segment, one. Resected lung segments are shown in *Table 3*.

One case had intraoperative bleeding of 1,450 mL, which was controlled with thoracoscopic operation and no blood transfusion was required. There were no perioperative deaths. Two patients of postoperative bleeding were controlled with hemostatic medicine without the need for blood transfusions, and no other serious complications occurred. All patients were cured and discharged. The overall mean operative length was 166 minutes (range 65-285 minutes), mean blood loss 75 mL (range 5-1,450 mL), mean postoperative chest drainage 294 mL (range 0-1,165 mL), mean chest drainage time 2 days (range 0-5 days), and mean postoperative hospital stay 5 days (range 3-8 days) (*Table 4*).

Of the ten patients with primary lung cancer, nine received mediastinal lymph node dissection or systemic lymph node sampling, and the pathological staging showed stage IA for them; one patient who did not receive the above procedure had micro invasive adenocarcinoma in the left lung. After 4-19 months of follow-up for the patients, no tumor recurrence and metastasis was found.

Table 4 Intra- and post-operative conditions of lung resection surgery

Characteristics	Value/number of patients
Mean operation length (min)	166 [65-285]
Mean intraoperative blood loss (mL)	75 [5-1,450]
Mean drainage volume, mL	294 [0-1,165]
Mean drainage days	2 [0-5]
Mean postoperative stay (days)	5 [3-8]
Perioperative complications	
Postoperative bleeding, n (%)	2 (13.4)

Discussion

Whether segmental resection can achieve comparable effects to lobectomy for the treatment of early stage lung cancer is still controversial. Previous studies have shown that for early lung cancer, particularly when the tumor diameter is ≤2 cm, segmental resection can yield comparable long-term survival as with lobectomy (13,14). However, evidence in this regard comes mainly from retrospective case comparisons and meta-analyses, and the role of segmental resection in NSCLC needs to be further confirmed by large international multi-center randomized controlled clinical studies (CALGB 140503 in the United States and JCOG0802/WJOG4607L in Japan).

Complete thoracoscopic segmental resectionis a complex and technically demanding procedure, requiring the surgeon to be extremely familiar with the anatomic structures of every segmental vessel and bronchus. One of the major technical difficulties is confirmation of the plane between segments. Most investigators traditionally suggest low-pressure ventilation after occlusion or transection of segmental bronchi, so that the plane can be determined by differentiating between the collapsed and expanded interface. The purpose of the ventilation is to avoid the influence on endoscopic vision and operation by excessive expansion of lung tissue. According to our experience, a long-handled tong may be used to clamp the plane after low-pressure ventilation, as it provides two main advantages: (I) in view of the traffic between the lung segments, adjacent lung segments can be expanded with ventilation, blurring the lung segment boundary;

(II) a stapler only provides a limited opening angle that is likely to injury the lung parenchyma when coming across the thicker portion of it, leading to the need of manual stitches and bleeding control after the resection, which will increase the length of operation. The use of this recommended instrument can provide local compression, making it easier for a stapler to pass the lung segment boundary. Some investigators on the other hand suggest the use of selective lung ventilation in patients with COPD, in which the target segment is expanded through bronchoscopy and separated from other collapsed lung segments, reducing the impact of endoscopic vision by lung expansion (15). Segmental veins can also be helpful in identifying the intersegmental plane, and separation along pulmonary veins and loose connective tissue in the lung segments usually does not damage large bronchi and pulmonary arterial branches. Some lesions are located between segments, and when reliable surgical margins are not secured, resection of the adjacent segments can be considered.

Compared with traditional surgery under general anesthesia, epidural analgesia reduces intubation-related complications and facilitates early mobility of patients (10,11,16). It also reduces the dose of intraoperative anesthesia drugs, which will help restore the breathing and digestive functions. Four to six hours after non-intubation segmental resection, the patients could start eating, drinking, and get out of bed. Chest X-ray scans could be performed on the same the day after surgery. If imaging tests suggest good lung recruitment and no air leaks, and 24-h chest drainage is less than 200 mL, the drainage can be removed. With non-intubated anesthesia, coughing induced by postoperative throat discomfort is significantly reduced. Coughing may worsen wound pain, which in turn suppresses the cough reflex, making pulmonary secretions difficult to discharge after surgery, and indirectly leading to alveolar hypoventilation due to rapid and shallow breathing; some patients may even experience atelectasis or lung infection after surgery. Therefore, non-intubation endoscopic resection of lung segments may reduce the incidence of pulmonary complications, maximize protection of lung function and reduce postoperative pain, shorten chest tube duration, shorten the length of hospital stay, and allow faster recovery to preoperative mobility.

Non-intubated anesthesia combined with C-VATS lung resection surgery should be one of the most minimally invasive lung cancer surgery at present. With non-intubation anesthesia, the biggest challenge for surgeons is the remarkable mediastinal motion, which requires full cooperation among the surgeon, anesthetists and assistants. Mediastinal movement occurs when the ipsilateral intrathoracic pressure was significantly higher than that of the contralateral side in open pneumothorax, resulting in mediastinal shift to the contralateral area that further limits expansion of the contralateral lung. During inhalation and exhalation, the unbalanced pleural pressure on both sides experiences cyclical changes so that the contralateral mediastinum moves toward the contralateral side during inhalation and the opposite side during exhalation. In non-intubation segmental resection, the patient's spontaneous breathing has to be retained in order to achieve atelectasis of the operative side and good ventilation of the contralateral lung, so that both the oxygen supply and a favorable operating field can be secured. With collapsed ipsilateral lung after thoracotomy, some patients will have obvious mediastinal swing, which will affect the surgeon's surgical operation, particularly when dealing with blood vessels in which excessive traction may lead to bleeding. To mitigate the impact of the mediastinal swing during surgery, anesthesiologists can increase the amount of opioids based on the operation, reduce the breathing frequency or the respiratory tidal volume, thereby reducing the amplitude of the swing. At the same time, appropriate ventilation can be given based on the results of blood gas analysis to avoid serious hypercapnia, so as to maintain the body's acid-base balance.

Based on the fifteen patients undergoing non-intubated anesthesia combined with C-VATS lung resection in our department, the technique is feasible and safe with the help of skilled anesthetists with experience in thoracoscopic lobectomy and non-intubated anesthesia. So far, there has been no shift to thoracotomy and lobectomy. Although there was one case of bleeding, it was well controlled endoscopically without the need of blood transfusion. As for the two cases of postoperative bleeding, no blood transfusions were needed and no other complications were observed. The incidence of perioperative complication was 13.4%. The mean operative time was 166 minutes, mean intraoperative blood loss 75 mL, mean postoperative chest drainage two days, and mean postoperative hospital stay five days. The operative time and the number of days in hospital are comparable to those reported with VATS under general anesthesia, while intraoperative blood loss, chest drainage time and perioperative complications were better than the latter (*Table 5*).

In summary, complete video-assisted thoracoscopic surgery (C-VATS) under non-intubated anesthesia for

Table 5 Thoracoscopic segmental resection (17-29)

Lead author	Year of publication	Number of cases	Operation time (min)	Intraoperative blood loss (mL)	Chest tube drainage (days)	Postoperative hospital stay (days)	Perioperative complications (%)
Tracheal intubation, VATS segmentectomy							
Shiraishi	2004	34	240±72	169±168	4.5±3.2	–	11.8
Atkins	2007	48	136±45	250±200	3.5±4.0	–	25.8
Watanabe	2009	41	220±56	183±195	3.0±2.0	–	31.3
Shapiro	2009	31	–	–	2 [1-33]	4 [1-98]	26.0
Schuchert	2009	104	136 [120-152]	171 [133-209]	–	5	6.9
Oizumi	2009	30	216 [146-425]	100 [3-305]	1 [1-7]	–	0
Leshnower	2010	15	145±55	–	2.8±1.3	–	11.6
Gossot	2011	50	188±54	91±82	3.3±1.0	–	19.0
Moroga	2011	20 a	303±103	182±291	4.6±3.4	–	20.0
Moroga	2011	63 b	241±82	118±127	5.1±3.8	–	34.5
Dylewski	2012	35	146 [82-229]	50 [20-100]	–	2 [1-15]	33.9
Yamashita	2012	90	257±91	132±181	4.8±3.4	–	34.6
Pu	2012	20	155 [120-235]	50 [10-600]	3 [1-6]	6 [3-9]	25.0
Lin	2012	20	133 [90-240]	85 [50-200]	3.2 [2-7]	6.7 [4-11]	0
Nonintubated VATS segmentectomy							
Present study		15	166 [65-285]	75 [5-1,450]	2 [0-5]	5 [3-8]	13.4

a, with SNB; b, without SNB; SNB, sentinel node biopsy.

the resection of anatomic pulmonary segments in the treatment of early lung cancer (T1N0M0), benign lung diseases and lung metastases is safe and feasible, and can reduce postoperative pain, improve the appearance with small incisions, shorten chest drainage duration and postoperative hospital stay, provide maximum protection of lung functions, and reduce complications after general anesthesia. However, it requires that the surgeon has extensive experience in thoracoscopic lung resection in good cooperation with anesthesia doctors. Due to the short follow-up period, the long-term efficacy needs to be further confirmed. The long-term effect of non-intubated thoracoscopic anatomic segmental resection needs to be further studied and identified in a larger-scale study.

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Intraoperative crisis resource management during a non-intubated video-assisted thoracoscopic surgery

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Abstract: The management of surgical and medical intraoperative emergencies are included in the group of high acuity (high potential severity of an event and the patient impact) and low opportunity (the frequency in which the team is required to manage the event). This combination places the patient into a situation where medical errors could happen more frequently. Although medical error are ubiquitous and inevitable we should try to establish the necessary knowledge, skills and attitudes needed for effective team performance and to guide the development of a critical event. This strategy would probably reduce the incidence of error and improve decision-making. The way to apply it comes from the application of the management of critical events in the airline industry. Its use in a surgical environment is through the crisis resource management (CRM) principles. The CRM tries to develop all the non-technical skills necessary in a critical situation, but not only that, also includes all the tools needed to prevent them. The purpose of this special issue is to appraise and summarize the design, implementation, and efficacy of simulation-based CRM training programs for a specific surgery such as the non-intubated video-assisted thoracoscopic surgery.

Keywords: Crisis; intraoperative complications; thoracic surgery; anesthesia

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Authors' introduction:

Figure 1 is part of our team at the University General Hospital of Alicante, and it is composed by thoracic surgeons (Dr. C. Galvez, Dr. S. Bolufer), anesthesiologists (Dr. J. Navarro-Martinez, Dr. MJ. Rivera, Dr. M. Galiana) and the nurses (Mrs. M. Perez, Mrs. E. Ortuño, Mrs. F. Rey). We began on July 2013 with non-intubated uniportal VATS procedures and we are evolving in the anesthetic care, major procedures and fast-track protocols to achieve the least invasive approach for our patients.

Figure 1 From left to right: (Up) Dr. F. Lirio (Thoracic Surgery Resident), Dr. C. Gálvez (Surgeon), Mrs M. Perez (Nurse), Dr. M.J. Rivera (Anesthesiologist), Dr. J. Navarro-Martínez (Anestesiologist), Dr. S. Bolufer (Surgeon); (Down) Mrs. Fini Rey (Care Assistant), Dr. M. Galiana (Anesthesiologist), Mrs. Eva Ortuño (Nurse).

Introduction

Introducing a new procedure in a daily routine practice, as is the thoracic surgery, is in many occasions challenging. To be prepared to do it, all the team (surgeons, nurses and anesthesiologists) must have the precise knowledge of what everybody is doing and be aware of the complications that could happen. The use of “awake” anesthesia, or as should be called instead, regional or local anesthesia for thoracic anesthesia, is still a matter of debate on continuous debate (1), despite increasingly encouraging results (2-4). The theoretical benefits are obvious (5); we avoid orotracheal intubation adverse effects of the use a double-lumen tubes, open pneumothorax with a better collapse of the lung and caudal movement of the diaphragm (6). The potential risks include hypoxemia, hypercapnia, cough, severe bleeding and anxiety attacks. All of these complications can evolve into a critical situation where skilled and trained personal is essential. Is it worth the trouble (7)? Or better still can we lower the risk? That’s what we will try to answer.

Critical resource management definition

Managing critical events during a surgery is one of the most challenging and important tasks required of the anesthesiologist and the surgeon. The way to get education and practice in these type of situations is on constant evolution. On the one hand, we have the traditional way of learning based on acquiring knowledge through books and afterwards applying them in the “real world”. On the other hand, we have all the resources available to try to simulate all the critical events before they happen. For that reason, Professor Gaba more than 20 years ago introduced the concept of crisis resource management (CRM) recently reviewed in a new book (8). The CRM refers to the non-technical skills required for effective teamwork in a crisis situation (8), where the patient’s safety during the surgery is the main objective. The concept of CRM was originally developed from the domain of the aviation. Initially it was called “cockpit resource management” and later “crew resource management” due to the importance of simulating all the different scenarios and the group reaction in a crisis.

The CRM is made out from three important words: The first word is “Crisis”, the dictionary define it as the “the turning point of a disease when an important change takes place, indicating either recovery or death.” (9). The second word is “Resource”, “a source of supply, support, or aid, especially one that can be readily drawn upon when needed”. The third word “Management”, “the act or manner of managing, handling, direction or control”. These three words resume very well how our medical knowledge and skills are essential components in the decisions and actions performed during crises, but we have to “see” the entire situation to take control of it. That includes the environment, the equipment and the patient care team. We have to act quickly and safely because the scenario where we work is dynamic and unpredictable. The main objective is the patient’s safety and try to reduce to a minimum the possibility of a human error (10).

Elements of the critical resource management

The key principles of the CRM are:

- Knowing the environment and available resources;
- Anticipate and plan, call for help early;
- Exercise leadership and followership;
- Distribute the workload;
- Mobilize all available resources;
- Communicate effectively;
- Use all the available information;
- Prevent and manage fixation errors;
- Cross (double) check;
- Use cognitive aids;
- Re-evaluate repeatedly;
- Use good teamwork;
- Allocate attention wisely;
- Set priorities dynamically.

The available resources can be categorized as oneself, operating room personal, equipment, cognitive aids, plans, systems, and other external resources. The self-resources are resumed in, our knowledge and our skills. Your performance won’t be constant during the course of the day, will be affected by fatigue, sleep deprivation, emotional disturbance, ill health, inexperience and of course lack of knowledge. The hazardous attitudes and production pressure of the institution must be reduced to a minimum. In order to prevent problems with the equipment we must ensure that this works properly before we start, ensure that critical backup equipment is immediately available (e.g., a self-inflating bag for emergency ventilation), and know how to operate each piece of equipment you use, including knowledge of its operating characteristics in both normal and abnormal circumstances. Included in the resources we have two special important issues: the hazardous attitudes and the production pressure. Examples of hazardous attitudes are: antiauthority “Don’t tell me what to do”, impulsivity “Do something quickly”, invulnerability “It won’t happen to me”, macho “I’ll show you I can do it”, resignation “There’s nothing we can do”. To those attitudes, we have to find antidotes and in some cases, you have to even consult a psychologist. The second is the production pressure, to avoid it you have to have multidisciplinary written consensus guidelines on the preoperative preparation of patients that address the appropriate workup for patients with various medical conditions in different surgical urgency categories. This means, one must adapt the daily surgical program depending on the patients not on the numbers.

The next step is the use of cognitive aids; this type of help is supported by different studies in the literature (11,12). Mnemonic checklists written in all the operation rooms or in the head of every physician are very useful even more during periods of stress. Systems and other external resources include to now "who" we can call for help in case of emergency and "where" the things you need are.

The anticipation and planning of the surgery is essential, even if this is carried out perfectly we will expose the patient to risk. We have to try to expect the unexpected and as the pilots say, "Always fly ahead of your plane".

The next group of CRM statements can be grouped into "when the crisis happens". A good teamwork is basic, knowing when to be leader and when to be a follower. The leader has to communicate effectively without raising the voice, state the commands or request as clearly and precisely as possible, avoiding making statements to the air, asking for the confirmation message when you ask for something or someone. The follower must listen what the leader says and do what is needed, but with an open-mind to help and transmit to the leader your concerns.

In an emergency or even a suspected emergency calling for help early is mandatory. When you are a junior physician, you will do it many times. It's your duty to do it and it's not a signal of low self-confidence. You must know what type of help you need: muscle, transport, general technical skill, thinking or just someone that you feel confidence.

A specific type of error in these situations is the fixation errors. This type of error is very common in dynamic settings and what creates it is the persistent failure to revise a diagnosis or plan in the face of readily available evidence that suggests a revision is necessary. The three most common are the following situations: "This and only this", not taking into account an alternative diagnosis, "Everything but this", neglecting one diagnosis, "Everything is ok", do not recognize the need to act in emergency mode.

Try to prevent these errors, cross (double) checking all the actions you perform and re-evaluation from the beginning. Even if you think you've done it properly. Acute medicine is dynamic. What is correct now may be wrong the next minute.

Use good teamwork, for that reason you have to build it before the situation begins. Every member should be prepared to know what the other team member is going to do. Allocate attention wisely to do it properly you may use two types of actions: (I) try to develop a sequence of actions, as the one used during a CPR; (II) try to alternate between focusing on details and focusing on the big picture.

Set priorities dynamically, as we said before, acute medicine is dynamic. The decision you make, it's your decision and it could not be the best decision. However, your main priority is ensuring stable signs at all the time. Let all the team to know them also.

Application of the critical resource management in NI-VATS

Knowing the environment and available resources

Self-resources

In the first place, always-experienced team performs the NI-VATS. To define experienced team we use the following criteria, the surgeons, anesthesiologists and OR nurses must have done more than 50 conventional VATS, overcome the learning curve in conventional multiportal VATS and uniportal VATS (more than 50 major procedures through each approach) and have experience with difficult cases of major lung resections [big and central tumors, broncho-angioplasties, tumors of the apex, tumors with invasion of surrounding structures (diaphragm, chest wall, pericardium)], and management of complications such as moderate to severe bleeding through the VATS or single-port approach. In addition, the anesthesiologist must be trained in the lateral intubation at least in 20 cases (left and right). This is very important; in case of a crisis, one must know how to intubate in the lateral position. During the regular training this type of technique is not done, for that reason before we started doing NI-VATS we trained ourselves in scheduled patients.

Lateral intubation special issues

The first thing to know is that this is not more difficult than do it in the supine position. Second, the lateral position of the patient is very useful for the entire team. The patient can put himself in the most comfortable position (preventing iatrogenic stretching injuries of the brachial plexus). The surgeon can obtain the best surgical approach without harming. The anesthesiologist can intubate without increasing the risk. The nurse doesn't have to move the entire heavy weighted patient once he

Figure 2 Correct position of the head. Neutral position, using a couple of surgical pillows and an occipital support to prevent the head going backwards during the laryngoscopy.

Table 1 Checklist for NI-VATS

Previous to surgery
Surgical and anesthesiological specific informed consent for NI-VATS
WHO surgical safety checklist
Remind the patient he can feel dyspnea
Two anesthesiologist and two surgeons available
High flow nasal canula (Optiflow®) in the operation room
Emergency table
Neutral position of the head and occipital support
Guedel canula
Macintosh laryngoscope and two blade sizes
Double lumen Airtraq® videolaringoscope
Two sizes of double-lumen tubes [35-37]
Two sizes of single lumen orotracheal tubes (7 and 7.5 internal diameter)
Arndt endobronchial blocker (7 Fr)
Bronchofiberscope ready to use (3.7 mm)
Anesthesia induction agents (propofol + fentanyl + rocuronium)
Neuromuscular reversal agents (Sugammadex®)
Thoracic drainage (24 Fr)

is asleep. Theoretically, everybody is happy. How is the correct way to do it? As we can see in *Figure 2*, the head must be in a neutral position, using a couple of surgical pillows and an occipital support to prevent that the head goes backwards during the laryngoscopy. Ventilation is more easily performed than in supine position, actually this position is the safe position to prevent lung aspiration and the hypopharyngeal structures won't easily cause an airway obstruction. Correct manual ventilation is normally achieved without the need of Guedel airway, regardless of the side to intubate. Laryngoscopy and intubation in right sided position are usually more hazardous compared to the left sided. This is because it is more difficult to direct the double lumen tube properly, even if normally we can do it without help of intubating introducers or similar. Once the double lumen tube is inside the trachea, it is generally well positioned the first time. We have to pay particular attention to patients with predictive criteria of difficult airway; those patients are not excluded from the NI-VATS (13), in which we directly use the Airtraq® videolaringoscope and the bronchofiberscope.

The hazardous attitudes and the production pressure

To solve this problem not all the surgeons or anesthesiologists can perform a NI-VATS, only the ones that knows their own limitations and try to improve them. The NI-VATS is scheduled the first case of the day.

The equipment

The surgical equipment we use is the standard VATS. We prepare a special equipment in case we have to convert into an emergency thoracotomy or general anesthesia, it's called "emergency table" and is composed by following items (*Table 1*): thoracic drainage (24 Fr), two sizes of double-lumen tubes [35-37], two sizes of single lumen orotracheal tubes (7 and 7.5 internal diameter), Guedel cannula, medication to induce a general anesthesia (200 mg of propofol, 300 mg of fentanyl and 100 mg of rocuronium), macintosh laryngoscope with two blade sizes and the Airtraq® videolaringoscope. We also have prepared and ready to use the bronchofibroscope.

Cognitive aids

We use a checklist described in *Table 1*, all items must be

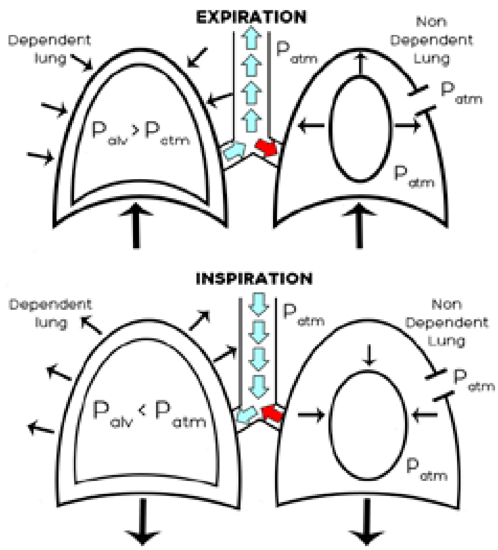

Figure 3 Distribution of ventilated gases in a subject lying in lateral decubitus with a surgical pneumothorax created in the non-dependent pleural cavity. During expiration, air moves out (sky-blue arrows) from the DL since Palv becomes higher than Patm. Part of the exhaled gases inflate (red arrow) the NDL, in which alveolar pressure equalizes atmospheric pressure. Instead, during inspiration, atmospheric air inflate the DL in which Palv becomes sub-atmospheric whereas the NDL deflates, contributing (red arrow) to ventilate the DL. DL, Dependent Lung; Palv, alveolar pressure; Patm, atmospheric pressure; NDL, Non-Dependent Lung.

fulfilled for a NI-VATS. We are currently in the process of developing the entire different intraoperative crisis checklist to have them in the operation room.

Systems and other external resources

In our hospital at the beginning of the case, we tried to be two anesthesiologists and two surgeons (as usual). In addition, we have a colleague to call in case of an emergency.

Anticipation and plans

In order to try to prevent patient related problems we have a strict selection protocol. The surgeon and the anesthesiologist explain the advantages and disadvantages of the NI-VATS to the patient. In case of doubt, we exclude him from the surgery and a conventional surgery is undertaken. We follow our checklist.

Exercise leadership and followership

If a surgical emergency happens (severe bleeding) and the patient is stable the leader is the surgeon. If a medical emergency happens (oxygen desaturation), the anesthesiologist takes control of the situation and can make the surgery stop. This is important to allocate the other human resources (nurses). When a NI-VATS is undertaken we have three nurses in the operation room. If an emergency happens, one nurse works with the surgeon and the other works with the anesthesiologist. In our hospital we don't have anesthesia specific nurses so the surgical nurse helps.

Call for help — prevent and manage fixation errors

When we started to do the NI-VATS, we were two anesthesiologists in the operation room. Nowadays there are always two at the beginning and one of our colleagues in the surgical area in case of an emergency. To prevent fixation errors, in case of a crisis, we always call an expert surgeon or anesthesiologist.

Use good teamwork

All the members of the team know what to do in every moment. We have had several briefing meetings before we started to do it.

Allocate attention wisely—set priorities dynamically

To train these skills we have a manikin (SimMan® Laerdal) where to simulate different crisis situations. The simulation is one of the bases of CRM.

Clinical and critical situations

To understand what situations we can find ourselves first we have to know the pathophysiology of the surgical pneumothorax in the NI-VATS (6). The collapse of the non-dependent lung starts once the atmospheric air enters the pleural cavity. Depending on the size of the chest opening, the degree of the collapse can be bigger o smaller. If the patient is in the lateral position, breathing spontaneously and the pneumothorax induced two circumstances, we have to bear in mind two things (*Figure 3*). First, mediastinal shift towards the dependent lung, due to the loss of negative pressure of the non-dependent lung. Second, paradoxical respiration, during inspiration the non-dependent lung collapses and expands during expiration. Both changes decrease the efficiency of the spontaneous ventilation with re-breathing of exhaled gases. This impaired respiratory function can be aggravated due to the reduced activity of the intercostal muscle function following the epidural anesthesia and the excess of sedation needed for the patient.

Respiratory acidosis

The permissive hypercapnia is very common in the NI-VATS, typically is well tolerated. The reason of this is not fully understood, it could be explained by hypoventilation produced with the changes before explained. When we first started, we used to use the nasal cannula to monitor CO_2 but we found an extremely big difference between the exhaled and arterial CO_2. Even in the same patient and depending on the degree of the collapse, the variation wasn't lineal. For that reason, we decided to take them out of the protocol. Nowadays we monitor directly pH, PCO_2 and PO_2 through the invasive motorization of blood pressure using the radial artery. In our experience, we have never had to treat a severe hypercapnia. In case we would need it, we always have a non-invasive ventilator prepared.

Hypoxemia

The degree of hypoxemia varies a lot depending of the type of patient. As we all see in our thoracic patients the PaO_2 arterial drop is much severe in "healthy patients" (14), those without preexisting lung problems related to ventilation and perfusion mismatching (15,16). During the surgery, our objective is to maintain oxygen saturation over 95%. This is normally reached with the administration of oxygen through a Venturi mask. We even had patients without the need of supplemental oxygen during the procedure. In case of a severe hypoxemia we first use a high flow oxygen ventilation (Optiflow®) with the lower flow that increases the volume of the non-dependent lung, usually 20-30 L/min and 100% oxygen fraction. If the patient is still hypoxemic, we can use the non-invasive ventilation. In our experience, if the patient does not tolerate the high flow ventilation, then the need to intubate in the side position is the only solution.

Dyspnea

At the beginning of the procedure, when the pneumothorax is done, they can feel dyspnea, even without a drop of oxygen saturation. We explain it to the patient in the preoperative evaluation and we repeat it before the pneumothorax is undertaken. If the patient knows this situation can occur it is far better tolerated. If the dyspnea continues, we then sedate the patient.

Cough

One of the very usual problems during the NI-VATS is the cough of the patient. Cough receptors are located mainly on the posterior wall of trachea, pharynx, and mucosa of bronchus. Impulses caused by stimuli travel via the vagus nerve to the medulla of the brain, and trigger a cough. The predominance of vagal tone after sympathetic block by TEA might potentially increase bronchial tone and reactivity.

There are several ways to block this coughing reflex, but none of them really suppress it 100% without risks: The first option is to administrate 1-2 mg/Kg of lidocaine and then a continuous perfusion , but the risk of reaching the local anesthetic toxicity is very near. The second way is to use inhalation of aerosolized 2-4% lidocaine in a high oxygen flow for about 30 min before the surgery. The third option is to do an intrathoracic vagal block with 2 mL of 0.25% bupivacaine adjacent to the vagus nerve (17) under direct thoracoscopic vision at the level of the azygous vein in the right side, and just below the aortopulmonary window in the left side, in order to avoid laryngeal recurrent nerve palsy. It has the risk of affecting heart rate, breathing rate, and blood pressure. This option has one variant, which consists on aerosolizing Bupivacaine 0.25% over the visceral pleura and the posterior mediastinal pleural through the vagus nerve course. The last one is to block the ipsilateral stellate ganglion with 10 mL of 0.25% bupivacaine. This aspect is on continuous evolution, what we usually do is a mixture of all the options. We start aerosolizing lidocaine 30 min before the surgery to anesthetize the tracheobronchial tree, and then we instill directly the intrathoracic vagus nerve or aerosolize the visceral and posterior mediastinal pleura with Bupivacaine. If with those maneuvers we do not obtain good results, we then add intravenous lidocaine to upgrade the effect.

Anxiety attack

To prevent it we evaluate the patients carefully. In case of doubt, we exclude it from the program. If during the surgery the patient starts with anxiety symptoms, we use midazolam.

Massive bleeding

In our protocol, the patient has two peripheral venous catheters in the contralateral side of the surgery. This is because in case of an emergency we would use one of the catheters to introduce a rapid infuse catheter set (RIC®Teleflex®) in case we need to infuse fluids rapidly. On a regular basis we don't cannulate central venous catheters, only after the patient is intubated and with the RIC inserted.

Criteria for a conversion to VATS multiportal, thoracotomy and/or general anesthesia

We use the criteria listed in *Table 2*. It is important to

Table 2 Criteria for a conversion to thoracotomy and/or general anesthesia

Conversion to GA
Respiratory acidosis with pH <7.1, with taquipnea (higher than 30 rpm)
Hypoxemia (PO_2 <60 mmHg) with no improvement despite high flow oxygenation nor non invasive-ventilation
Continuous cough with no improvement despite aerosolized lidocaine nor vagal blockade
Anxiety attack with no improvement with sedation
Patient voluntary desire of conversion
Conversion to VATS multiportal
Extense adhesions of the lung to the chest wall in more than 50% of its surface
Big tumors, particularly in the most central and anterior lung that make difficult to manipulate the hilar structures through the single incision
Non-adequate lung collapse which difficult lung mobilization
Mild bleeding
Conversion to open thoracotomy
Impossibility of nodule palpation through the single-incision in the awake patient (small nodules, central location) in the case we do not have a hook for guidance
Conversion to open thoracotomy and GA
Moderate to major bleeding, uncontrollable with the single incision/awake procedure, which requires more important maneauvers (pulmonary artery clamp, primary suture, reconstruction)

GA, general anesthesia.

distinguish between a surgical or a medical crisis. In the medical crisis (usually cough, anxiety or in some cases hypoxemia) we induce general anesthesia, intubate the patient and introduce thoracic drainage through the incision. Once done, we connect it to water seal system and close the wound with a sterile transparent dressing around the drainage, to let the lung reexpand again and improve oxygen saturation or dyspnea. The main causes are:

(I) Respiratory acidosis with pH <7.1, with taquipnea (higher than 30 rpm);
(II) Hypoxemia (PO_2 <60 mmHg) with no improvement despite high flow oxygenation nor non-invasive ventilation;
(III) Continuous cough with no improvement despite aerosolized lidocaine nor vagal blockade;
(IV) Anxiety attack with no improvement with sedation;
(V) Patient voluntary desire of conversion.

If the crisis is surgical (bleeding), we have less time to react and the anesthesiologist tries not to ventilate the patient until the double lumen tube is not correctly positioned (checked using the bronchofibroscope). We do it this way otherwise the ventilation of the non-dependent lung in the uniportal NI-VATS would make the correction of the emergency very difficult.

We usually perform awake non-intubated procedures through a uniportal approach with a single incision between 4-5 cm length. The main reason for using this approach is that it's the most used for our pulmonary major and minor resections because it reduces the pain to just a single intercostal nerve and allows a more anatomical view of the hilar structures and the pleural cavity. However, it also proves to be useful because its bigger size facilitates surgical pneumothorax compared to a thoracoscopic port, allowing easier manipulation of the lung in a patient with diaphragmatic motion and mediastinal displacement preserved.

Should a complication happen during the procedure, we choose if we need conversion to multiportal VATS or open thoracotomy.

Reasons for conversion to multiportal VATS

Usually these situations may challenge the surgeon's skill to solve it through a single incision but do not need emergent maneuvers:

(I) Extense adhesions of the lung to the chest wall in more than 50% of its surface in a spontaneously breathing patient;
(II) Big tumors, particularly in the most central and anterior lung that make difficult to manipulate the hilar structures through the single incision;
(III) Non-adequate lung collapse which difficult lung mobilization;
(IV) Bronchoplasties (wedge or sleeve techniques);
(V) Mild bleeding (small pulmonary artery and vein branches, bronchial arteries).

With thoracoscopical view through the incision, one or two more thoracoscopic ports are designed. In our VATS multiportal approach we set one of the ports in the same anterior axillar line but several intercostal spaces below, and the third one more posterior in the line of the tip of the scapulae (2 or 3 spaces above the diaphragm), but at the same horizontal line with the previous secondary port, creating a triangle shape. We use a thoracoscopic port if we are introducing the thoracoscope through it, but if we only need endograspers to handle the lung we just perform the incision and introduce them without port, in order to avoid intercostals nerve traumatism.

Reasons for conversion to an open thoracotomy

Reasons for conversion to an open thoracotomy are more severe and challenging, and need that the nurse team, anesthesiologist and the surgeons work coordinately, efficiently and fast, without space for a mistake. The non-intubated patient is, at least, partially aware of what the team says and what is happening, and also has no muscular relaxation and this can aggravate the situation, especially if anxiety develops. Situations that require open thoracotomy usually require also general anesthesia conversion, but not all of them:

(I) Moderate to major bleeding, uncontrollable with the single incision/awake procedure, which requires more important maneauvers (pulmonary artery clamp, primary suture, reconstruction);

(II) Impossibility of nodule palpation through the single-incision in the awake patient (small nodules, central location) in the case we do not have a percutaneosly set hook for guidance.

If the complication is life threatening and we cannot assure conversion to general anesthesia delaying the surgical response in order to preserve a uni/multiportal VATS approach, then we need to temporarily control it while conversion by the anesthesiologist is initiated, and meanwhile opening the single incision anterior and posteriorly as quick as possible to put a Finochietto retractor. The main cause for this emergent global conversion is major bleeding, which needs compression through a sponge-stick through the incision while converting. After the thoracotomy is opened, we can remove the compressing sponge-stick and control the bleeding by means of harmonic or bipolar cautery, primary suture, pulmonary artery clamping or stapling the vessel.

On the other hand, we have situations where we need to enlarge the utility incision scarcely but conversion to general anesthesia is not mandatory, such as small-undiagnosed nodules or central lesions sometimes cannot be palpated through a small incision if a hook has not been foreseen preoperatively. We then need to enlarge barely the utility incision in order to introduce our fingers.

Many surgeons are afraid of the potential complications of non-intubated procedures. In our experience, after developing the skill in many minor and major uniportal VATS surgeries, the main issue for initiating a non-intubated program requires strict and adequate selection of the patients depending on their pathologies, but also their anatomical and psychological features. Developing an Emergency Protocol as we did is the second step to systematize the action should a problem occurs. The third step, lies on the confidence between the surgical, anesthetic and nursing teams.

Conclusions

The surgical and medical emergencies during a non-intubated video-assisted thoracoscopic surgery must follow the CRM principles. Knowing the environment and available resources, anticipating, planning and using cognitive aids are the basis to minimize the risk of complications. Even if we do it perfectly, crisis occurs, for that reason it is mandatory calling for help early, exercise leadership and followership, distribute the workload, mobilize all available resources, communicate effectively, prevent and manage fixation errors, cross (double) check, use cognitive aids, re-evaluate repeatedly, use good teamwork, allocate attention wisely, set priorities dynamically. The only way to maintain or increase our patient's care is to practice and train them, with all the team involved in the care.

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State of the art and perspectives in non-intubated thoracic surgery

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Abstract: Non-intubated thoracic surgery (NITS) entails procedures performed through regional anesthesia methods in awake or mildly sedated, spontaneously ventilating patients. The rationale is the avoidance of side-effects of intubated general anesthesia and maintenance of more physiologic muscular, neurologic, and cardiopulmonary status in order to reduce the procedure-related traumas, fasten recovery and optimize outcomes. Preliminary reports including some randomized studies have suggested optimal feasibility of several surgical procedures including management of pleural effusion, of spontaneous pneumothorax, wedge resection of undetermined pulmonary nodules, lung volume reduction surgery (LVRS) for severe emphysema and anatomical lung resection for lung cancer treatment. So far more widely accepted indications for NITS include easy-to-perform procedures as well as surgical management of patients with significant risks for intubated general anesthesia. On the other hand, the adoption of NITS for major procedures such as anatomic lung resections and LVRS is still controversial. Further detailed investigation including further randomized trials is expected to help define indications, advantages and limitations of NITS, which might represent excellent ultra-minimally invasive strategies of treatment to be reliably offered in the near future to an increasing number of patients.

Keywords: Non-intubated thoracic surgery (NITS); awake video-assisted thoracoscopic surgery (VATS); lung cancer; lung volume reduction surgery (LVRS); thoracic epidural anesthesia (TEA); spontaneous ventilation

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Presentation text (*Figure 1*)

Non-intubated thoracic surgery (NITS) entails procedures performed through thoracic epidural or local anesthesia in fully awake or mildly sedated, spontaneously ventilating patients.

The rationale of NITS is the avoidance of side-effects of intubated general anesthesia with single-lung mechanical ventilation (2) and maintenance of a more physiologic muscular, neurologic, and cardiopulmonary status, in order to minimize the overall surgery- and anesthesia-related trauma, fasten recovery, optimize outcome and possibly reduce costs (3-8).

There are several theoretical advantages that have been hypothesized for NITS including an easier acceptance of surgery; a reduced need of high-dependency stay postoperatively; a better respiratory function in the early postoperative period; a reduced operative mortality; a reduced morbidity; a shorter hospital stay; lower procedure-related costs; an attenuated stress hormone response; an attenuated impairment of immune response; and possibly a better survival in oncological surgery.

The birth of modern thoracic surgery coincided with the development in 1959 of double-lumen endobronchial tubes permitting single-lung ventilation. In fact, general anesthesia with one-lung ventilation assures optimal conditions for safe and easy surgical manipulation of the lung and so far, this type of anesthesia is considered mandatory for most thoracic surgery procedures.

Despite several indisputable advantages, use of general anesthesia with single-lung ventilation can be associated with several potential adverse effects including an increased

Figure 1 State of the art and perspective in non-intubated thoracic surgery (1). Dr. Pompeo's live presention on "Non-intubated thoracic surgery" in the Minimally Invasive Thoracic Surgery Symposium held in Haerbin, China.
Available online: http://www.asvide.com/articles/368

risk of pneumonia; an impaired cardiac performance; neuromuscular problems; a risk of major airways injury; a composite ventilator-induced injury with barotraumas, volutrauma, atelectrauma and biotrauma; and the development of atelectasis in both the dependent and the nondependent lung (2).

Following general anesthesia, early postoperative lung function is influenced by residual muscular relaxation, time of extubation, pain therapy, and vigilance. In particular, immediately after a surgical procedure, the ability to cough seems to be one of the most important factors affecting lung function and is depending in great part to the efficacy of diaphragmatic contraction and pain relief.

The main physiologic difference between NITS strategies and intubated general anesthesia, is that with the latter the diaphragm is pharmacologically paralized and ventilation is mechanically driven whereas with the formers, spontaneous ventilation and an efficient contraction of the diaphragm are maintained leading in lateral decubitus to optimal ventilation/perfusion matching in the dependent lung.

Thoracic epidural anesthesia (TEA) has been preferred by the majority of the teams performing NITS even though intercostal and paravertebral blocks by local anesthesia, and use of laryngeal mask with sedation, have been also reliably employed and have shown pros and cons.

Chen and coworkers (3), first reported on thoracoscopic lobectomy and segmentectomy carried out by an innovative NITS protocol which included the use of TEA/intercostals blocks, with target-control sedation and bispectral index monitoring. They also employed the block of the vagus nerve achieved by intrathoracic local injection of lidocaine, which permitted to abolish the coughing reflex for up to 2-3 hours.

In our program we have preferred to employ TEA in fully awake and cooperative patients to assure neurologic vigilance that we consider an ideal way of physiologic monitoring and which allows a constant verbal interaction with the surgical staff (5,6,8).

More recently for simpler procedures such as management of pleural effusion and biopsies, we now prefer intercostal blocks that are easier and faster to be performed and also assure satisfactory thoracic analgesia (9).

It has been suggested that following TEA limited sensory block from dermatom T1 to T5, vital capacity and forced expiratory volume in one second can decrease by 5-6%, an effect which can be explained by a direct motor blockade of intercostal muscles. It has also been hypothesized a potential detrimental effect of sympathicolysis, which could result in an unopposed vagal tone leading to increased bronchial tone and reactivity (2).

However, it is worth noting that in a study published by Gruber and coworkers (10) in 2001 the effect of TEA on maximal inspiratory pressure, pattern of breathing, ventilatory mechanics and gas exchange were not impaired by TEA in awake subjects with severe emphysema. Instead, TEA induced an increase in minute ventilation by means of increased tidal volume, an increase in peak inspiratory flow rate and a decrease in pulmonary resistance.

Overall these findings suggest that TEA has no significant detrimental effects on bronchial tone whereas it improves diaphragmatic contractility and breathing pattern, and provides better postoperative analgesia than patient-controlled intravenous administration of opioids.

It is reasonable to assume that one of the main effects that contribute to keep respiratory function satisfactory throughout NITS, is the maintained diaphragmatic motion, which decreases the detrimental effect of the abdominal pressure leading the paralyzed diaphragm to compress the dependent lung during general anesthesia (8).

Cardiovascular effects of epidural anesthesia include decreased determinants of myocardial oxygen demand, improved myocardial blood flow and left ventricular function, and reduced thrombotic-related complications. Furthermore, it has been shown that epidural anesthesia can reduce heart rate and occurrence of arrhythmias (2).

During NITS, the degree of lung collapse achieved by creation of the surgical pneumothorax is usually comparable to that achievable by intubated single-lung ventilation.

The surgically-induced pneumothorax, represents the first physiologic change that allows NITS procedurers to be actually feasible. In fact, in most instances, the newly developed intrapleural, atmospheric pressure environment, leads to a drop of lung volume down to the functional residual capacity that assures an adequate space for easy surgical manoeuvring.

The effect of an open pneumothorax on oxygenation is mainly based on clinical evidence due to the paucity of experimental studies in this setting. Some human and animal investigations suggested that changes in ventilation/perfusion ratio are more relevant than the impairment in ventilation. However, it seems that the decrease in arterial oxygenation that occurs following the surgical pneumothorax, is usually of limited extent and can be easily corrected by simple oxygen administration through a Venturi mask.

A frequent finding during NITS is the development of a certain permissive hypercapnia. Both hypoxemia and hypercapnia may be due to a reduced tidal ventilation induced by a rebreathing effect that has been also called *pendular ventilation* and is generated by the development of pressure gradients amongst the lungs following creation of an iatrogenic pneumothorax. Nonetheless, the level of permissive hypercapnia is usually well tolerated even in patients with impaired respiratory function and in most of instances resolves immediately after surgery (8).

The use of TEA to perform NITS was first proposed by the American surgeon Buckingham who reported in 1950 on a series of 607 patients who underwent major thoracic surgery procedures by this method.

In the same period, Vischnevski in Russia developed a multi-step analgesia protocol, which consisted in the block of both phrenic and vagus nerves at the neck, followed by extensive intercostals and lung hilum blocks by novocaine. The rationale of phrenic nerve block was to avoid diaphragmatic motion during the operation, while the parasympathetic block was aimed at limiting the possibility of dangerous vagal reflexes, which could be triggered by surgical manipulation, iatrogenic pneumothorax, or both. Using this technique, Vischnevski performed more than 600 major thoracic surgery procedures, including major lung resections and even esophagectomies (11).

So far several preliminary reports have suggested optimal feasibility of several minor and major NITS procedures including, amongst minor procedures, management of pleural effusion with or without talc pleurodesis (7,9); management of spontaneous pneumothorax including bullectomy with partial pleurectomy (12); management of pleural empyema, bullectomy or bullaplasty for giant bullous emphysema; mediastinal biopsy in bulky undetermined masses; lung biopsy in interstitial lung disease (13); wedge resection of undetermined pulmonary nodules/isolated lung metastases (5,6).

Amongst major procedures, lung volume reduction surgery (LVRS) for severe emphysema (8); thymectomy (14); anatomical lung resection for lung cancer including segmentectomy (15), lobectomy (3,16) and pneumonectomy (4); and even tracheal resection.

Rates of conversion to intubated general anesthesia were reported to be between 2.3% and 10.0%, depending on the type of procedure and the experience matured by the surgical teams (3).

Nonetheless, since conversion to intubated general anesthesia can be rapidly required in emergency instances, a consolidated multidisciplinary team experience including dedicated thoracic surgeons and anesthesiologists must be pursued to optimize the outcomes of NITS.

Indications for NITS are far to be definitively delineated. Nonetheless, some of them are relatively uniformly accepted whereas others are still widely debated.

Amongst the more widely accepted I would include simple and easy-to-perform procedures and surgical management of patients with significant risks for intubated general anesthesia.

Conversely, debated indications include use of NITS for major procedures such as anatomic lung resections, LVRS and thymectomy.

The main contraindications for NITS include, hemodynamic instability; morbid obesity with body mass index >25-30; the presence of expected dense and extended pleural adhesions; non-compliant patients; non-experienced surgical teams and the presence of large and centrally located tumors greater than 6 cm in maximal size. Specific contraindications for use of TEA include thoracic spinal deformity or coagulopathy.

Although NITS entails procedures performed by open approaches or video-assisted thoracoscopic surgery (VATS), in most of instances NITS strategies are employed in association with VATS according to the rationale of a globally minimally-invasive surgical management.

In a survey amongst European Society of Thoracic Surgeons (ESTS) members, I have investigated the currents trends, rates of adoption as well as potential for future expansion of NITS. Out of 105 responders, 68 admitted to have already performed NITS procedures. The preferred types of anesthesia were intercostal blocks with or without sedation, followed by TEA with sedation.

The most frequently performed procedures included VATS management of recurrent pleural effusion, pleural decortication for empyema thoracis and lung biopsy for interstitial lung disease. More complex procedures such as lobectomy, LVRS and thymectomy have been performed by a minority of responders.

Poor-risk patients due to co-morbidities and elderly patients were considered the ideal candidates for NITS by the majority of responders whereas a faster, recovery, reduced morbidity and shorter hospital stay with decreased costs were indicated as the main potential advantages.

The main technical disadvantages, which were reported included coughing and poor maneuverability due to diaphragmatic and lung movements.

Overall, 68% of responders indicated that NITS procedures will be likely to increase in the near future.

So far there have been few randomized studies dealing with NITS procedures.

In a first randomized study performed by our team (5), 60 patients with undetermined solitary pulmonary nodules underwent wedge resection through either NITS with TEA (30 patients, awake group) or general anesthesia with double-lumen intubation plus TEA (30 patients, control group). There was no difference in technical feasibility although two patients in each group required conversion due to unexpected lung cancer requiring lobectomy.

Comparative results amongst study groups showed that anesthesia satisfaction score, changes in arterial oxygenation, need of nursing care and median hospital stay were significantly better in the awake group. In particular, 47% of the patients in the awake group could be discharged within the second postoperative day whereas this was possible only in 17% of patients in the control group.

In 2007, in a small randomized trial we (12) have compared VATS bullectomy and pleural abrasion performed in patients with spontaneous pneumothorax by either sole TEA or general anesthesia with one-lung ventilation. Results of this study have suggested that awake VATS bullectomy with pleural abrasion was easily feasible and resulted in shorter hospital stay and reduced procedure-related costs than equivalent procedures carried out through general anestesia while providing equivalent recurrence rate.

As far as surgical management of patients with severe emphysema is concerned, it has been clearly shown by several randomized and nonrandomized studies that LVRS can offer superior benefits than optimized medical therapy including respiratory rehabilitation in patients with upper-lobe predominant emphysema and compromised exercise capacity. However, the findings of high morbidity rates and of not negligible operative mortality rates with LVRS have led to raise question about the cost-effectiveness of this clinically highly effective procedure.

In order to reduce the significant morbidity associated with resectional LVRS that can be mainly attributed to deep resection of lung tissue in fragile emphysematous lungs as well as to the use of intubated general anesthesia that also represents a significant risk factor in patients with emphysema, we have developed a novel nonresectional LVRS technique, which entails an introflexive plication of the most emphysematous lung regions and can be ideally performed in spontaneously ventilating awake subjects through TEA only. This original method respects the basic concepts of resectional LVRS including a reduction of about 30% of the overall lung volume, suturing performed along a single ideal line and use of stapling devices. Yet, it adds some potential advantages including peripheral suturing, a linear but interrupted suture line which is more flexible, avoidance of any pleural discontinuation, and a 4-fold inlay buttress created by the plicated bullous tissue itself, which are aimed at facilitating postoperative lung reexpansion and at reducing the occurrence of air leaks.

Following several encouraging non-controlled studies, in 2012, our team (8) published results of a randomized study entailing 63 patients receiving awake nonresectional LVRS under TEA or standard resectional LVRS with general anesthesia.

Results of this study have shown that the proportion of patients who could be discharged within 6 days was significantly greater in the awake group (21 *vs.* 10 patients, P=0.01). In addition, nonfatal adverse events including air leaks were significantly less in the awake group (7 *vs.* 16, P=0.01).

At 6 months, forced expiratory volume in one second improved significantly in both study groups as did forced vital capacity, residual volume, six-minute walking test and the physical functioning short-form-36 health-related quality of life domain, which remained significantly better than baseline values for up to 24 months. At 36 months, freedom from contralateral treatment and survival were also comparable between the study groups.

Patients with malignant pleural effusion are frequently associated with medical comorbidities and carry additional risks for intubated general anesthesia.

It is worth noting that chronic lung collapse due to the existing pleural effusion enables these patients to favorably tolerate surgical pneumothorax during spontaneous ventilation leading them to represent optimal candidates for NITS management.

In a small controlled study (9), 40 patients with malignant pleural effusion were randomized to undergo VATS talc pleurodesis by NITS with TEA or general anesthesia and single-lung ventilation.

No patient in the NITS group required sedation or conversion to general anesthesia. Thirty-day mortality regarded one patient in the control goup who died due to cancer progression.

The proportion of early discharges and overall costs were significantly better in the NITS group than in the control group whereas oxygenation and postoperative pain at 24 h as well as rates of effusion recurrence and survival were comparable.

More recently, results of the largest unicenter randomized trial completed so far have been published by Liu and coworkers (17).

The trial enrolled 354 patients undergoing bullectomy, pulmonary wedge resections and lobectomy who were randomized either to NITS by VATS with TEA and sedation (174 patients) or to standard intubated VATS management (180 patients).

Seven patients in the NITS group were withdrawn due to by necessity changes in type of anesthesia. Reasons for conversion included pleural adhesions contraindicating the procedure, carbon dioxide retention and hypoxemia, unsatisfactory lung collapse, intraoperative bleeding and need to switch from wedge to lobectomy.

The reported outcomes have been highly satisfactory. In particular, independent by the type of surgical procedure, NITS resulted in shorter fasting time and shorter duration of postoperative antibiotics.

A shorter hospital stay occurred in the groups undergoing NITS bullectomy or lobectomy whereas a decreased volume of postoperative pleural drainage occurred in the NITS lobectomy group only.

Finally, in patients undergoing bullectomy, NITS was associated with a decreased difference between pre-to-postoperative concentration of tumor necrosis factor-α level in the bronchoalveolar lavage fluid.

I believe that there exist three main paths towards which the next future clinical research on NITS might be driven (18).

The first is a standardization of the indications for simple and fast procedures including management of recurrent pleural effusion and of spontaneous pneumothorax for which feasibility of NITS has been shown to be excellent.

The second path entails surgical procedures such as awake LVRS and lung biopsy for interstitial lung disease, which are performed in patients with impaired respiratory function and in whom general anesthesia and one-lung ventilation per se represents a not negligible risk factor.

The third path entails NITS procedures performed for treatment of lung cancer and including metastasectomy and anatomical lung resections. Indications for these procedures are still controversial. In fact it is likely that most of thoracic surgeons would still prefer general anesthesia with single-lung ventilation that assures deeper sedation and an immobile collapsed lung, to perform surgical procedures requiring fine vascular dissection.

Nonetheless, it is worth noting that reduced postoperative stress hormone response and a lesser impairment in lymphocytes activity (19) have been both reported by NITS in preliminary clinical studies performed at our institution. These features led us to hypothesize novel oncologic perspectives including reduced risks of early cancer spread and possibly, even better survival rates.

Critical general issues that merit a careful consideration when trying to foresee the future of NITS include the challenge of newly available nonsurgical alternatives, which promise to offer equivalent benefits with minor or no need of in-hospital stay; the worldwide ageing of populations that will increase the overall burden of health care due to an increasing need of specialistic surgical care to be provided to subjects in an advanced age and with frequently associated multiple comorbidities; and the finding that minimal invasiveness and cost-effectiveness are likely to become the main driving forces in thoracic surgery.

As a result, NITS, which is aimed at minimising both surgery- and anesthesia-related traumas might represent a strong answer to these future challenges by providing excellent ultra-minimally invasive strategies of treatment to be reliably offered to an increasing number of patients.

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Nonintubated thoracoscopic surgery: state of the art and future directions

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Abstract: Video-assisted thoracoscopic surgery (VATS) has become a common and globally accepted surgical approach for a variety of thoracic diseases. Conventionally, it is performed under tracheal intubation with double lumen tube or bronchial blocker to achieve single lung ventilation. Recently, VATS without tracheal intubation were reported to be feasible and safe in a series of VATS procedures, including management of pneumothorax, wedge resection of pulmonary tumors, excision of mediastinal tumors, lung volume reduction surgery, segmentectomy, and lobectomy. Patients undergoing nonintubated VATS are anesthetized using regional anesthesia in a spontaneously single lung breathing status after iatrogenic open pneumothorax. Conscious sedation is usually necessary for longer and intensively manipulating procedures and intraoperative cough reflex can be effectively inhibited with intrathoracic vagal blockade on the surgical side. The early outcomes of nonintubated VATS include a faster postoperative recovery and less complication rate comparing with its counterpart of intubated general anesthesia, by which may translate into a fast track VATS program. The future directions of nonintubated VATS should focus on its long-term outcomes, especially on oncological perspectives of survival in lung cancer patients. For now, it is still early to conclude the benefits of this technique, however, an educating and training program may be needed to enable both thoracic surgeons and anesthesiologists providing an alternative surgical option in their caring patients.

Keywords: Thoracoscopy; lung cancer; intubation, anesthesia, intercostal nerve block; thoracic epidural anesthesia

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Introduction

In the past two decades, video-assisted thoracoscopic surgery (VATS) has become a common and globally accepted alternative in place of thoracotomy to surgically treated patients with various thoracic conditions involving lungs, pleura and mediastinum (1-3). A minimally invasive approach is demonstrated to be superior in shortening length of hospital stay, alleviating postoperative pain, improving postoperative lung function and reducing overall morbidities after surgery (4-6). Traditionally, intubated general anesthesia with one-lung ventilation, using a double-lumen tube or an endobronchial blocker, has been considered mandatory during VATS to obtain a quiet, optimally visualized and better surgical environment (7). In spite of well-tolerated, complications and adverse effects following intubated general anesthesia and one-lung ventilation are inevitable, including intubation-related airway trauma, ventilation-induced lung injury, residual neuromuscular blockade, impaired cardiac performance, and postoperative nausea and vomiting (8-10).

Recently, interests and efforts have been made to adopt a thoracoscopic technique without tracheal intubation for avoidance of intubation-related complications and for a smoother postoperative recovery. Successful results are accumulating not only from anecdotal case reports of difficult and high-risk patients not suitable for an intubated general anesthesia (11-14), but also from a systemic application of this technique to various thoracic procedures, including management of pneumothorax, wedge resection of pulmonary tumors, excision of mediastinal tumors, lung volume reduction surgery, segmentectomy, and lobectomy (15-35). Encouragingly, the safety and feasibility of this surgical modality were well established in previous studies. Although its short- and long-term benefits comparing to standard intubated general anesthesia are not clearly addressed yet, several prospective studies are recruiting patients by now to answer this issue.

In this article, we revisit the current literature about anesthetic management and results of nonintubated VATS in various thoracic diseases, and suggest its future role in the field of thoracic surgery.

Anesthetic management of nonintubated VATS

Nonintubated VATS entails thoracoscopic procedures performed under regional anesthetic techniques, with or without consciousness sedation, in spontaneously breathing patients. The anesthetic techniques consist of local anesthesia, intercostal nerve blocks, paravertebral blocks or thoracic epidural anesthesia. Mostly, thoracic epidural anesthesia can be enough to serve solo for nonintubated VATS (36).

To be feasible and safe in performing nonintubated VATS, anesthetic management should meet the considerable physiological derangements during the procedure. The pathophysiological disturbances are mainly attributed to spontaneous one-lung breathing in an open pneumothorax status, influence of the chosen anesthetic techniques and type of surgical manipulations (37).

Open pneumothorax after trocar insertion can cause the nondependent lung to collapse gradually so that nonintubated VATS can be performed. In the meantime, patients may become dyspneic or tachypneic because of open pneumothorax. In such circumstances, awake patients should be reassured and coached to slow their breath. However, sedation may be necessary occasionally if patients become anxious and panic. In patients with conscious sedation, incremental titration of opioid can also be used to attenuate the respiratory responses after open pneumothorax.

Hypoxemia and hypercapnia are always major concerns during one-lung ventilation in thoracic surgery, which may also develop in nonintubated VATS. On contrary to one-lung ventilation during intubated general anesthesia with neuromuscular blockade, efficient contraction of dependent hemidiaphragm in spontaneous one-lung breathing during nonintubated VATS preserves favorably match of ventilation and perfusion in a lateral decubitus position. However, a paradoxical respiratory pattern may cause carbon dioxide rebreathing from nondependent, collapsed lung while mediastinal shifting after open pneumothorax may decrease the compliance and tidal volume of the dependent lung. Fortunately, although hypercapnia may occur, they are usually mild and well-tolerated. After returning to two-lung breathing after surgery, the level of carbon dioxide returns to the normal level. In addition, oxygenation is usually satisfactorily maintained with supplemental oxygen via a facemask (29).

Current results of nonintubated thoracoscopic surgery

Management of lung tumor

As progresses in cancer screening and treatment, patients with lung tumors are increasing, and requiring thoracoscopic management of their lung tumors either for diagnostic or therapeutic purposes. Surgical treatment of lung tumors includes wedge resection, anatomical segmentectomy, lobectomy or pneumonectomy with or without mediastinal lymph node dissection, depending on the nature of the lung tumors (38).

In 2004, Pompeo and his coworkers evaluated the feasibility of awake thoracoscopic resection of solitary pulmonary nodules in 30 patients under sole thoracic epidural anesthesia (15). Comparing to patients with intubated general anesthesia, their results showed that awake technique were safely feasible with better patient satisfaction, less nursing care and shorter in-hospital stay. However, it is important to note that two of the awake patients were converted to intubated general anesthesia because of lung cancer requiring lobectomy via thoracotomy approach (15). Similar results were obtained in patients with metastatic lung tumors using awake VATS metastasectomy (19) and even via a single-port VATS approach (39).

For surgical management of primary lung cancer, major pulmonary resections such as segmentectomy or lobectomy with mediastinal lymph node dissection are usually necessary (38). However, these procedures are associated with longer operating time, frequent lung traction and intense hilar manipulation, which can trigger cough reflex in awake patients. When thoracic epidural anesthesia is used, the reactivity of coughing response can be exaggerated because of an unbalanced parasympathetic activity after sympathetic block (36). While Al-Abdullatief *et al.* used stellate ganglion block to attenuate cough reflex (18), Chen and his colleagues used ipsilateral intrathoracic vagal block to achieve effective control of cough reflex (29-33,40). In addition, intravenous opioid and propofol were titrated with monitoring of anesthesia depth to further control respiratory rate and alleviate anxiety of patients. Using their nonintubated methods, they reported that nonintubated VATS lobectomy and segmentectomy with mediastinal lymphadenectomy for early stage non-small cell lung cancer could be safely performed (29-33). Rates of conversion to intubated general anesthesia were reported to be between 2.3% to 10.0%, depending on the type of procedure and which could be further decreased as the learning curve progressed (29-33). In addition to be feasible and safe, nonintubated thoracoscopic lobectomy for lung cancer using thoracic epidural anesthesia also offered better postoperative pain control, lower rates of sore throat, earlier resumption of oral intake and shorter length of hospital stay with better noncomplication rates, when comparing to its counterpart of intubated general anesthesia (29,30,32), especially in geriatric lung cancer patients (32).

Spontaneous pneumothorax

Nonintubated VATS for wedge resection of blebs and pleural abrasion have been reported in several studies for management of either primary or secondary spontaneous pneumothorax with satisfactory results (11-13,20,39,41-48). High-risk patients with pneumothorax are usually considered difficult, and might be harmful, to maintain adequate respiratory function during intubated one-lung ventilation, including patients after pneumothorax (11,13,41,42), lung transplantation (47) or those pregnant women (43,46). Successful results are obtained in these high-risk patients using either local anesthesia, intercostal blocks, or thoracic epidural anesthesia.

In a small randomized trial performed by Pompeo *et al.*, 43 awake patients with spontaneous pneumothorax were anesthetized with sole thoracic epidural anesthesia to received VATS bullectomy and pleural abrasion (20). Their results have shown that the awake procedures were not only easily feasible, but also shorten the hospital stay, reduced the cost with comparable clinical outcomes to patients anesthetized with intubated general anesthesia (20). Noda *et al.* reported similar results in 15 patients with secondary spontaneous pneumothorax with shorter operating room stay and less respiratory complications in awake patients (42).

Recently, awake single-access (uniportal) VATS was also reported feasible for management of spontaneous pneumothorax (39,43,45), even in a case of bilateral pneumothorax (45).

Pleural effusion and empyema

Patients with pleural effusion are frequently associated with medical comorbidities. These patients therefore carry additional risks for intubated general anesthesia. However, chronic collapse of operated lung enables these patients to favorably tolerate surgical pneumothorax during spontaneous one-lung breathing. As a result, they rarely develop significant hypoxemia requiring additional ventilatory support and seem to be the optimal candidate for nonintubated VATS (49).

When management of pleural effusions with medical thoracoscopy, local anesthesia with or without sedation has been widely reported (16,21,50-53). In addition, thoracic paravertebral block or epidural anesthesia are also useful and reported for more accurate pleural biopsies or extensive pleurodesis to be easily performed by nonintubated VATS (14,22).

Moreover, Tacconi *et al.* had reported 19 cases with thoracic empyema treated with awake VATS decortication under sole thoracic epidural anesthesia or paravertebral block (24). Notably, conversion to lateral thoracotomy was performed in four patients because of thick pleural adhesions. The oxygenation was satisfactory during surgery except permissive hypercapnia developed in three patients but no need of conversion to intubated general anesthesia. Their results are successful and no recurrence requiring another surgery in all patients (24). Nonetheless, thoracic epidural catheterization in patients with empyema should be cautiously evaluated to avoid of epidural abscess resulting from bacterial contamination (54).

Emphysema and lung volume reduction surgery

Resectional lung volume reduction surgery is a palliative surgical treatment in severe emphysema patients with impaired exercise tolerance to improve pulmonary function, exercise capacity, and quality of life (55,56). However, it still carries high rates of mortality and morbidity, especially prolonged air leak after surgery (57,58). In 2006, Mineo *et al.* developed a novel nonresectional technique to perform awake lung volume reduction surgery in awake patients under thoracic epidural anesthesia (17). Their further studies including a randomized trial showed that awake nonresectional lung volume reduction surgery caused significantly functional improvement, including absolute increase in forced expiratory volume in one second, functional vital capacity and residual volume, improvement in exercise capacity index and 6-minute walking test. These improvements lasted for more than 24 months (26,27,59). Comparing to conventional intubated general anesthesia, durations of postoperative air leak and hospital stay were significantly shorter in awake technique, while 3-year survival was comparable (26,60). Similar results were also reported in patients with bullous emphysema (25,61).

Lung biopsy for interstitial lung diseases

Patients with interstitial lung disease are usually associated with impaired respiratory function (62). Although precise histopathologic characterization by surgical lung biopsy can help orient therapy and reliably predict prognosis, VATS biopsy using intubated general anesthesia still carries not negligibly mortality rate (63). In 2012, Pompeo and his colleagues reported 30 awake patients completed VATS biopsy for interstitial lung disease using thoracic epidural anesthesia or intercostal blocks without operative mortality and only one minor complication (3.3%) (28). In addition, precise histopathologic diagnosis was achieved in 29 (97%) patients. They concluded that awake VATS lung biopsy by regional anesthesia might become the safest and most accurate surgical method for obtaining precise histopathologic diagnosis, and potentially leading to better management of interstitial lung diseases (28).

Myasthenia gravis/thymectomy and biopsy of mediastinal masses

Patients with myasthenia gravis are usually sensitive to neuromuscular blockade and perioperative uses of muscle relaxants are associated prolonged mechanical ventilation or re-intubation in these patients. In addition, risks of intubated general anesthesia are increased when anterior mediastinal mass compresses the airway. The rationale of avoiding use of muscle relaxants in these patients, both Matsumoto *et al*. (64) and Al-Abdullatief *et al*. (18) reported satisfactory feasibility and results of awake VATS thymectomy using thoracic epidural anesthesia. VATS biopsy of anterior mediastinal masses could also be satisfactorily achieved with high diagnostic yield and no mortality and limited morbidity (23).

Other nonintubated VATS procedures were also reported to manage pericardial effusion (14) and treat palmar hyperhidrosis via thoracic sympathectomy (65).

Potential advantages of nonintubated VATS and its future directions

Although thoracic surgery has its traditional root under regional anesthesia without tracheal intubation, modern thoracoscopic surgery benefits and fundamentally develops under the establishment and safety practice of intubated general anesthesia with effective one-lung ventilation (7). Still, critically ill patients are sometimes challenging and their risks for an intubated general anesthesia are not negligible (9). For instance, prolonged use of mechanical ventilator and stay of intensive care unit are not uncommon for patients with compromised lung function or neuromuscular diseases such as myasthenic patients. Renaissance of nonintubated techniques for VATS, either in awake or sedative patients, are naturally applied not only on anecdotal difficult cases but also broadly on a variety of VATS procedures.

Current reported studies in the literature support the feasibility and safety of nonintubated VATS for management of pleural, mediastinal and pulmonary diseases. Potential advantages of nonintubated VATS are faster postoperative recovery and less over-all complication rates, by which enhance a short length of hospital stay. Therefore, use of nonintubated VATS may translate into a fast track protocol bypassing intensive care or postoperative ventilator support. For patients with high risks for an intubated general anesthesia, this technique may offer better chances for surgical treatment.

In addition to these beneficial early outcomes, nonintubated VATS under thoracic epidural anesthesia are also demonstrated to attenuate surgical stress responses as decreased level of stress hormones and preservation of function of natural killer cells, comparing to intubated general anesthesia (66,67). It is recently hypothesized

Table 1 Suggested indications and contraindications of nonintubated VATS

Indications
• Patients with significant risks for an intubated general anesthesia
• Simple and easy-to-perform procedures
• Major pulmonary resections (requiring experienced surgical team consisting of both surgeons and anesthesiologists)
Contraindications
• Hemodynamically unstable patients
• Expected difficult airway management
• Obesity (body mass index >30)
• Expected dense and extensive pleural adhesions (previous ipsilateral chest surgery, pulmonary infection etc.)
• Inexperienced and poorly cooperative surgical team
• Large and central pulmonary lesions (>6 cm) for pulmonary resections
• Thoracic spinal deformity and coagulopathy when thoracic epidural catheterization considered

that regional anesthesia and analgesia may protect cancer patients from recurrence or metastases after surgery (68-70). This implies that further investigation including long-term outcomes (recurrence-free survival or over-all survival) by large controlled trial is needed in attempts to develop safer, more effective and less invasive surgical strategies for an optimal treatment of lung cancer patients.

For institution applying this technique, we suggest that collaborative thoracic surgeons and anesthesiologists should select their patients carefully in the early phase of learning curve. Individualized decisions should be made according to the intended procedure, anesthetic method and characteristics of patients without jeopardizing the safety of patients. Suggested indications and contraindications of nonintubated VATS are listed in *Table 1*. Notably, nonintubated thoracoscopic experiences can be accumulated from simple and minor procedures. When both surgeon and anesthesiologist getting familiar with this technique, major pulmonary resections for lung tumors, such as segmentectomy or lobectomy, are feasible. However, we suggest an effective sedative anesthetic care and blockade of cough reflex are imperative in nonintubated procedures for major pulmonary resections. Monitoring of anesthetic depth and adequacy of ventilation are important for patients' safety, which requiring the continuing vigilance of caring anesthesiologists through the procedure. Even so, conversion to intubated general anesthesia may occasionally mandatory. Plans and equipment for a prompt conversion to intubated general anesthesia should be available immediately and performed without hesitation to decrease the risk of emergency intubation (29).

Conclusions

In a modern era of minimally invasive thoracoscopic surgery, we are encouraged that tracheal intubation with double lumen tube or bronchial blocker is no longer regarded as a prerequisite for single lung ventilation in series of reported studies. Nonintubated thoracoscopic surgery is feasible and safe in a variety of thoracic procedures, including pulmonary resection, empyema, and excision of pleural and mediastinal tumors. Although the risks and benefits of this technique are not clear yet, it seems to offer an equally effective and safe alternative for those patients with high risks to intubated general anesthesia. Postoperative recovery is faster with less complication rates. Nonetheless, further studies are still necessary to clarify the indications and true benefits of this technique and its potential beneficial role against postoperative recurrence in lung cancer patients.

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Non-intubated complete thoracoscopic bronchial sleeve resection for central lung cancer

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Abstract: Bronchial sleeve resection has emerged as an effective thoracoscopic approach for central lung cancer with reduced operation mortality rates, optimal lung function and long-term survival. Endobronchial intubation is a commonly used method of anesthesia for such thoracoscopic procedures, but is associated with increased intubation-related and lung complications. Non-intubated epidural anesthesia represents an alternative approach which may avoid such difficulties, particularly in complicated sleeve resection situations. Here we have described a case of complete endoscopic bronchial sleeve resection of right lower lung cancer under non-intubated epidural anesthesia.

Keywords: Lung cancer; bronchial sleeve resection; non-intubated epidural anesthesia

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Introduction

Bronchial sleeve resection of lung tumors has emerged as an effective approach which not only removes the lesion but also avoids pneumonectomy, thereby reducing surgical mortality and maximizing lung function and long-term survival (1). Chen *et al*. reported a video-assisted thoracic surgery (VATS) lobectomy for lung cancer under non-intubated epidural anesthesia, which demonstrated acceptable safety and feasibility (2). However, there are no reports describing bronchial sleeve resection under non-intubated anesthesia. Here, we describe a case of complete endoscopic bronchial sleeve resection of right lower lung cancer under non-intubated epidural anesthesia.

Case report

A 70-year-old man presented with a mass in the right lower lung during physical examination. Lung function tests showed forced vital capacity (FVC) of 73.1% and forced expiratory volume in 1 s (FEV_1) of 71.5%. Computed tomography (CT) showed a mass at the dorsal segment of the lower right pulmonary lobe (*Figure 1*), measuring approximately 3×4 cm^2, as a thick-walled eccentric cavity. On November 11, 2013, the patient underwent complete thoracoscopic resection under non-intubated epidural anesthesia. Intramuscular midazolam (0.07 mg/kg) and atropine (0.01 mg/kg) were administered at 30 min before anesthesia. Epidural puncture was performed at the T7-8 intervertebral space, with the epidural catheter tip pointed towards the head and fixed after confirming successful placement. Following epidural injection of 0.375% ropivacaine and a test dose of 2 mL ropivacaine, the patient was observed for 5 min for signs of total spinal anesthesia. If total spinal anesthesia was not achieved, two more injections of 0.375% ropivacaine were administered, totaling 8 mL.

With a mask to supply oxygen and remove nitrogen, 2 μg/mL of intravenous propofol was given via target-

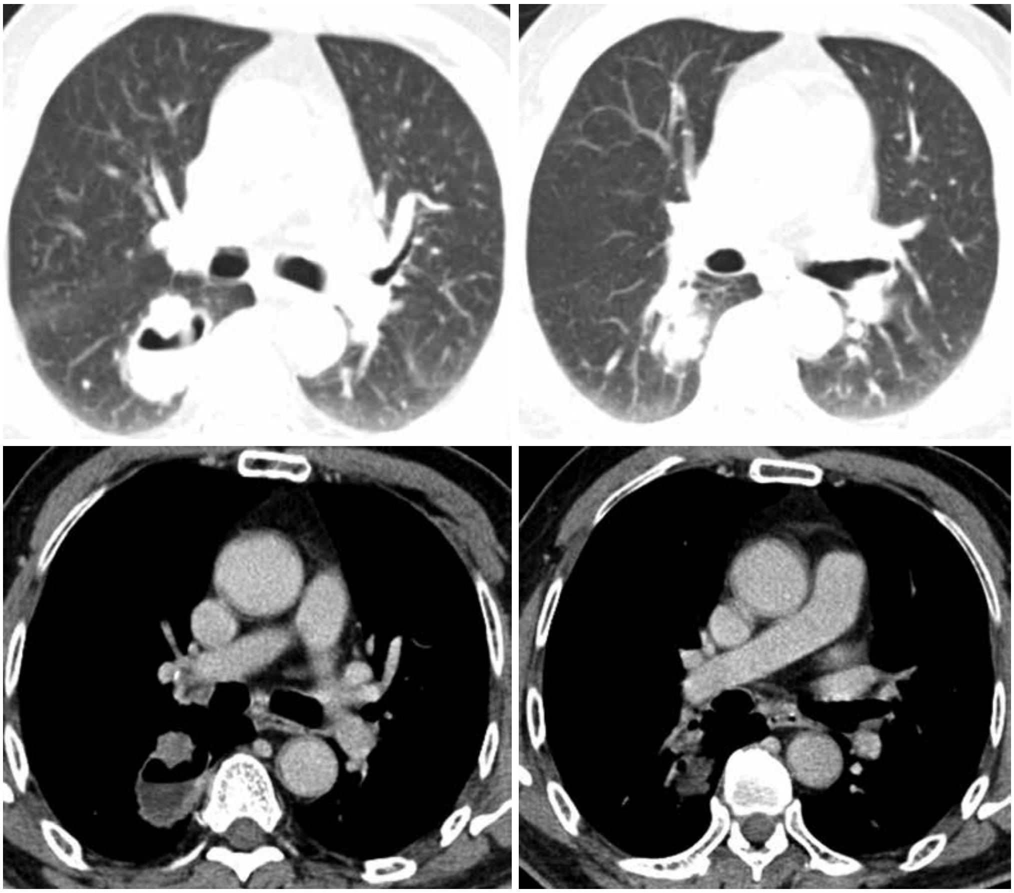

Figure 1 Mass at the dorsal segment of the right lung on computed tomography (CT).

controlled infusion (TCI) in combination with 0.2 μg/kg intravenous infusion of sufentanil. When adequate sedation was achieved, a laryngeal mask airway (LMA) was inserted and the anesthesia machine was connected to provide simultaneous intermittent mandatory ventilation (SIMV). Arterial catheterization was performed at the right internal jugular vein and the radial artery on the non-operative side.

Epidural injection of 4 mL 0.375% ropivacaine was administered at an interval of 60 min. Continuous intravenous infusion of 1.0-1.5 μg/mL propofol was performed via TCI. Continuous infusion of remifentanil 0.03 μg/kg·min and dexmedetomidine hydrochloride 0.5-1.0 μg/kg·h was administered to maintain sedation. An intraoperative spectrum analyzer was used to monitor the sedative effect, with the bispectral index (BIS) maintained at 40-60. The sedation depth was adjusted according to the monitored parameters. Spontaneous breathing was maintained, with a respiratory rate of 12-20 beats/min.

To suppress the cough reflex caused by lung tissue stretch during the thoracoscopic operation, the intrathoracic vagus nerve was blocked. Under direct vision in thoracoscopy, 3-5 mL of 0.375% ropivacaine was injected near the vagus nerve inferior to the mediastinal pleura above the azygos arch adjacent to the trachea.

The approach for non-intubated epidural thoracoscopic surgery was the 3-port method. With the patient in a left lateral position, the endoscopic observation port was made in the 7^{th} intercostal space at the anterior axillary line, the working port in the 5^{th} intercostal space at the anterior axillary line, and the auxiliary port in the 7^{th} intercostal space at the posterior axillary line. Using a 30° endoscope, the observation field covered the entire chest cavity. Using the connection between the operated side and the outer atmosphere and a gentle push on the lesion side, an iatrogenic pneumothorax was formed to collapse the right lung. After vagus nerve blockade, exploration of the dorsal side of the right lower lung was performed, where a mass measuring 4×5×5 cm^3 was found, with evident pleural surface indentation. Johnson's endoscopic automatic stapler was initially used to isolate the incomplete fissure, and the right lower pulmonary artery and vein were incised. The right lower lobular bronchus was then similarly transected, sent for frozen biopsy and shown to be "bronchial margin residual cancer". While waiting for the pathological result, systematic lymphadenectomy was performed. To preserve the right and middle lung, bronchial sleeve resection was planned, and the surgery was continued without switching to intubation. The right middle lobe and the bronchi in the middle segment were transected at the root. The frozen pathology showed no residual lesions in the margin of the intermediate segment and the proximal middle bronchus. The right middle lobular bronchus was then joined with the right intermediate bronchus, and was continuously sutured with single 3-0 Prolene suture silk. After anastomosis, a pressurized balloon was applied in conjunction with laryngeal mask ventilation to expand the lungs, and no leakage was observed at the bronchial anastomosis. Upon confirmation of hemostasis, the operation was completed.

Results

The operation time was 165 min, involving 25 min of bronchial anastomosis and 120 mL blood loss. Five groups of a total of 18 lymph nodes were dissected during surgery. Histopathology results were as follows: moderately differentiated squamous cell carcinoma of the right lower lung, stump carcinoma in situ of the lower lobe bronchus, no tumor in the proximal margins of the right middle lobe and intermediate bronchi, and no lymph node metastasis in any dissected group (0/18). The patient did not require assisted breathing postoperatively. He was able to drink and eat at 4 h postoperatively and was mobile at postoperative day 1. At postoperative day 3, the drainage was removed, and no leaks, pulmonary infection, atelectasis, bronchial fistula, or other complications were observed. He was discharged on postoperative day 6. Pulmonary CT at 1 month postoperatively showed no anastomotic strictures (*Figure 2*).

Figure 2 Postoperative pulmonary computed tomography (CT) revealed no anastomotic stricture at 1 month after surgery.

Comment

In the present case, since there was a stump residual tumor in the bronchus after lobular resection, we switched to the sleeve resection technique. Given that the patient was stable and the advantage of reduced operative time required for bronchial anastomosis, the non-intubated anesthetic approach was undertaken with the hope of avoiding further injury. Therefore, we performed bronchial sleeve resection under non-intubated anesthesia with satisfactory results, demonstrating that non-intubated anesthesia could be successfully used in not only conventional VATS lobectomy but also for complicated bronchial anastomosis.

To avoid perioperative respiratory failure, non-intubated epidural anesthesia is usually performed only in a select group of patients, with estimated operation time within 3 h and have ASA grade I-II, body mass index <25, and good lung function reserves. In such patients, SPO_2 ≥90% can be maintained (2-4). In this patient, since we needed to open the airway for bronchial sleeve resection, which stopped the inhalation of oxygen from the nostrils, the inhaled oxygen concentration was reduced and the SPO_2 briefly decreased to 80%. We therefore provided assisted ventilation with a laryngeal mask and balloon to increase the oxygen flow and ventilation, rapidly improving the SPO_2 to a safe range of 90-95%, reversing the hypoxemia while reducing CO_2 reabsorption. After completing bronchial anastomosis, the patient's ventilation recovered immediately, and hypoxemia and hypercapnia improved significantly.

In conclusion, thoracoscopic bronchial resection under non-intubated epidural anesthesia can be performed, allowing successful removal of the tumor while retaining adequate functionality of the lung tissue. The patient recovered rapidly, awakened quickly postoperatively, began to eat and drink and was mobile soon after surgery, with a short hospital stay.

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Non-intubated video-assisted thoracic surgery in patients aged 80 years and older

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Background: Video-assisted thoracic surgery (VATS) is routinely performed with general anesthesia and double-lumen endotracheal intubation, but this technique may stress an elderly patient's functional reserve. We chose to study the safety and efficacy of non-intubated VATS, utilizing local anesthesia, sedation, and spontaneous ventilation in the elderly.

Methods: The medical records of all patients aged 80 years and older who underwent VATS under local anesthesia and sedation during the time period 6/1/2002 to 6/1/2010 at Geisinger Health System (Pennsylvania, USA) and 10/1/2011 to 12/31/2014 at Sinai Hospital (Maryland, USA) were retrospectively reviewed. Unsuccessful attempts at this technique were eligible for inclusion but there were none. No patient was excluded based on comorbidity.

Results: A total of 96 patients ranging in age from 80 to 104 years underwent 102 non-intubated VATS procedures: pleural biopsy/effusion drainage with or without talc 73, drainage of empyema 17, evacuate hemothorax 4, pericardial window 3, lung biopsy 2, treat chylothorax 2, treat pneumothorax 1. No patient required intubation or conversion to thoracotomy. No patient required a subsequent procedure or biopsy. Complications occurred in three patients (3.1% morbidity): cerebrovascular accident, pulmonary embolism, prolonged air leak. One 94-year-old patient died from overanticoagulation and two 84-year-old patients died of their advanced lung cancers (3.1% morbidity).

Conclusions: Non-intubated VATS utilizing local anesthesia and sedation in the elderly is well tolerated and safe for a number of indications.

Keywords: Empyema; geriatric surgery; geriatric anesthesia; pleural effusion; thoracoscopy; video-assisted thoracic surgery (VATS)

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Authors' introduction:

Figure 1 is a picture of Dr. Mark R. Katlic, the Chairman of Department of Surgery in Sinai Hospital of Baltimore, USA. *Figure 2* is a picture of Dr. Matthew A. Facktor from Geisinger Health System in Danville, USA.

Introduction

One of the principles of geriatric surgery (1) is: the elderly handle stress satisfactorily but handle severe stress poorly because of lack of organ system reserve. For example, the elderly can return to normal function after stressful operations (such as colectomy and hepatectomy) but after the most stressful operations (such as Whipple pancreaticoduodenectomy) it will take much longer (2). Fortner and Lincer (3) found that the increased number of deaths among elderly patients undergoing hepatic resection for liver cancer were nearly all in the extended-resection group (i.e., extended right hepatectomy or trisegmentectomy), among whom 60% of deaths were due to hepatic insufficiency.

There is some evidence that stressing functional reserve

Figure 1 Dr. Mark R. Katlic.

Figure 2 Dr. Matthew A. Facktor.

even less will be beneficial. This can be done by performing lesser cancer operations without compromising survival (such as pulmonary wedge resection or segmentectomy rather than lobectomy) or by performing identical operations in a less stressful way [such as video-assisted thoracic surgery (VATS) lobectomy or laparoscopic colectomy].

Jaklitsch *et al.* (4) found decreased mortality, length of hospital stay, and postoperative delirium after 307 video-assisted procedures in patients aged 65-90 compared to those factors associated with open thoracotomy. Video-assisted pulmonary lobectomy in half of a group of elderly lung cancer patients resulted in fewer complications (P=0.04) and decreased length of stay (P<0.001) compared to the half who underwent open (thoracotomy) lobectomy (5). Patel (6) reported shorter hospitalization and similar late outcomes following endovascular thoracic aortic procedures in patients greater than 75 years, compared to open procedures.

Even these "lesser" procedures noted above require general anesthesia and endotracheal intubation, but some operations do not; and there are risks to such anesthesia.

Encouraged by the results treating pleural disease with VATS under local anesthesia—and success creating an unplanned pericardial window in a patient undergoing such surgery for a malignant pleural effusion—we broadened our indications for this technique (7). We believed that it would prove to be safe and particularly valuable for octogenarians, nonagenarians, and centenarians.

Methods

The medical records of all patients aged 80 years or older who underwent VATS utilizing local anesthesia and sedation at the Geisinger Health System (Pennsylvania, USA) between 6/1/2002 and 6/1/2010 and Sinai Hospital (Maryland, USA) between 10/1/2011 and 12/31/2014 were retrospectively reviewed. The authors or residents under their direct supervision performed all procedures. Unsuccessful attempts at this technique were eligible for inclusion but there were none. No patient was excluded based on comorbidity. The Geisinger Health System Institutional Research Review Board (Protocol 2005-0166) and the Sinai Hospital Institutional Review Board (Protocol 1915) approved this research. Eighteen of these patients were part of a preliminary study (115 patients, ages 21-88 years) published in 2006 (7). Sixty-three patients were included in a more recent general paper discussing the technique (353 patients in our study time period, ages 21-100 years) (8).

Technique

Selection criteria

Patients were not selected for this technique if any of the following pertained: hemodynamic instability, patient already intubated and ventilated, anticipated need for extensive decortication, solitary pulmonary nodule, or pericardial effusion without coexisting large pleural effusion. All other patients with large unilateral pleural effusion, empyema, or diffuse lung disease were offered local anesthesia and sedation (*Table 1*). No patient was excluded based on comorbidity. No patient who met the criteria underwent general anesthesia or

Table 1 Patient selection

General anesthesia	
	Hemodynamic instability
	Patient already intubated/ventilated
	Empyema, decortication anticipated
	Solitary pulmonary nodule
	Pericardial effusion
Local anesthesia/sedation	
	Hemodynamic stability
	Large unilateral pleural effusion
	Empyema
	Diffuse lung disease, multiple nodules
	Pericardial effusion with coexisting pleural effusion
	Chronic hemothorax

endotracheal intubation.

General

Patients were sedated with an individualized combination of midazolam, fentanyl, and propofol; a continuous infusion of propofol has been effective (starting at about 120 mg/kg/min and increasing as needed). Supplemental oxygen was administered via face mask; and oxygen saturation, electrocardiogram, and blood pressure were monitored. End-tidal carbon dioxide could be monitored via a catheter tucked into an oral airway. Flexible bronchoscopy was carried out when indicated, then the patient was turned into full lateral position. Local anesthesia (1% xylocaine, 10 to 30 mL depending on number of incisions) was infiltrated into skin, then 1-3 2-cm incisions were made. Optimally, intercostal muscle and pleura were infiltrated under direct vision or palpation through the skin incision.

Contingency plans for intubation or conversion to thoracotomy (never used) included immediate placement of a chest tube through one incision and occlusive dressings to others, followed by turning the patient supine for intubation. Alternatively, a laryngeal mask airway could be placed with the patient in lateral position depending upon circumstances.

Elective patients were discharged the same or next day, usually with a small drainage container (Atrium Mini-Express®, Atrium Medical Corporation, Hudson, New Hampshire, USA) attached to the chest tube or, in some cases, with a PleurX® catheter (CareFusion Corporation, San Diego, CA, USA). The chest tube was removed in the office as appropriate.

Pleural disease

One port was employed, with cup biopsy forceps and possible talc insufflation catheter passed along the outside wall of the short trocar (Endopath®, Ethicon). When necessary, e.g., for multiloculated empyema, a second site without trocar allowed introduction of other instruments in order to disrupt adhesions.

Lung biopsy

Three incisions allowed introduction of telescope via trocar, grasping ring forceps, and endoscopic stapling device. Finger palpation was performed as needed. Pleural adhesions could be divided bluntly or with scissors or cautery. Typically, two or three wedge biopsies were performed with targeted areas of the lung identified from preoperative computed tomographic (CT) scans.

Pericardial window

If a pleural effusion co-existed, and the lung was thereby "accustomed" to being collapsed, two sites would suffice, with grasper being passed alongside the telescope and an anterior site for #15 scalpel blade then endoscopic scissors. If necessary a third anterior-superior site allowed the lung to be further retracted superiorly with a grasper or blunt instrument.

Results

Ninety-six patients ranged in age from 80 to 104 years (mean 84, median 84). There were 51 men and 45 women. American Society of Anesthesiologists Physical Status Class was as follows: 1 (none), 2 (5 patients), 3 (52 patients), 4 (45 patients).

Diagnoses (*Table 2*) included malignant pleural effusion 36, benign pleural effusion 34, empyema 17, chronic hemothorax 4, malignant pericardial effusion 3, mesothelioma 3, usual interstitial pneumonitis 2, chylothorax 2, pneumothorax 1.

Operations (*Table 3*) included drainage of pleural effusion/pleural biopsy 73 (63 with talc insufflation, 10 without talc), drainage of empyema 17, evacuate hemothorax 4, pericardial window 3, lung biopsy 2, treat chylothorax (drainage and localized pleurodesis along course of thoracic duct) 2, treat pneumothorax 1. Overall mean operating time was 25 min

Table 2 Diagnoses

Diseases	Number
Malignant pleural effusion	36
Lung cancer	17
Breast cancer	8
Mesothelioma	5
Other, 1 each (laryngeal, prostate, colon, prostate, anaplastic carcinoma, stomach)	6
Benign pleural effusion	34
Chronic pleuritis	30
Chronic pleuritis, radiotherapy	3
Ascites	1
Empyema	17
Chronic hemothorax	4
Pericardial effusion (all metastatic lung cancer)	3
Mesothelioma	3
Lung disease (both usual interstitial pneumonitis)	2
Chylothorax	2
Pneumothorax	1
Total	102

Table 3 Operations

Operations	Number
Drain effusion/pleural biopsy	73
With talc insufflation	63
Without talc insufflation	10
Drain empyema	17
Evacuate hemothorax	4
Pericardial window	3
Lung biopsy	2
Treat chylothorax	2
Treat pneumothorax	1
Total	102

(range, 9-173 min), with types of cases as follows: drain effusion/pleural biopsy 24 min (range, 10-68 min), drain empyema 24 min (range, 9-173 min), drain hemothorax 27 min (range, 13-40 min), pericardial window 25 min (range, 17-34 min), lung biopsy 33 min (mean, 31-34 min), treat chylothorax 37-48 min, treat pneumothorax 17 min.

No patient required intraoperative intubation or epidural or nerve block analgesia. No patient required conversion to thoracotomy. Diagnosis was achieved, without need for additional procedure, in all cases of biopsy. No subsequent procedure was required for empyema. No patient had awareness or memory of the operation. Oxygen saturation was maintained at preoperative levels or greater, generally greater than 90%. There were three complications (3.1% morbidity): an 84-year-old man suffered a non-fatal cerebrovascular accident following drainage of malignant pericardial and bilateral pleural effusions; an 89-year-old woman developed a pulmonary embolus and atrial fibrillation a week following decortication for chronic hemothorax; an 86-year-old man manifested an air leak for 8 days following a procedure for pneumothorax. There were three deaths (3.1% morbidity): a 94-year-old woman died from bleeding (and her desire for no further therapy) 5 days following drainage of malignant pericardial effusion, when she became over anticoagulated; two 84-year-old men died of their advanced lung cancers on postoperative days 1 and 6 following procedures for malignant pleural effusions.

Discussion

General anesthesia and endotracheal intubation are needed for many types of VATS lobectomy or thymectomy for example. For the procedures in our present study, however, neither general anesthesia nor intubation is necessary, and there are risks to each in the elderly. In addition, many of these procedures are performed for palliation in patients with advanced malignancy, making risk minimization even more salutary.

Deep anesthesia—itself necessary for double-lumen endotracheal intubation—carries hemodynamic consequences and slower recovery. The nonagenarian, even without advanced malignancy or empyema, cannot maintain cardiac output if venous tone and cardiac filling are compromised. In most cases muscle paralysis is required. There also is more potential for drying of the airway.

Rarely discussed, but reported every year in the surgical literature, is the potential for endotracheal tube trauma to the trachea, esophagus, or hypopharynx. In 2005 Gómez-Caro Andrés (9) reviewed 90 cases of iatrogenic tracheobronchial injuries from seven series. Conti (10) in 2006 discussed 30 consecutive cases over a 12-year period. Schneider (11) in 2007 reported 29 cases from a single institution over a 10-year period. Miñambres (12) found 182 reported cases of post-intubation tracheal rupture over 40 years, with a mortality of 22% and significant morbidity. The elderly patient may tolerate the stress of the original surgery but not the added stress of iatrogenic trauma, due

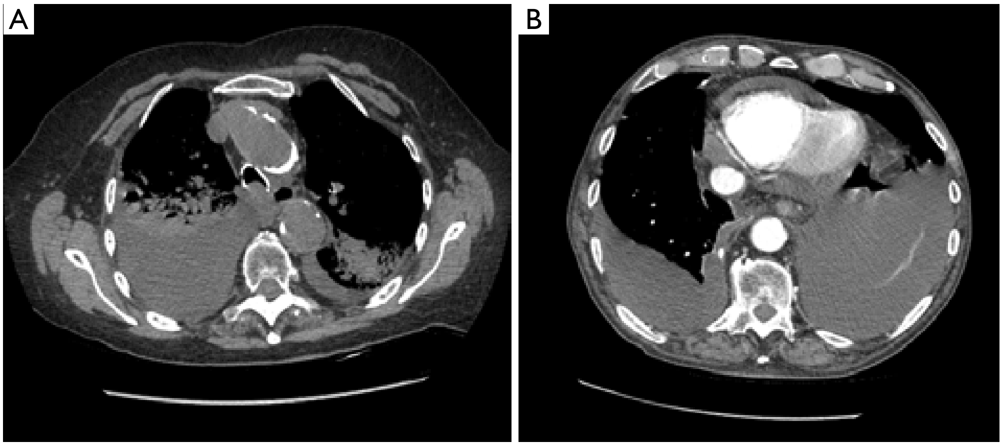

Figure 3 (A) Right empyema and bilateral pneumonia; (B) pericardial effusion and bilateral pleural effusions.

to their lack of reserve. An unknown author has written that "the elderly tolerate operations but not complications".

It is beyond the scope of this report to argue for the effectiveness of VATS for drainage of empyema (13), the effectiveness of talc insufflation or PleurX® for pleurodesis (14) or the reliability of pleural biopsy [as opposed to pleural fluid cytology (15)] in suspected malignancy; the authors advocate all of these. Tube thoracostomy and talc pleurodesis at bedside is an alternative to our technique for patients with simple pleural effusions. Endotracheal intubation and spontaneous ventilation under deep sedation is another alternative, though our experience shows that this is unnecessary. Our goal was to show that these procedures can be safely performed under local anesthesia/sedation in the elderly, with spontaneous ventilation and without intubation.

Our "oldest old" tolerate VATS utilizing local anesthesia, sedation, and spontaneous ventilation. The obligatory unilateral pneumothorax is a concept that frightens even experienced surgeons but it should not. Many patients have had one lung partially collapsed already from effusion or empyema. In addition, the ipsilateral lung receives both less ventilation and less perfusion with the patient in lateral position, resulting in less physiologic shunt than might be expected. Even patients with empyema and bilateral pneumonia or pericardial and pleural effusions (*Figure 3*) tolerated their procedure. One tedious but successful decortication lasted 173 min. One centenarian, as many younger patients, was discharged home the same day of the procedure with his chest tube; the other went home with her chest tube the day following surgery.

It may be argued that the line separating deep sedation and general anesthesia is indistinct. Whatever our technique is called, it is safe and effective in the elderly, who tolerate the obligatory pneumothorax, spontaneous ventilation, and local analgesia.

Ironically, thoracoscopy under local anesthesia is integral to the early history of VATS (16,17), but was supplanted for decades by the siren call of general anesthesia. Our present technique is made possible by sedating drugs, attentive local anesthesia, and careful manipulation of instruments. These cases require no special skills and are routinely performed by our residents under the authors' guidance. Our anesthesiology staff has come to prefer this approach and express disappointment when we request general anesthesia for a more complicated case.

In conclusion, less stressful procedures which accomplish the same goal are particularly valuable for the elderly due to their lack of reserve. Non-intubated VATS utilizing local anesthesia and sedation is well-tolerated, safe, and valuable in octogenarians, nonagenarians, and centenarians.

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Disclosure: The authors declare no conflict of interest.

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Benefits of awake uniportal pulmonary resection in a patient with a previous contralateral lobectomy

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Abstract: Surgical resection of a contralateral recurrence of non-small cell lung cancer (NSCLC) is indicated in patients without evidence of disseminated disease and considered functionally operable. General anesthesia and double-lumen intubation involves one lobe ventilation in a patient treated with a previous lobectomy, thus increasing the risks of ventilator-induced injuries and the morbidity. Awake procedures facilitate the surgery decreasing the anesthetic and surgical times, keeping the diaphragm motion and diminishing the ventilator-induced injuries into the remaining contralateral lobe. We present a 43-year-old woman with a previous left-lower lobectomy for a 3.1-cm mucinous adenocarcinoma 15 months before without nodal involvement, who presents a right-lower lobe 8-mm cavitated nodule, with evident radiological growth and fine-needle aspiration concordant with mucinous adenocarcinoma. We suggest an awake procedure with locoregional epidural anesthesia.

Keywords: Thoracoscopy/VATS; lung cancer surgery; anesthesia

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A 43-year-old woman with past history of left-lower lobectomy for a mucinous adenocarcinoma pathologic stage IB without nodal involvement, presents in a follow-up CT scan a 6-mm nodule in the upper segment of the right-lower lobe, growing to 8 mm in a later control. A fine needle aspiration is performed with diagnosis of mucinous adenocarcinoma concordant with a contralateral recurrence. Pulmonary function tests with 85% FEV1 and 73% DLCO enable surgery. We are developing two clinical trials comparing the standard general anesthesia with double-lumen orotracheal intubation and the awake nonintubated with locoregional epidural anesthesia, for both pulmonary metastasis and interstitial lung disease. In this specific case, we proposed an awake procedure in order to avoid double-lumen intubation and deleterious adverse effects of mechanical ventilation in the remaining left-upper lobe during the surgery, that we hypothesized could adversely affect the postoperative course of the patient in terms of pulmonary complications. After the proposal explaining the advantages and disadvantages of both ways of proceeding, the patient accepted the nonintubated one, so she signed a written informed consent.

A thoracic epidural catheter was inserted at the T4-T5 level with a single injection of 15 mL of bupivacaine 0.5% and left in place during the procedure, until 24 hours after the operation. Pressure of carbon dioxide ($PaCO_2$) and oxygen (PaO_2) were measured during the surgery. Midazolam and fentanyl were administered intravenously to keep the patient calm but under conscious sedation throughout the procedure, so she could communicate with the anesthetist and the surgeon. She was placed in left lateral decubitus position and continued breathing spontaneously. An intranasal multiperforated catheter was inserted with local anesthesia and left above the vocal cords to elevate the oxygen concentration in the inspired air. This device was used because it is very easy to put, well tolerated and it doesn't increase inspiratory flow. Before the incision, the O_2 pressure in arterial blood was 400 mmHg, and the CO_2 pressure was 44 mmHg.

Then we performed a 4-cm single incision in the 5th intercostal space (uniportal VATS) resulting in a surgical pneumothorax with excellent lung collapse owing to the

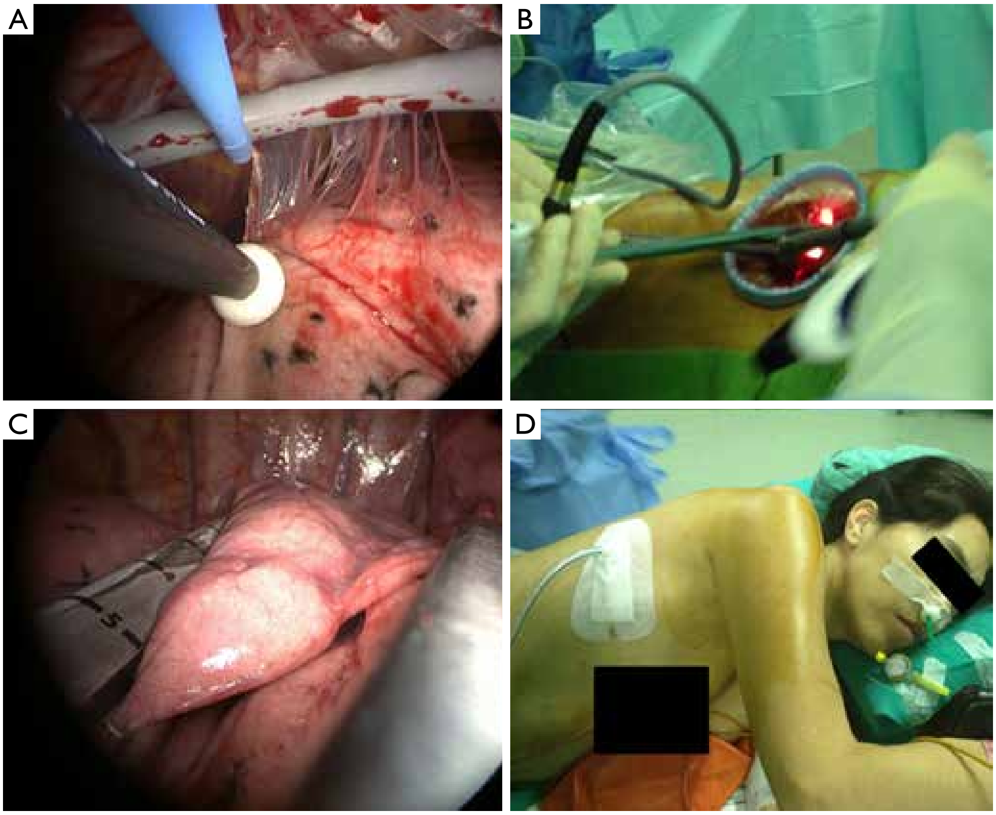

Figure 1 (A) Liberating adhesions through the incision with electrocautery; (B) working through the single incision of 4 cm with the camera, lung forceps and EndoGIA black load (Autosuture, Norwalk, CT); (C) performing the resection of the right-lower lobe nodule with oncologic margins after palpating the lesion; (D) the patient is mild-sedated with the intranasal multiperforated catheter breathing spontaneously.

absence of underlying pathology in her lungs. There were adhesions from the right upper and middle lobes to the chest wall. Some of the adhesions were liberated with monopolar electrocautery and the adhesions in the most-upper part were left in place to keep the apex without complete collapse (*Figure 1A*). After the surgical pneumothorax the O_2 pressure in arterial blood kept in 446 mmHg, and the CO_2 pressure elevated to a moderate hypercapnia degree (56 mmHg) without clinical repercussion. There were no changes in the heart rate, blood pressure and respiratory rate (*Table 1*).

After visualization and palpation of the nodule in the right-lower lobe, we performed a wide wedge resection of the lesion (EndoGIA black load, Autosuture, Norwalk, CT) and the specimen was removed with a specimen bag (*Figure 1B,C*). Intraoperative analysis showed an adenocarcinoma with more than 1-cm free margin. There were no other lesions and no lymph nodes enlarged. A 24 Fr chest drain was inserted through the single-port and connected to suction under 10 cm H_2O while the patient was asked to breathe deeply and cough to completely reexpand the lung. Operative time was 30 minutes, and total anesthesia time was 40 minutes, with a global in-operation time of 70 minutes. Intranasal catheter was well tolerated (*Figure 1D*) and kept the oxygenation high, while hypercapnia was completely asymptomatic.

The patient stayed in an intermediate care unit for 24 hours, without evidence of air leak, and the chest X-ray showed complete lung reexpansion since 2 hours after the operation. In the 6 hours control heart rate, blood pressure and respiratory rate were kept in normal values. O_2 pressure in arterial blood was kept in 87 mmHg with nasal cannula at 3 lpm, and CO_2 pressure decreased to normal values immediately after the surgery (38 mmHg). There was no pain with the epidural catheter (visual analogue scale), and the patient resumed oral intake in the evening. A total of 24 hours after the procedure, she was moved into the hospitalization unit, the drainage was removed without air leak and epidural catheter was changed by oral analgesia,

Table 1 Operative and postoperative parameters

Parameters	Supine decubitus	Lateral decubitus	Surgical pneumothorax	Chest wall closed	24 hours	Discharge
Heart rate (bpm)	86	68	83	70	73	80
Blood pressure (mmHg)	96/72	112/74	120/80	110/82	116/75	120/70
Respiratory rate (/min)	12	12	12	13	15	16
% O_2	60	60	80	80	21	21
PaO_2 (mmHg)	227	253	87	345	82	78
$PaCO_2$ (mmHg)	53	53	60	60	42	44
pH	7.32	7.32	7.28	7.26	7.39	7.40
PAS	–	–	–	–	3	2
Pain location	–	–	–	–	Drainage	Drainage

bpm, beats per minute; % O_2, oxygen inspired fraction; PaO_2, oxygen blood partial pressure; $PaCO_2$, carbon dioxide blood partial pressure; pain analogue scale [0-10].

and with a chest X-ray showing complete lung reexpansion she was discharged 1 day after the surgery. In the late control she had O_2 pressure in arterial blood of 94 mmHg without any device, and no changes in CO_2 pressure (38 mmHg). We systematically quantify the satisfaction level according to a subjective four degree scale (excellent, good, tolerable, bad), and this patient expressed excellent tolerance without any complaint.

Final pathologic exam confirmed the recurrence nature of the lesion, with an 8-mm mucinous adenocarcinoma concordant to the former one, free margins of 1.3 cm.

In the postoperative visit to the clinic three weeks later she had no pain, and she expressed high level of satisfaction with the procedure, with radiological and clinical excellent parameters.

Discussion

Awake thoracic procedures have gained approval in the last years as an alternative to the standard procedures performed under general anesthesia and double-lumen intubation (1). Pioneers surgical teams as E. Pompeo and colleagues have shown feasible and safe to perform pulmonary biopsies, lung-volume reduction surgery of the emphysematous patient, sympathectomies for hyperhidrosis and pulmonary resections, as many other groups do. Even some groups have proved feasible to perform major pulmonary resections like lobectomies and also thymectomies in the awake patient (2).

Indications for awake procedures are getting elucidated after accumulating experience, but it is essential that the surgical and anesthetic team understand the physiologic changes occurring during the awake procedure in a spontaneously breathing patient, the changes in the operating maneuvers, and the potential complications of the procedure, and working with a skilled nursing team used to awake operations (3). An emergency protocol has to be well designed before venturing (*Table 2*). One of the main aspects of suggesting these procedures consists on strictly selecting the patient, because not all the patients are psychologically prepared and if the patient gets nervous and anxious the operation can be difficult (4).

The potential advantages of these procedures include minimizing the ventilator-induced injuries (barotraumas, atelectrauma, volutrauma) thus decreasing the risks of respiratory postoperative infections, special in patients with pulmonary underlying disease. Avoiding the effects of general anesthesia on the cellular and humoral immune response, can potentially diminish the incidence of postoperative infections and even it has been suggested the possibility of decreasing the chance of tumor progression (5). Uniportal VATS approach, in experienced hands, allows to perform the procedure without extending the operative time, and seems to reduce postoperative pain unless there is still a lack of clinical trials comparing with normal VATS approaches.

In this patient we suggested an awake surgery because she had been previously performed a contralateral lobectomy. We hypothesized that avoiding mechanical ventilation in the remaining lobe could prevent potential damages, so the remaining lobe was spontaneously ventilated with high oxygen concentration, keeping the diaphragm motion. It only appeared what has been called "permissive hypercapnia", but the patient didn't experience dyspnea. She could also resume normal activities like walking and oral

Table 2 Emergency protocol

Criteria for a conversion to thoracotomy or general anesthesia
Respiratory acidosis with pH <7.1, with taquipnea (higher than 30 rpm)
Hypoxemia (pO2 <60 mmHg) with no improvement despite high flow oxygenation nor non invasive-ventilation
Continuous cough with no improvement despite aerosolized lidocaine nor vagal blockade
Anxiety attack with no improvement with sedation
Moderate to major bleeding, uncontrollable with the single incision/awake procedure, which requires more important maneuvers (pulmonary artery clamp, primary suture, reconstruction)
Non adequate lung collapse which make lung mobilization and resection difficult
Adhesions in more than 50% of the lung surface which lengthens the procedure or makes the procedure difficult
Impossibility of nodule palpation through the single-incision or the awake fashion (small nodules, central location, excessive cough reflex without improvement with vagal blockade)
Pulmonary lesions requiring major lung resection (lobectomy, pneumonectomy) through the single-incision/awake procedure (relative criteria)
Patient voluntary desire of conversion
Conversion to general anesthesia/thoracotomy
Introduce thoracic drainage through the incision, connect it to water seal system and close the wound with a sterile transparent dressing around the drainage, to let the lung reexpand again and improve oxygen saturation or dyspnea
General anesthesia and orotracheal lateral decubitus intubation
Perform the thoracotomy or the additional ports and proceed

intake the same day of the surgery, and the reexpansion was complete without air leak so she was discharged 24 hours after a lung resection without pain, so recovery of normal life can be fastened. Cardiovascular parameters remained without changes throughout all the process and CO_2 pressure in arterial blood decreased to normal values immediately after the surgery ($PaCO_2$ 42 mmHg).

Intranasal multiperforated catheter has proved to be a very useful device and well tolerated with mild sedation, increasing the oxygen concentration just above the airway without elevating the flow neither the pressure in the airway, keeping the O_2 pressure in arterial blood in excellent values.

Decreasing the need of general anesthesia and mechanical ventilation, the operative and anesthetic times, and the length of stay, also decreases the economical costs of the procedure (6).

We hypothesized that decreasing the interference with immune response with an awake procedure can potentially be beneficial in recurrent neoplastic disease in order to decrease the chance of reappearance of the tumor, but more evidence is needed showing that this benefit could potentially counteract the hypothetic stress related to surgical pneumothorax in an awake patient.

We conclude that awake uniportal limited pulmonary resections in recurrent non-small cell lung cancer (NSCLC), in the absence of high comorbidity and satisfactory functional tests, are feasible and have a safe pattern avoiding complications related to mechanical ventilation and general anesthesia, letting the patient resume his normal life sooner. Multiperforated intranasal catheter is a useful device in this purpose. Prospective randomized clinical trials are needed to confirm this hypothesis.

Acknowledgements

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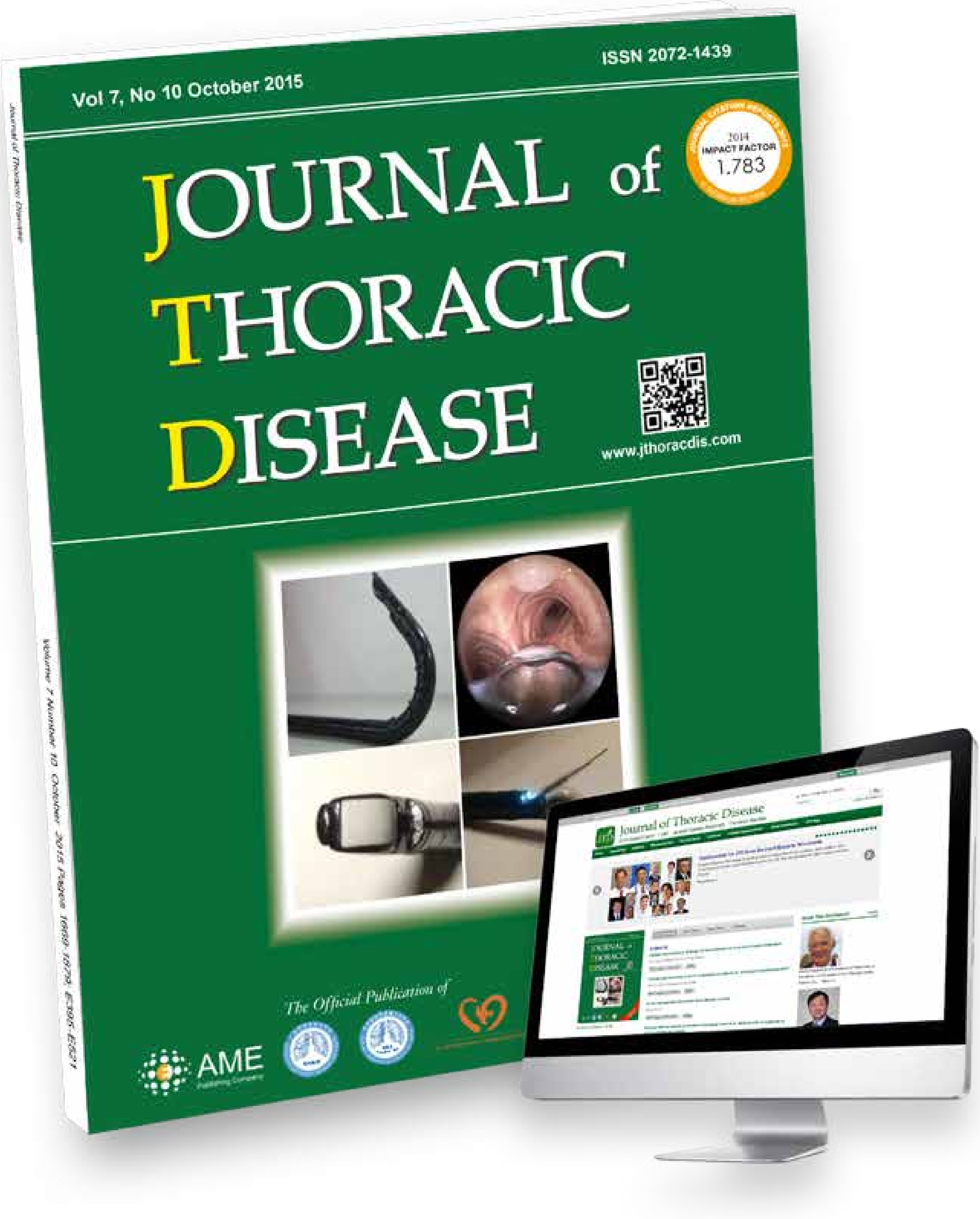
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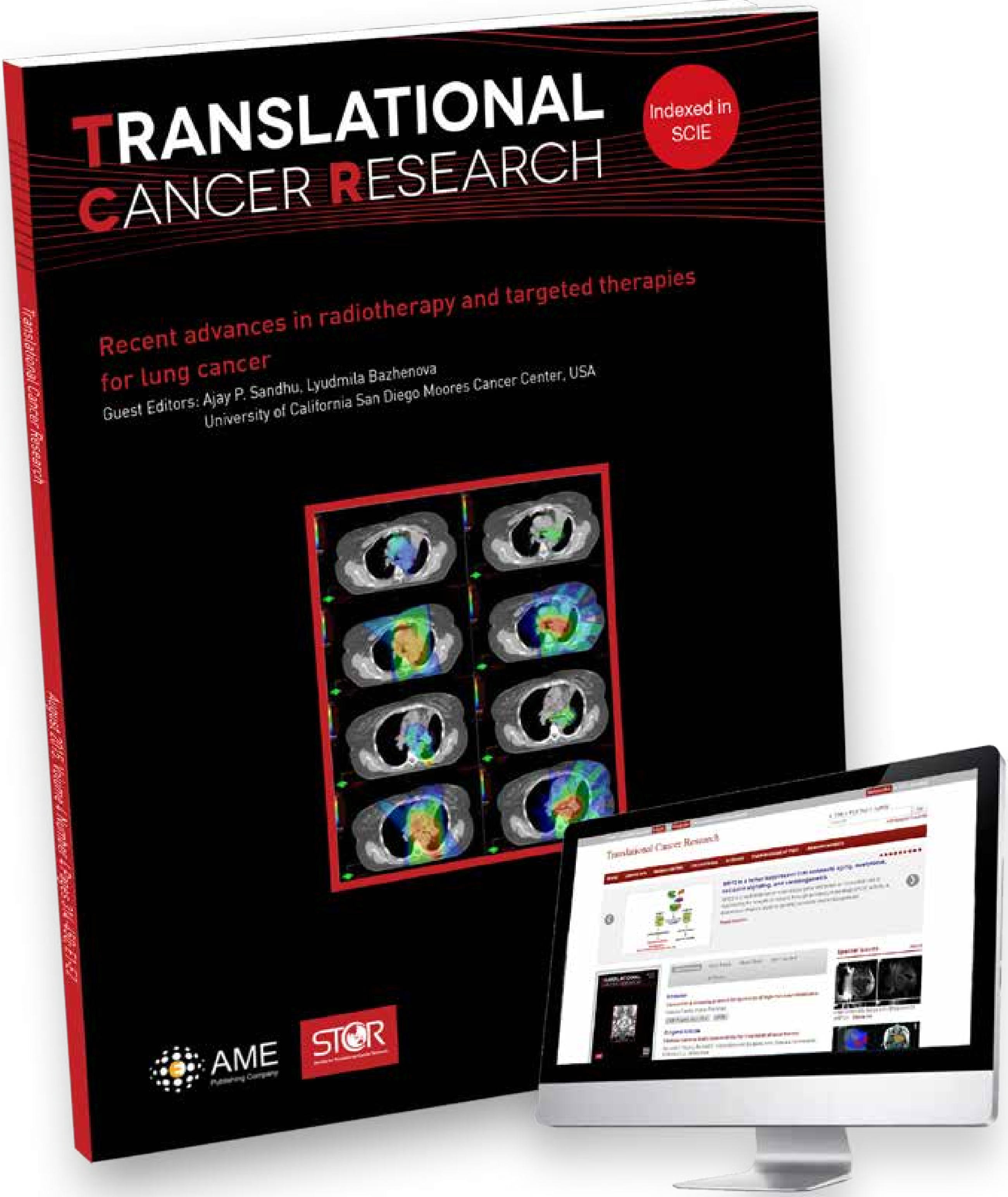
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【规　　格】200mg/瓶，1g/瓶
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胰腺癌：吉西他滨推荐剂量为1000mg/m²，静脉滴注30分钟。每周1次，连续7周，随后休息1周。随后的治疗周期改为4周疗法：每周1次给药，连续治疗3周，随后休息1周。

乳腺癌：推荐吉西他滨与紫杉醇联合给药。在每21天治疗周期的第1天给予紫杉醇(175mg/m²)，静脉滴注约3小时，随后在第1天和第8天给予吉西他滨(1250 mg/m²)，静脉滴注30分钟。根据患者对吉西他滨的耐受性可考虑在每个治疗周期或一个治疗周期内降低剂量。（详情请参阅详细处方资料）

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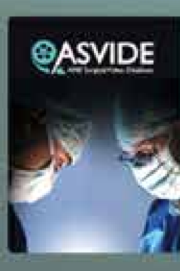

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