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Cover image:

Single-port VATS—Transection of left superior pulmonary vein. (See P16 in this issue).

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Preface

New directions and technologies for minimal invasive thoracic surgery

Since the use of video-assisted thoracoscopic technique and refinement of related endoscopic instruments, minimal invasive thoracic surgery has developed vary rapidly in the management of various kinds of thoracic and cardiovascular diseases. Until now, minimal invasive thoracic surgery is not just an alternative to thoracotomy or sternotomy, but has become a standard in the treatment of many cardiothoracic diseases. In the recent meeting of The 11th Asia Pacific Congress of Endoscopic and Laparoscopic Surgery (ELSA) in Taipei on November 21-24, 2013, we invited many physicians, surgeons, and anesthesiologists to share about their experiences in the development of new concepts, refinement of new technologies, and collaboration of multiple disciplines for minimal invasive thoracic surgery.

This special issue of the *Journal of Thoracic Disease* extends the ideas, presentations, and discussions of this exciting meeting to provide a comprehensive overview on a variety of aspects related to the recent advances in minimal invasive thoracic surgery, with a special emphasis on the nonintubated anesthetic techniques (1-4). Through 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. As for the evolving techniques of thoracoscopic surgery, single-port and natural orifice surgery will definitely play important roles in the near future (5,6). And thoracoscopic surgery can be an effective alternative to thoracotomy in situations such as systematic lymphadenectomy for lung cancer and reoperation for postoperative recurrent primary spontaneous pneumothorax (7,8). Finally, the current status and personal experience of video-assisted or robotic-assisted cardiac surgery are also provided (9,10).

I am grateful to our guest speakers and invited authors who have shared their expertise and contributed diverse and comprehensive knowledge for this excellent issue. With new technologies and refined instruments, it is time to reconsider the new directions of minimal invasive thoracic surgery.

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Review Article

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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Review Article

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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Review Article

Single-port video-assisted thoracoscopic surgery for lung cancer

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Abstract: In 2004, novel results using pulmonary wedge resection executed through single-port video-assisted thoracoscopic surgery (VATS) was first described. Since that time, single-port VATS has been advocated for the treatment of a spectrum of thoracic diseases, especially lung cancer. Lung cancer remains one of the top three cancer-related deaths in Taiwan, and surgical resection remains the "gold standard" for early-stage lung cancer. Anatomical resections (including pneumonectomy, lobectomy, and segmentectomy) remain the primary types of lung cancer surgery, regardless of whether conventional open thoracotomy, or 4/3/2-ports VATS are used. In the past three years, several pioneers have reported their early experiences with single-port VATS lobectomy, segmentectomy, and pneumonectomy for lung cancer. Our goal was to appraise their findings and review the role of single-port VATS in the treatment of lung cancer. In addition, the current concept of mini-invasive surgery involves not only smaller resections (requiring only a few incisions), but also sub-lobar resection as segmentectomy. Therefore, our review will also address these issues.

Keywords: Lobectomy; lung cancer; segmentectomy; single-port; video-assisted thoracoscopic surgery (VATS)

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A new trend: video-assisted thoracoscopic surgery (VATS) for lung cancer

On October 19, 2013, four live demonstrations of successful single-port VATS lobectomies were performed at Shanghai Pulmonary Hospital. More than 200 chest surgeons witnessed this demonstration and shared their thoughts. Based on this response, it is clear that lung cancer, and, in particular, single-port VATS lobectomy for lung cancer, are popular topics among Asian thoracic surgeons (1,2).

Both the general public and the government are aware of the high incidence, morbidity, and mortality rates (as well as the high medical costs) associated with advanced-stage lung cancer. Several screening tools, including chest radiography and low dose computed tomography (CT) (3,4), have been advocated in high risk patients. As a result, more patients are presenting with early-stage lung cancer. If they can be adequately treated, they usually harbor a better prognostic outcome. These patients are also, potentially, the best candidates for minimally invasive surgery which can reduce their recovery time and suffering after surgery. Thus, we will focus on the role of single-port VATS for lung cancer lobectomy.

Current VATS practice in Taiwan

Before 2000, conventional posterolateral open thoracotomy remained the "gold standard" for the treatment of patients with lung cancer. However, VATS has replaced open thoracotomy and has become the current mainstay of lung cancer surgery (5). Actually, the penetration rate of VATS in Taiwan is extremely high. As surgical creativity

Table 1 Comparisons among RATS, non-intubated VATS, and single-port VATS

	Special equipment	Cost	Experienced anesthesiologist	Operator skill demands	Experienced cameraman	Experienced assistant	Surgeon's satisfaction	Patient's satisfaction
RATS	Robotic system	+++	–	+	–	For stapling	++	?
Non-intubated VATS	–	–	+++	+	+	–	?	+
Single-port VATS	Double joint instruments	–	–	+++	+++	–	?	++

–, not required; +, low level of requirement; ++, medium level of requirement; +++, high level of requirement; ?, uncertain; RATS, robotic-assisted thoracoscopic surgery; VATS, video-assisted thoracoscopic surgery.

and innovation have progressed, three variants of VATS have been developed in our society, the robotic-assisted thoracoscopic surgery (RATS), non-intubated VATS, and single-port VATS (6,7). Differences regarding cost, instrument settings, special anesthesia demands, surgical techniques, patient selection, and insurance coverage among these VATS alternatives are quite difficult to have evidence-based comparison (*Table 1*). Shows the summary based on our interpretation.

For lung cancer surgery, several controversies exist concerning RATS (8), including the high cost, the increased number of utility wounds, and the need for skilled assistants to perform stapling for bronchus and pulmonary vessels. However, with the advances in new instrumentation, especially the endocutter, and the reduced size of the robotic arm which has avoided collisions during surgery, the role of RATS in lung cancer has exceeded our expectations. Although non-intubated VATS did not represent an improvement in surgical technique, it has the advantage of reduction in airway trauma caused by standard double-lumen endotracheal intubation. Furthermore, both the introduction of vagus nerve blockade to inhibit cough reflex and the insertion of an epidural catheter to reduce pain emphasize the need for team work between chest surgeon and anesthesiologist (9,10) during this technique.

Due to high cost limitations associated with RATS or the discomfort associated with mediastinal movement during non-intubated VATS, single-port VATS is another option for chest surgeons who are familiar with the conventional 4-, 3- or 2-ports VATS. In this review, we will assess the various uses of single-port VATS, especially for lobectomy.

Current evidence

Single-port surgery has been adopted in several surgical fields, especially in colorectal and gynecologic training programs (11). In 2004, Rocco *et al*. reported their pioneering work with pulmonary wedge resection through single-port VATS (12). Thereafter, more and more chest surgeons used single-port VATS for pulmonary resection, including wedge resection (12), segmentectomy (13-15), lobectomy (16-19), pneumonectomy (20,21), and pleural surgery (including pleural biopsy and pleural resection or decortication) (22), for both benign or malignant disease (*Table 2*). Lobectomy plus radical mediastinal lymph node dissection remain the "gold standard" for resectable lung cancer. However, pneumonectomy or segmentectomy/wedge resection may be executed based on lung cancer status, according to oncological principles or clinical considerations. Between 2012 and 2013, Gonzalez-Rivas *et al.* shared their innovative experiences with single-port VATS lobectomy, segmentectomy, and pneumonectomy for lung cancer (13,14,17-21). They also explained, in detail, the procedure and necessary equipment for meticulous application of single-port VATS. However, this was only one report from a single institution. The advantages and disadvantages of single-port VATS *vs.* conventional 2-, 3-,or 4-ports VATS, especially for lobectomy or segmentectomy of lung cancer, deserved further re-appraisal.

Our experiences at the Koo Foundation Sun Yat-Sen Cancer Center

We began performing 3-ports VATS lobectomy in 2005, and shifted to 2-ports VATS lobectomy in 2007. As described by Rocco *et al.* (12), surgeons always stand in front of the patient while performing VATS, in contrast to conventional open thoracotomy. Concerning the 2-ports VATS lobectomy that we perform, one port is used for instrument insertion (utility port, 3-5 cm in length, retracted by wound protector) and the other port is used for camera scope insertion (scope port, 1 cm in length, kept by trocar). A 30-degree camera scope was applied

Table 2 Summary of the specific issues regarding single-port VATS

Issues of single-port VATS		Reported articles
Pioneer	How to do it	(12)
History/evolution review	Conventional to single-port VATS	(7,16,23)
Geometric configuration	Cranio-caudal perspective	(12,24)
Clinical application		(22)
Clinical diagnosis	Wedge resection/biopsy	(12,25)
Lung cancer/tumor	Wedge resection	(12)
	Segmetectomy	(14,15)
	Lobectomy/sleeve lobectomy	(15,17-19,26)
	Pneumonectomy	(20,21)
Pneumothorax		(12,25,27,28)
Empyema		(29)
Lymph node dissection	Overall number/areas	(19)
	Lobe specific	(15,30)

VATS, video-assisted thoracoscopic surgery.

Figure 1 Two ports VATS—Transection of right superior pulmonary vein.

Figure 2 Single-port VATS—Transection of left superior pulmonary vein.

to our VATS. Actually, during 2-ports lobectomy, we insert multiple instruments into the utility port, which is the training basis for single-port VATS lobectomy. During upper lobe lobectomy, the straight endocutter is usually shifted to the camera port for the division of superior pulmonary vein, and all other instruments plus thoracoscope are inserted through the utility port (*Figure 1*). More specifically, if we can insert the endocutter through the same wound, i.e., the utility port, it becomes a single-port VATS. The application of the curved endocutter plays an important role in this specific procedure (*Figure 2*).

We began single-port VATS lobectomy in December 2010 (30). The first case we performed was actually a single-port segmentectomy for a centrally located carcinoid tumor over the left common basilar segment of the left lower lung. Because this patient had chronic obstructive pulmonary disease (COPD) with poor lung function, we shifted our tentative single-port VATS lobectomy to a segmentectomy, and this may represent the first single-port VATS segmentectomy reported in the literature (15,30). Despite the severely adherent anthracotic segmental lymph nodes, we completed the procedure smoothly and successfully. Since that time, we have been capable of single-port VATS anatomic lung resection. However, during that period, the concept of single-port VATS lobectomy or segmentectomy was neither popular nor well accepted. Most chest surgeons performed VATS lobectomy through 2-, 3-, or 4-ports procedures, or through a needle scope. Inevitably, however, a small utility wound is necessary for surgical specimen retrieval. Based on the need to reduce surgical trauma, we began our single-port VATS lobectomy/segmentectomy program, depending on careful case selection, the need for resident training, or sufficient surgical time without a tight schedule. Between November 2010 and May 2012, we retrospectively collected 19 cases of single-port VATS lobectomy/segmentectomy at our institute, and we shared our experiences with an emphasis on patient safety and surgical skill during radical lymph node dissection. This preliminary experience demonstrated the feasibility of single-port VATS lobectomy and radical lymph node dissection for benign pulmonary disease and early-stage lung cancer (15).

In Dr. C.C. Liu's practice, single-port lobectomy has become the standard procedure for lung cancer surgery, if there is no chest wall invasion or obvious hilar structural invasion. The size of the tumor is seldom a contraindication, since the larger the tumor, the larger the utility wound needed. Usually, the incision is approximately 3 cm in length if the tumor diameter is less than 3 cm.

Our collection of cases totals 63 single-port VATS lobectomies and 24 segmentectomies. The conversion rate from single-port VATS was low (3.45%, 3 in 87, converted to 2-ports VATS because of adhesion/anthracotic lymph nodes) and no surgical mortality occurred. Post-operative recovery was similar to traditional 2-ports VATS lobectomies.

The concept of minimally invasive surgery is not only preferred for reduction in the size of the external wound but also for reduction in inner trauma, including the extent of tumor resection and lymph node dissection. Therefore, sub-lobar resection (especially segmentectomy) for early stage lung cancer is crucial (31). Regarding the resection planes used in segmentectomy, we prefer the endocutter stapler to seal off air leakage rather than electrical coagulation (32). The segmental structures, including segmental artery, bronchus and veins, are dissected towards the hilum and then divided. The dissected lymph nodes and the resection margins deserve special mention. They are examined by experienced pathologists through frozen section to guarantee a complete resection. One of our patients harbored a ground glass opacity (GGO) lesion over the basal segment of the lower lobe, which proved to be lung cancer during intra-operative pathological diagnosis. The basal segmentectomy was converted to lobectomy due to a close resection margin. At present, we have already performed 24 segmentectomies using endocutter stapler to divide the intersegmental planes. Compared with conventional cauterization along the intersegmental plane and for ligation of branches from intersegmental veins, endocutter stapler is much easier to use. Although transient postoperative lung atelectasis with subsequent fever is not inevitable, this procedure does reduce the incidence of prolonged or delayed air leak (33). With regards to conventional segmentectomies, e.g., superior segmentectomy for the lower lobe, lingular segmentectomy, trisegmentectomy of left upper lobe (lingular sparing) and common basal segmentectomy of lower lobe, they can all be executed using a single-port technique. We have also begun lobe-specific lymph node dissection for early stage lung cancer. It not only reduces the degree of mediastinal trauma and saves more time, but also lessens the complications related to extensive lymph node dissection (15).

OR setting

We use the same setting as used in traditional VATS in our group.

Anesthesia

General anesthesia with double lumen endotracheal tube intubation is applied for right sided procedures. For left sided procedures, in contrast, single lumen endotracheal tube intubation with endobronchial blocker is applied, especially when left subcarinal lymph node dissection is required. A low tidal volume of approximately 350 mL with a PEEP at a setting of approximately 5 mmHg is preferred. Central venous catheter insertion is not our routine. Intercostal nerve block with bupivacaine is injected by the surgeon along the utility wound [including one more intercostal space (ICS) up and down] at the end of surgery.

Patient positioning

We use the same position as used in traditional VATS.

Instruments

Scanlan® VATS instruments, laparoscopic grasp, laparoscopic needle holder, knot pusher, and harmonic scalpel are the main instruments used during single-port VATS. We prefer to use longer instruments to avoid their possible collision due to crowding during manipulation. The surgical field can be viewed clearly through a 10 mm (preferred) or 5 mm 30 degree endoscope. The utility wound is retracted by wound protector (XS in size).

Incision

We prefer to create the utility wound at the sixth ICS that crosses the anterior axillary line for the following reasons:

(I) For upper lobe lobectomy, this incision is away from the superior pulmonary vein and provides adequate space for applying the endocutter;

(II) For lymph node dissection, this incision allows for easier subcarinal lymph node dissection, especially when we encounter a bulky bronchial tree caused by double lumen tube with an inflated balloon or a relatively rigid bronchus;

(III) Such an incision avoids hypersensitive areas or avoids causing paresthesia involving the breast, particularly the nipple, because the nipple is innervated by 4^{th} intercostal nerve;

(IV) The incision may be shifted more laterally along the sixth ICS in female patients, and along the fifth ICS only for left upper lobe $LB_{1+2,3}$ trisegmentectomy for early lung cancer and lobe specific lymph node dissection and the upper mediastinum lymph nodes, rather than the subcarinal lymph nodes.

Handling of instruments

To achieve a smooth surgical procedure, the long curved sucker (Scanlan®) is manipulated by the surgeon's left hand, and the hook, laparoscopic or Scanlan® dissectors are manipulated using his right hand. Such a combination of long straight and long curved instruments can minimize their collision and interference during surgery. Generally, the entire single-port VATS procedure is similar to traditional 2-ports VATS, except for the application of the endocutter through a narrower space that requires more skill. Adequate dissection and release of the surrounding soft tissues of the vascular structures are important steps that provide sufficient space for insertion of the endocutter blade during conventional 3- or 2-ports VATS. The Endo-GIA was originally designed for gastrointestinal anastomosis, rather than pulmonary vascular structures. We feel that it is a problem of instrument design rather than a problem with technique. The newly designed curved-tip endocutter is a useful option when performing division of a vessel, especially the superior pulmonary vein.

Camera scope handling

An experienced cameraman is crucial for a successful single-port VATS lobectomy, and a 30-degree camera scope (10 or 5 mm) is recommended. After an initial inspection of the surgical field from the eagle view through the camera, an impression of the anatomic landmarks should be fully realized. The surgeon can re-adjust the settings to facilitate the exposure and dissection. Usually the surgeon will choose the best position for performing the surgical procedure, and then bring in the camera to take advantage of the 30-degree lens to provide the best view. Every step should be under direct vision in order maintain safety, especially during dissection and application of the endocutter to the great vessels. Concerning the relative positions inside the utility port, grasp and camera scope are usually maintained in the upper part of the port and the surgeon's instruments are in the lower part during dissecting process. However, during application of the endocutter or other specific procedures, a dynamic change in position may be necessary in order to command a clearer view and perform a safer procedure (*Figure 2*).

VATS lymph node dissection

Lymph node dissections on the right side of the mediastinum and left upper mediastinum are similar to traditional 2-ports VATS procedure (*Figures 3,4*). Although usually not difficult, it requires more time and patience to perform. However, the left subcarinal area can be challenging. We developed a special method, called the Liu's maneuver, to facilitate exposure of the left subcarinal space. We placed a non-elastic bandage above the inferior pulmonary vein to hook on the left lower lobe bronchus; thus, the lung parenchyma and hilum can be pulled away from the aorta and esophagus. With this maneuver, we obtain a clearer view of the carina, bilateral main bronchi, bilateral inferior pulmonary veins, pericardium, and esophagus along with right and left vagus nerves, right lung and right mediastinal pleura. In our early series using this maneuver, the average number of dissected lymph nodes for lung cancer was 23, similar to traditional VATS (15).

Learning curve, education, and training

Regarding learning curves, we went through a process similar to that of Diego Gonzalez-Rivas (6,16). As shown in his review articles, he also shifted from 3-ports to 2-ports and then to single-port VATS lobectomy. As a result, this process could be a training model for those who had VATS experience and who wanted to shift to single-port

Figure 3 Relative positions between the surgeon and cameraman during single-portright superior mediastinal lymph node dissection.

Figure 4 Single-port VATS for right subcarinal lymph node dissection.

VATS lobectomy, and for the new learner starting VATS lobectomy.

However, for the new learner without VATS experience, we are not certain about the need for a shift from 3-ports to 2-ports and then to single-port VATS. This question is similar to questions regarding the training required for traditional VATS. An open procedure is not absolutely necessary for the trainee to learn VATS. Similar to Diego Gonzalez-Rivas's group, we found that trainees without previous VATS experience are more open to new ideas and settings using single-port VATS. Actually, they accept these procedures and perform them better and more easily than experienced VATS surgeons who have already performed multiple ports VATS.

There is insufficient supporting data concerning the learning curve associated with VATS. Some thought that experienced VATS surgeons harbored a basic concept for VATS, and thus they could reach the plateau of the learning curve much quicker. However, if we take the Cases/Time curve into consideration when predicting the learning curve, perhaps the new learner will reach the learning plateau quicker than I did as it took me two years to pass the learning curve by accumulating more than 30 cases, which was really slow going in the beginning! This was not due to the difficulty of the technique, but rather the difficulty in making the determination whether or not to do it. To quote a well-known proverb:

The Difficulty lies, not in the new ideas, but in escaping from the old ones

——By John Maynard Keynes

The aggressive mind of the chest surgeon plays an important role in promoting the rapid development of commercial equipment necessary for single-port VATS, including the single-port wound protector, articulating instruments, harmonic scalpel, various sized straight or curved endocutter staplers, and higher resolution camera scopes with less scopic diameter. The mutual interaction between the desire of the surgeon and new manufacturing designs is the stimulus for advances in VATS.

More and more single-port VATS symposiums and conferences are held worldwide. Specific training programs on single-port VATS are also available. Furthermore, there are many single-port VATS videos, including trouble shooting for incomplete fissures, anthracotic lymph nodes, sleeve resection/bronchoplasty, bleeding, etc. These videos are available over the internet through YouTube.

Careful patient selection by the chest surgeon, for either benign or malignant disease, plays an important role when starting a single-port VATS lobectomy program. A single port VATS lower lobe lobectomy can be accomplished as easily as traditional VATS if there are no anthracotic nodes in the hilum nor incomplete fissures. The chest surgeon can then gradually expand his expertise to include all patients with early-stage lung cancer, if there are no specific contraindications.

In conclusion, we have reviewed the feasibility and safety of single-port VATS lobectomy for early-stage lung cancer. Single-port VATS is just another variant of VATS surgery in the modern era. More time and effort is need to procure sufficient evidence to show that single-port VATS is more beneficial to patients compared with standard techniques, in terms of less trauma and less postoperative pain, without compromising ontological outcome.

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Review Article

Videoscope-assisted cardiac surgery

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Abstract: Videoscope-assisted cardiac surgery (VACS) offers a minimally invasive platform for most cardiac operations such as coronary and valve procedures. It includes robotic and thoracoscopic approaches and each has strengths and weaknesses. The success depends on appropriate hardware setup, staff training, and troubleshooting efficiency. In our institution, we often use VACS for robotic left-internal-mammary-artery takedown, mitral valve repair, and various intra-cardiac operations such as tricuspid valve repair, combined Maze procedure, atrial septal defect repair, ventricular septal defect repair, etc. Hands-on reminders and updated references are provided for reader's further understanding of the topic.

Keywords: Minimally invasive surgery; video-assisted thoracic surgery; coronary artery bypass; cardiac valves; cardiac surgical procedures

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Introduction

Videoscope-assisted cardiac surgery (VACS) is a platform that provides less incisional trauma but equivalent corrective procedures for cardiac lesion as conventional open approach. It is one of the various techniques of minimally-invasive cardiac surgery (MICS) or minimal access cardiac surgery (MACS) (1) that minimizes incision size in order to lower morbidity while preserving quality in carefully selected patients (1). Compared with direct vision in minimal access approach (2), videoscope may offer smaller incisions, brighter illumination, larger images, and easier recording and broadcasting, whereas it may require more learning curve for eye-hand coordination. Three-dimensional imaging is only available in da Vinci robotic system and thoracoscope can only offer two-dimensional imaging that is a drawback relatively to direct vision. Almost all minimal access cardiac operations are videoscopic per se or have a videoscope-assisted version. Not repeating the abundant literature that covers the issues in MACS, such as comparisons to the conventional approach, peripheral cannulation, cardiopulmonary bypass management, etc., here we would like to focus on the issues that are more specific to videoscope-assisted approach, both robotic (3,4) or thoracoscopic (5), and on the procedures that we are more experienced in our own institution: endoscopic saphenous vein and radial artery harvesting (6-12), robotic left internal mammary artery (LIMA) takedown (13), robotic-assisted coronary artery bypass, mitral valve operations (4,5), aortic valve operations, and various intra-cardiac operations. We will cover the topics that include patient selection and preparation, technical concerns and issues, and some relevant issues. We welcome both novice or expert audience and this article may not be perfectly comprehensive but will serve as decent reminders and highlights.

General considerations

Ironically, intending to lower surgical morbidity, VACS is seldom performed in high-risk patients in which full sternotomy possesses insignificant risk comparing to surgical mortality. Only in elective low-risk but symptomatic patients, it matters more for smaller wounds with uncompromised surgical outcomes when the goal of surgery is to improve life quality. VACS approach further lowers surgical risks in properly selected low-risk patients.

We estimate the surgical risk of our cardiac surgery patients by calculating EuroScore II (14,15). VACS patients usually fit low-risk profile that includes: elective, no comorbidity, and good myocardial contractility. With clinical feasibility, patient's cosmetic needs and financial affordability will be next determinants of selecting VACS approach. Taiwanese have government-managed universal health insurance and patients have higher co-payments for VACS that costs higher than full sternotomy approach—robotic is even higher than thoracoscopic. Thus patient's socio-economic status cannot be ignored for hospital cost management.

Once VACS approach has been chosen and agreed by the patient and the surgeon, we begin preoperative workup for risk assessment and surgical planning, for example, lung function test for selective one-lung ventilation, ankle-brachial index for peripheral artery integrity for peripheral femoral cannulation, chest non-contrast CT for aortic calcification and thoracic anatomy overview (16,17), confirmatory echocardiography for global contractility, regional wall motion, valve competency, and relevant structural and functional assessment, and other workups are like conventional cardiac operation such as carotid Doppler, laboratory panel, etc. If we identify excessive risk, either for VACS or overall cardiac procedure, we will re-evaluate the operation, or seek solutions accordingly.

As mentioned earlier, VACS is only a platform or vehicle to the target. Procedure-specific issues are paramount and the surgeon must have full expertise of the surgical planning and corrective procedure of the cardiac lesions as in conventional open approach. For example, is the coronary revascularization to be totally surgical or hybrid with cardiologists? What are the coronary bypass targets? What is the repair strategy for mitral annulus, leaflets, chordae, papillary muscle, and left ventricle? Also, perfusion strategy must be error-free for on-pump cases. For example, we must select the best cannulation method, cannulae sizes, venous drainage vacuum, etc. Furthermore, like conventional cardiac operations, hemostasis is also very important and it is often more difficult due to minimally invasive approach. Port bleeding is the most common reason for postoperative re-exploration in minimally invasive cardiac surgery.

Postoperative management is almost the same as the conventional cardiac surgery. One of the reminders is that the clinical alertness should not be lowered because of the minimal invasiveness or the relatively low-risk profile. Delayed management of cardiac tamponade in a routine MIDCAB can lead to mortality. Another issue specific to VACS is the pain control, especially in robotic cases or rib-spreading mini-thoracotomy cases. Chest wall pain will impair the pulmonary recovery and may cause pneumonia in fragile cases. Anesthesiologists must be involved in the pain-control issue and we may use controlled-release local infiltrative analgesics or intravenous patient-controlled analgesia.

Robotic videoscope- and thoracoscope-assisted operations

VACS included robotic and thoracoscopic approaches and each has special considerations. Because of the market dominance, here our discussion on robotic surgery is limited to the da Vinci HD Si system by Intuitive Surgical, Inc. only. Logistic issues are not addressed here but they are essential for the back-stage operating room management.

Robotic videoscope provides three-dimension vision for the console-side surgeon and the surgical cart has robotic arms and instruments that offer supreme dexterity duplicating surgeon's hands movements. Patient-side surgeon or assistant is very important and must have expertise in both robotic and thoracoscopic techniques. There are lots of robotic arm maneuvers and troubleshooting, knot-pusher tying, suture management, and object hand-overs. We must also get used to the dependency of visual clues that replace tactile feedback that is absent in the current robotic system, preventing excessive forces to the objects in visual field. There are also some basic robotic rules to follow as emphasized in the boot camp training such as the avoidance of moving robotic instruments outside visual field, "sweet spot" issues, etc.

Thoracoscopic approach offers equivalent results without bigger incision wounds for experienced minimally invasive surgeons. Its weaknesses include non-stereo two-dimensional images and less dexterity comparing to robotic counterpart that can be overcome in the learning curves. Its strengths include lower costs, tactile feedbacks, and less dependency on the assistant, as compared with robotic approach; the operating surgeon works mostly at the patient-side like conventional operations. Just as general abdominal and thoracic surgeon's laparoscopic and thoracoscopic operations, there are a variety of selections of scopes, instruments, and accessories, and the operating surgeon must pick the optimally customized specifications of each item. For example, in our institute we prefer Delacroix-Chevalier minimally invasive surgery instruments set and our custom-made thoracoscope is 17 cm long, 30-degree, and using 5-mm ports.

After the general considerations, let us move on to the procedure-specific parts that we will share our experience below.

Coronary artery revascularization

Endoscopic vein and radial artery harvesting

There have been debates for intima integrity and long-term graft patency for comparing endoscopic and open vein harvesting (7,9-12). With techniques and equipment advancement, endoscopic vein harvesting has become a mature method and most concerns are experience and learning curves. With well-trained and experienced staff, the conduit quality is comparable to open method and not compromised as reported evidences (7,12). Our experience has shown satisfactory and encouraging results for both saphenous vein (8) and radial artery (6). Endoscopic vein harvesting has been our default practice if the veins fit and the patient can afford. Technical aspects have been covered elsewhere (8,11) and one of the key points of success is the preoperative vein echo mapping for endoscopic feasibility. We mark the vein paths and take the open method if the vein diameters fall outside the range of 2 to 4 mm.

Robotic left internal mammary artery (LIMA) takedown

Robotic surgery is an advanced version of videoscopic approach. Robotic coronary revascularization, assisted or total, has been reviewed in previous literature (13,18-20) and robotic internal mammary artery takedown has been considered an essential step (21). Detailed technical issues, including set-ups, are available in "da Vinci® Beating Heart Coronary Revascularization Procedure Guide", a booklet offered by the vendor. As the most expensive among all methods, robotic LIMA takedown may offer easier learning curves than other minimal invasive methods and it offers the possibility of taking bilateral internal mammary arteries (13). Surgeons can choose preferred instruments such as 30-degree camera, right permanent cautery spatula, and left black diamond micro forceps, and take either skeletonized or pedicle method. With proper patient positioning and optimally placed ports, the surgical views and maneuvers should be satisfactory without the blockade of left shoulder. Timely troubleshooting of the robotic arms by the patient-side assistant is very valuable for the success of the procedure (*Figure 1*).

Robotic-assisted CABG and TECAB (3,4)

With LIMA and/or RIMA and other conduits ready, the coronary revascularization can proceed in a variety of ways, such as off-pump, beating on-pump, arrest on-pump, hand anastomosis, or robotic anastomosis, depending on learning curves or surgeon's expertise (3,19,20,22). We may have MIDCAB, robotic-assisted CABG, or TECAB (18). In the arrest on pump approach, the aortic occlusion method must be chosen (4). Coronary anastomosis may be done with prolene, U-clips, or anastomotic connectors such as C-Port Flex A (Cardica, Redwood, CA, USA), depending on availability and surgeon's preference. In minimally invasive CABG, we cannot forget the role of hybrid CABG, a mode of teamwork that takes both strengths: surgeons bypass left anterior descending artery and cardiologists open left circumflex and right coronary arteries. During cardiologist's coronary intervention, immediate postoperative angiography can be done for the revascularized coronary artery for quality assurance in addition to surgeon's transit time flow probes.

Pitfall scenarios and suggestions

Here we show some near-miss scenarios and provide some proposed troubleshooting.

Shock develops upon inserting the first port trocar with core

The patient develops sudden decrease of systolic blood pressure from 110 to 70 mmHg right upon the insertion of the camera trocar port with core. Electrocardiogram shows sinus rhythm and pulse oximetry shows 99%. Instantly we inflate both lungs, release intra-thoracic CO_2, and anesthesiologists begin fast fluid intravenous infusion. The blood pressure is still low. How to troubleshoot?

Trans-esophageal echocardiography (TEE)!

TEE finds pericardial effusion with cardiac tamponade! Our port trocar with core injures epicardium and leads to bleeding. Then we make a mini-thoracotomy just as big as we need for robotic-assisted CABG and use minimally invasive long instruments to drain the tamponade and fix the problem. The hemodynamics is restored. We proceed to place ports, dock, and finish the robotic-assisted CABG.

After LIMA takedown, ventricular fibrillation attacks during pericardial opening

With LIMA mobilized and ready, we proceed to open the pericardium with micro-forceps and cautery spatula. While we cauterize the pericardium, suddenly pulseless ventricular tachycardia attacks! Defibrillator shock paddles are

Figure 1 Robotic-assisted CABG.

non-sterilized and in the closet! Intra-thoracic defibrillator shock paddle are sterilized but too big to enter the mini-thoracotomy.

External defibrillator pads are already in place!

We immediately deliver defibrillator shocks and convert the rhythm back to sinus. Anesthesiologists begin some lidocaine and amiodarone intravenous infusion. Operation proceeds. For all MICS or VACS, we routinely place external defibrillator pads in case of pericardiotomy-related ventricular arrhythmia that mandates electric defibrillation. Unprepared access for electric defibrillator will lead to disaster.

Progressive hypotension and hypoxia develop during robotic LIMA takedown

During robotic LIMA takedown, anesthesiologists report dropping blood pressure to below 90 mmHg and O_2 saturation down to 90%. From the videoscope, there is no bleeding and the left lung is not injured.

CO_2 over-inflation!

Robotic LIMA takedown needs artificial left pneumothorax with CO_2. The patient has to tolerate both one-lung ventilation and left CO_2 pneumothorax. In fragile patients, hypoxia may develop from inadequate lung reserve by one-lung ventilation and have hypotension from relative "tension pneumothorax". The optimal CO_2 intra-thoracic pressure may vary in different settings. We may adjust or lower the CO_2 pressure first if hypotension develops. We may also take a break and anesthesiologists can ventilate both lungs for a while. The ventilation and pressure must be addressed for robotic LIMA takedown.

Mitral valve operations

Mitral valve procedures are among the most successful applications of VACS. There have been plenty of recent literature on the topic, either robotic (4,23-27) or thoracoscopic (28-31), and there are coverage of perfusion and

Figure 2 Robotic mitral valve operation.

Figure 3 Mitral valve MICS.

cardioplegia strategy (30,32-34) and anesthesia planning (35). There are also discussions on detailed technical issues (36-40). Readers are encouraged to seek these excellent references.

In our institute, our mitral VACS has been performed since 2000, with the methodology has been described elsewhere (28,33). In brief, either robotic (*Figure 2*) or thoracoscopic (*Figure 3*), we use double-lumen endotracheal tube, right-up 30-degree supine, right mini-thoracotomy, femoral arterial and venous cannulation, transcutaneous pigtail adenosine-induction cardioplegia delivery (41), HTK cardioplegia as default for robotic (34) or difficult cases, Chitwood transthoracic aortic cross-clamps, and Delacroix-Chevalier tripod atrial lifter with CO_2 insufflation line.

We could like to do mitral VACS in the most cost-effective way. For example, we prefer Chitwood transthoracic aortic cross-clamps to endo-aortic balloon, in addition to cost advantage, clinical benefits have been demonstrated in a recent comparative study (42). There have been encouraging reports of mitral VACS without aortic occlusion (43,44) that we may try in selected cases, but we still believe trans-thoracic aortic cross-clamps with myocardial arrest provide optimal myocardial protection and operative exposure. With experience and confidence obtained over the years, we also perform mitral VACS in less ideal patients and get satisfactory results, like the recent reports for the patients with left ventricle dysfunction (45,46).

Since the rules and methods of mitral valve repair per se are similar in either conventional sternotomy or VACS approaches (36-39,47), and the readers must also have expertise in the techniques, we would not repeat them in the following discussions that are just highlighted reminders and we welcome further incoming comments and advices.

Pitfall scenarios and suggestions (5,28)

During peripheral cannulation, the cannula fails to advance properly

Using Seldinger technique, with our guidewire in place and we have dilated the vascular entry, we insert the cannula through the wire, but it gets stuck and cannot advance.

Peripheral cannulation with proper pump perfusion is vital in mitral VACS. We may take open or puncture techniques for artery and vein cannulation and each has strengths and weaknesses. Sometimes we use graft interposition for femoral artery. Whenever we get access into femoral vein and upward, we always ask anesthesiologist to check the TEE for the guidewire position that is best in right atrium. With the properly placed guidewire, the cannula should advance smoothly. If not, we have several solutions. First, we may downsize the cannula. Second, we can repeat dilators to open fascia entry further. Third, we can use alternative cannulation site while ask the assistant to compress the failed puncture site firmly.

With arterial and venous cannulae ready, the heart-lung machine pump cannot achieve adequate flows

With artery and vein cannulae placed properly at groin, we find the cannulae fluctuate vigorously and the pump flow cannot reach 3 liters/min and up, with adequate intravascular volume.

Our solutions to the scenario include the following. We can add venous drain vacuum (Maquet VAVD Controller, Maquet Cardiopulmonary AG, Hirrlingen, Germany) to facilitate venous drainage. Also, we can place an additional venous cannula at right internal jugular vein. Of course, cannula sizes must be big enough to fit patient's body size.

Persistent or progressive acidosis develops during cardiopulmonary bypass

During the mitral VACS, everything seems going smoothly. But our perfusionists have found metabolic acidosis persists even with the correction by using sodium bicarbonate.

This scenario should be reported to the operating surgeon as early as possible and timely troubleshooting is mandatory. It may reflect sub-optimal perfusion, either cannula-related or unrelated. Is mean arterial pressure optimal? Is there any unexpected blood loss? Is there any distension for peritoneal or retroperitoneal space? Are all cannulae in good positions? Is there any kinking of venous cannula inside right atrium or vena cava that is retracted up for left atrial opening? We may ask the anesthesiologists to use TEE to explore additional clues. We must keep alert and continue troubleshooting until the event improves or is resolved.

After mitral valve repaired and atrial lifter released, left atrial opening is too floppy to close

Following a saline jet test, the repaired mitral valve is competent and we proceed to remove the left atrial lifter and close the left atriotomy. However, from the camera, left atrial wall dropped and we cannot see the edges for placing stitches. The assistant also sees the problem on the screen, but it is almost impossible to place an additional grasper to help.

Like conventional open operations, good retractions are vital for VACS exposure. Left atrial midway traction suture can solve the problem. We can place a traction suture in left mid-atrium and pull it out through the entry of left atrial lifter when opening left atrium. At the end of mitral valve repair, we remove the left atrial lifter but the traction suture still holds the left atrium open. Without any additional assistance, we can close the left atriotomy with ease.

Pigtail catheter for cardioplegia and dearing (33)

Even with limited exposure and controlled budgets, we have found cardioplegia delivery and deairing venting can be done easily with our inexpensive 8-French pigtail catheter. The technical details are covered elsewhere (41). In brief, it is placed transcutaneously under videoscope vision into ascending aorta, can be used to deliver cardioplegia solution and remove air bubbles during deairing, and is removed after pledgetted purse-string suture. When it is removed from aorta, we keep it inside thorax as an additional pericardial drain. Along with adenosine induction and Chitwood trans-thoracic aortic-cross clamps, we can achieve rapid myocardial arrest optimal myocardial protection without expensive endovascular devices for aortic occlusion or cardioplegia delivery.

Aortic valve operations and other intra-cardiac operations

In contrary to mitral valve procedures, aortic valve procedures often can be done with minimally invasive non-endoscopic approach (48-51). We have done it with endoscope by anterior/axillary approach whereas mostly we do aortic valve replacement under direct vision via right mini-parasternotomy approach. We may share our endoscopic methodology in the future.

With our VACS platform, we can perform other intra-cardiac operations, such as Ebstein's anomaly, tricuspid valve operations, ventricular septal defect, atrial septal defect, Maze procedures, and many combined cardiac operations, of course, in optimized and selected patients. One of the reminders is the bi-caval cannulation and occlusion for opening right atrium. With femoral vein cannula in inferior vena cava, right internal jugular vein cannula can be placed in superior vena cava, and both cavae must be clamped when right atrium is opened.

Specific complications

When VACS meets most outcomes and quality measurements such as mortality, coronary patency, valve competency, major morbidity such as stroke, ventilator dependency, bleeding re-exploration, sepsis, pneumonia, shock, cardiac events, hemolysis, etc., we address some minor complications specific to VACS here: groin morbidity, and compressive neuropathy.

Groin complications are related to peripheral cannulation and include seroma, and wound infection. They may prolong the hospital stay and affect patient's satisfaction. There are several solutions. We should expose the femoral vessels with appropriate dissections, not too much. We may place artery and vein cannulae at different sides to minimize the local exploration. Proper hemostasis and decannulation techniques that avoid excessive bleeding also reduce the incidence. Adequate local wound compression or good surgical closure is also essential for prevention. But once a seroma or infection develops, it is advisable to do surgical debridement and place a drain, as well as local compression.

Compressive neuropathy is related to inadequate cushions or improper pressure in patient positioning, such as brachial plexus injury, ulnar nerve palsy, peroneal nerve palsy. Care must be taken during patient positioning for VACS. Excessive pressure to any body parts should be avoided, or adequate cushion must be applied. Its prevention is easier than treatment. Once it develops, neurological clinic and rehabilitation may help but the recovery process is lengthy. Sometimes, walking or forearm movement is impaired and the life quality is considerably affected.

Conclusions

With appropriate hardware set-up, staff training, patient selection, and surgeon's learning curves, VACS can be performed for most cardiac procedures, such coronary artery bypass and mitral valve repair. Teamwork approach, including anesthesiologist, is essential for timely troubleshooting. We must ensure safety and provide quality to the target patients of VACS.

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Original Article

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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Original Article

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

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)

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.

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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Original Article

Comparative study of systematic thoracoscopic lymphadenectomy and conventional thoracotomy in resectable non-small cell lung cancer

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Objective: To assess the feasibility and safety of the video-assisted thoracoscopy surgery (VATS) systematic lymph node dissection in resectable non-small cell lung cancer (NSCLC).

Methods: The clinical data of patients with NSCLC who underwent VATS or thoracotomy combined with lobectomy and systematic lymphadenectomy from January 2001 to January 2008 were retrospectively analyzed to identify their demographic parameters, number of dissected lymph nodes and postoperative complications.

Results: A total of 5,620 patients were enrolled in this study, with 2,703 in the VATS group, including 1,742 men (64.4%), and 961 women (35.6%), aged 59.5±10.9 years; and 2,917 in the thoracotomy group, including 2,163 men (74.2%), and 754 women (25.8%), aged 58.5±10.4 years. Comparing the VATS with the thoracotomy groups, the mean operative time was 146 *vs*. 157 min, with a significant difference (P<0.001); and the average blood loss was 162 *vs*. 267 mL, with a significant difference (P<0.001). Comparing the two groups of patients data, the number of lymph node dissection: 18.03 in the VATS group and 15.07 in the thoracotomy group on average, with a significant difference (P<0.001); postoperative drainage time: 4.5 days in the VATS group and 6.37 days in the thoracotomy group on average, with a significant difference (P<0.001); postoperative hospital stay: 6.5 days in the VATS group and 8.37 days in the thoracotomy group on average, with a significant difference (P<0.001); proportion of postoperative chylothorax: 0.2% (4/2,579) in the VATS group and 0.4% (10/2,799) in the thoracotomy group, without significant difference (P>0.05).

Conclusions: For patients with resectable NSCLC, VATS systematic lymph node dissection is safe and effective with fewer postoperative complications, and significantly faster postoperative recovery compared with traditional open chest surgery.

Keywords: Non-small cell lung cancer (NSCLC); video-assisted thoracoscopy surgery (VATS); systematic lymph node dissection

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Introduction

Lung cancer is a serious hazard to human health and life, with a significant rising trend in terms of morbidity and mortality around the world in recent years. This condition has become the leading cause of morbidity and mortality worldwide, both for developed and developing countries (1). Although there are many methods for treating lung cancer at present, the recognized option of choice for the treatment of early- and mid-stage non-small cell lung cancer (NSCLC) is surgical excision, and the standard surgical method is lobectomy combined with systematic lymph node dissection. As early as in 1983, Martini *et al*. (2) first reported the use of lobectomy and mediastinal lymph node dissection for the treatment of primary lung cancer.

With the wide application of minimally invasive techniques in the surgical field, the use of video-assisted thoracoscopy surgery (VATS) in the treatment of NSCLC has been increasingly valued by thoracic surgeons. With the greatest advantage of minimal invasiveness, reduced postoperative pain and less damage to the respiratory muscle and pulmonary function, the VATS technique has been applied in the lobectomy of lung cancer as early as in 1992 (3). In 1995, McKenna *et al*. (4) first reported the use of VATS lobectomy combined with mediastinal lymph node dissection in the treatment of primary lung cancer.

Thorough lymph node dissection is one of the keys for successful comprehensive treatment of lung cancer, as it provides definite staging and guidance for the prognosis and the next treatment, and can improve the local remission rate and prolong disease-free survival time. According to the guidelines issued by the European-Society of Thoracic Surgeons (ESTS), systematic lymph node dissection is required for resectable NSCLC regardless of VATS or thoracotomy (5). Whether VATS allows thorough mediastinal lymph node dissection and can achieve comparable effects to thoracotomy has been controversial. At present, the reported results varied in different studies on the use of VATS for lobectomy combined with lymphadenectomy of resectable NSCLC compared with thoracotomy (6-14). So far, however, the number of studies comparing the two techniques is not large enough for a comprehensive assessment of the effectiveness and safety of systematic lymphadenectomy using VATS versus thoracotomy. This study aims to determine the effectiveness and safety of VATS-based systematic lymphadenectomy by retrospectively analyzing the related multi-center, large-scale clinical data.

Materials and methods

Clinical data

The clinical data of patients with NSCLC who underwent VATS or thoracotomy combined with lobectomy and systematic lymphadenectomy in eight hospitals in China from January 2001 to January 2008 were retrospectively analyzed, and 5,620 patients were included in this study. Upon enrollment, all participants were engaged in a series of preparation before surgery, including quitting smoking, respiratory function exercise, administration of phlegm drugs and chest physiotherapy.

Preoperative examination and surgical methods

Before surgery, all participants received physical examination, routine blood tests, ECG, cardiac color Doppler ultrasound and lower extremity deep venous color Doppler ultrasound. Respiratory function tests included pulmonary ventilation-dispersion function tests. Coronary artery CT or treadmill activity tests were performed in patients with suspected coronary heart disease over the age of 60, as well as coronary interventional examination, if necessary.

Preoperative tumor staging was based mainly on chest CT, head and abdominal MRI, whole body bone scan, and bronchoscopy. PET/CT scans were recommended for patients considered to be stage II or above.

All participants underwent VATS or open chest lobectomy and hilar and mediastinal lymph node dissection, of which the specific surgical techniques were already reported in our previous study (15).

Thoracotomy group: a standard posterolateral incision of about 10-20 cm was made for placement of intercostal distraction to carry out the thoracotomy under direct vision. The operation included anatomic lobectomy plus systematic mediastinal lymph node dissection.

Systematic mediastinal lymph node dissection was common in both procedures, instead of lymph node sampling, involving at least three groups of mediastinal and intrapulmonary lymph nodes (including subcarinal lymph nodes). The surrounding fat tissue was be resected together with the lymph nodes en bloc. The resected lymph node specimens were independently examined and interpreted by two or more senior pathologists.

Data collection and follow-up

The demographic data, operative time, blood loss, number

Table 1 Characteristics of included patients

	VATS (%)	Open (%)	P
Numbers	2,703	2,917	
Sex			<0.001
Male	1,742 (64.4)	2,163 (74.2)	
Female	961 (35.6)	754 (25.8)	
Age (mean ± SD), years	59.5±10.9	58.5±10.4	0.002
Histology			<0.001
Squamous carcinoma	675 (25.0)	1,081 (37.1)	
Adenocarcinoma	1,663 (61.5)	1,326 (45.5)	
Adenosquamous carcinoma	126 (4.7)	168 (5.8)	
Large cell carcinoma	62 (2.3)		
BAC	75 (2.8)	198 (6.8)	
Others	102 (3.8)	101 (3.5)	
TNM stage			<0.001
Stage I	1,415 (52.3)	1,246 (42.7)	
Stage II	657 (24.3)	794 (27.2)	
Stage III (A)	631 (23.3)	877 (30.1)	

Abbreviations: VATS, video-assisted thoracoscopy surgery; BAC, bronchioloalveolar carcinoma.

of dissected lymph nodes, postoperative hospital stay, postoperative chest tube duration, postoperative tumor type, stage, and occurrence of postoperative chylothorax were collected for all patients.

Statistical analysis

Measurement data were expressed as mean ± standard deviation ($x \pm s$). The statistical analysis was completed in SPSS 13, with P<0.05 indicating a statistically significant difference.

Results

Clinical data

A total of 5,620 patients were finally included in the retrospective study, with 2,703 in the VATS group, including 1,742 men (64.4%) and 961 women (35.6%), aged 59.5±10.9 years; and 2,917 in the thoracotomy group, including 2,163 men (74.2%), and 754 women (25.8%), aged 58.5±10.4 years (*Table 1*).

All patients underwent VATS or open chest lobectomy plus systematic lymphadenectomy. Comparing the VATS with the thoracotomy groups, the mean operative time was 146 *vs.* 157 min, with a significant difference (P<0.001); and the average blood loss was 162 *vs.* 267 mL, with a significant difference (P<0.001) (*Table 2*). The postoperative pathological test showed 1,663 patients with adenocarcinoma (61.5%), 675 patients with squamous cell carcinoma (25.0%), 126 patients with adenosquamous carcinoma (4.7%), and 239 patients with other types of tumors (8.9%) in the VATS group; and 1,326 patients with adenocarcinoma (45.5%), 1,081 patients with squamous cell carcinoma (37.1%), 168 patients with adenosquamous carcinoma (5.8%), and 342 patients with other types of tumors (11.8%) in the thoracotomy group (*Table 1*). According to the 2009 International Association for the Study of Lung Cancer (IASLC) staging criteria (16), all patients were subject to clinical pathological staging classification. There were 1,415 patients at stage I (52.3%), 657 patients at stage II (24.3%), and 631 patients at stage IIIA (23.3%) in the VATS group; and 1,246 patients at stage I (42.7%), 794 patients at stage II (27.2%), and 877 patients at stage IIIA (30.1%) in the thoracotomy group (*Table 2*).

Postoperative conditions (Table 2)

Comparing the two groups of patients data, the number of lymph node dissection (*Figure 1*): 18.03 in the VATS

Table 2 Comparisons of numbers of sampled lymphnodes and operation duration between VATS and open surgery for resectable stage NSCLC

Mean (SD)	VATS (N=2,703)	Open (N=2,917)	P
No. of sampled LNs			
Total	18.03 (10.14)	15.07 (8.55)	<0.001
Stage I	17.26 (9.29)	14.32 (7.98)	<0.001
Stage II	18.53 (11.20)	15.38 (8.91)	<0.001
Stage IIIA	19.27 (10.68)	15.86 (8.90)	<0.001
Operation length/minutes			
Total	145.71 (13.03)	156.72 (17.03)	<0.001
Stage I	145.75 (12.95)	156.09 (17.06)	<0.001
Stage II	145.40 (12.51)	157.63 (16.95)	<0.001
Stage IIIA	145.96 (13.71)	156.80 (17.04)	<0.001
Blood loss/mL	162.20 (142.56)	267.34 (220.31)	<0.001
Drainage days	4.50 (1.84)	6.37 (3.45)	<0.001
Length of hospitalization/days	6.50 (1.84)	8.37 (3.45)	<0.001
Chylothorax	4/2,579 (0.2%)	10/2,799 (0.4%)	0.117

Abbreviations: NSCLC, Non-small cell lung cancer; VATS, video-assisted thoracoscopy surgery; LNs, lymph nodes; Total, all stages (stage I-III).

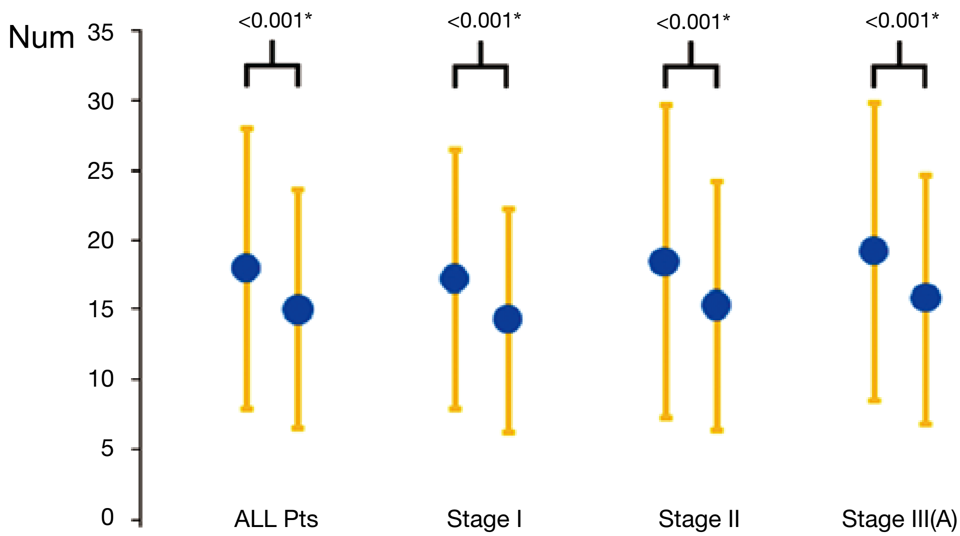

Figure 1 Comparisons of numbers of sampled lymph nodes between VATS and open surgery for resectable stage NSCLC. Abbreviations: NSCLC, Non-small cell lung cancer; VATS, video-assisted thoracoscopy surgery. *, With a significant difference.

group and 15.07 in the thoracotomy group on average, with a significant difference (P<0.001); blood loss: 162.2 mL in the VATS group and 267.34 mL in the thoracotomy group on average, with a significant difference (P<0.001); postoperative drainage time: 4.5 days in the VATS group and 6.37 days in the thoracotomy group on average, with a significant difference (P<0.001); postoperative hospital stay: 6.5 days in the VATS group and 8.37 days in the thoracotomy group on average, with a significant difference (P<0.001); proportion of postoperative chylothorax: 0.2% (4/2,579) in the VATS group and 0.4% (10/2,799) in the thoracotomy group, without significant difference (P>0.05).

Discussion

Lymph node metastasis is an important way of local and distant metastases in malignant cancer, as well as in NSCLC. It has a very important role in the prognostic determination and development of therapeutic strategies. Thus, for resectable NSCLC, the standard surgical method is lobectomy in combination with systematic lymph node dissection, which can improve the local control rate and prolong disease-free survival time.

Although it remains unconfirmed whether systematic lymphadenectomy can benefit patients with NSCLC oncologically, accurate lymph node staging still plays an important role in determining the need of postoperative adjuvant therapy and prognosis. Studies have shown that systematic lymphadenectomy is significantly superior to lymph node sampling in accurate staging. Investigators have found 4% patients at N2 stage with systematic lymph node dissection from 524 stage I patients who were identified with negative lymph nodes based on the sampling (17).

In the past, standard posterior lateral open chest lobectomy and lymph node dissection was mostly used for early and mid-stage resectable NSCLC. However, it is associated with a surgical incision often larger than 10 cm, extensive injury, slower postoperative recovery and higher incidence of postoperative complications. Since the early 1990s, 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.

The safety and effectiveness of VATS lobectomy combined with lymph node dissection for the treatment of early NSCLC has been confirmed, more and more studies have shown that this technique has comparable long-term oncological outcomes as a radical option to traditional open thoracic surgery (18,19). Moreover, National Comprehensive Cancer Network (NCCN) treatment guidelines for NSCLC has also clarified that VATS is a viable option for treating resectable lung cancer, particularly for those who can not tolerate standard thoracotomy due to physical conditions. This means that VATS treatment of NSCLC has covered most internationally recognized indications for surgical treatment of lung cancer.

As we all know, a thorough lymph node dissection is essential for the prognosis of patients with NSCLC, but it remains controversial whether this can be achieved with thoracoscopic systematic lymphadenectomy for NSCLC. In contrast to the thoracic surgery, many surgeons suspect the feasibility and thoroughness of thoracoscopic lymph node dissection. The primary concern is residual lymph nodes. In this regard, many studies have confirmed that after VATS lymph node dissection, the residual lymph node rate is very low. Hoksch *et al*. (20) did VATS lymphadenectomy in corpses followed by standard lateral open chest exploration, and the results showed no significant residual hilar and mediastinal lymph nodes. Sagawa *et al*. (21) performed VATS lymph node dissection in 29 NSCLC stage I patients followed by open chest exploration, and confirmed that there were only 2-3% of residues.

Since it has been applied in lymph node dissection, VATS has witnessed numerous controversies about whether it is superior or inferior to thoracotomy in this regard. Retrospective or prospective clinical studies yielded varying results as well (6-14,22). Ramos *et al*. (11) conducted a retrospective study to compare the number of dissected lymph nodes and stations with the two approaches by collecting the clinical and pathological data from patients with stage I non-small cell lung cancer patients. The results showed that an average dissection number of 5.1 stations in the VATS group, which was more than 4.5 stations in the open chest group, with a significant difference. However, the average number of 22.6 dissected nodes in the VATS group was far fewer than 25.4 nodes in the open chest group, with a significant difference. Lee *et al*. (23) analyzed 141 VATS patients and 115 cases of thoracic surgery for resectable NSCLC, finding that VATS yielded fewer dissected nodes compared with the open chest group (11.3 ± 6.4 *vs*. 14.3 ± 8.8, P=0.001), and the total number of dissected stations (3.1 ± 1.1 *vs*. 3.8 ± 1.2, P<0.001). Further analysis revealed that both differences came mainly from the dissection of mediastinal lymph nodes. On the other hand, some studies have confirmed that there is no difference in the number of either dissected nodes or dissected stations between the two approaches. Yang *et al*. (22) compared 62 patients with resectable NSCLC, which 31 cases in each of the VATS and thoracotomy groups, and found no significant difference in the number of either node or station dissected. In the present study, we found through statistical analysis that there was a mean number of dissected nodes of 18.03 in the VATS group and 15.07 in the thoracotomy group, with a significant difference (P<0.001)

Table 3 Comparisons between VATS and open surgery for resectable stage NSCLC

References	No. of patients		No. of sampled LNs		Hospital stay/days		Drainage days		Chylothorax	
	VATS	Open	VATS	Open	VATS	Open	VATS	Open	VATS	Open
Merritt RE, *et al*. 2013 (12)	60	69	9.9	14.7	4.5	5.1				
Ramos R, *et al*. 2012 (11)	96	200	22.6	25.4	7	10.3	4	5.7	2	3
Denlinger CE, *et al*. 2010 (13)	79	464	7.4	8.9	5.1	7.3				
Scott WJ, *et al*. 2010 (10)	66	686	15	19	5	7			0	7
Yang H, *et al*. 2013 (22)	31	31	28.2	29.8	10.6	12.4	6.3	8.3	0	1
Our study	2,703	2,917	18.03	15.07	6.5	8.37	4.5	6.37	4	10

Abbreviations: NSCLC, Non-small cell lung cancer; VATS, video-assisted thoracoscopy surgery; LNs, lymph nodes.

between the two groups, which is inconsistent with previous reports. We believe that the thoracoscopic vision has almost zero dead angles during intrathoracic operations. It can provide a good surgical field and has a visual zoom effect to magnify the surgical field, with which the hilar structures and mediastinal lymph node stations can be more clearly identified and exposed. In this way, we are able to clean out more mediastinal lymph node, reducing the incidence of residual lymph nodes.

The safety of VATS lobectomy in combination with systematic lymphadenectomy for resectable NSCLC is another concern. We have found through literature review and comparison (*Table 3*) that the majority of studies suggest that VATS has great advantages in terms of postoperative complications, postoperative chest tube drainage duration and postoperative hospital stay compared with thoracotomy. This study also confirms this conclusion. We believe that the smaller surgical wound and more clearly exposed blood vessels, lymph nodes and lymph vessels during VATS have made it possible to accurately dissect target tissue during dissection without damaging small blood vessels and lymph nodes, thus reducing lymphatic drainage and the occurrence of postoperative chylothorax, allowing earlier postoperative extubation and reduced postoperative hospital stay.

However, there are several limitations in this study due to its retrospective nature. Although this study has involved the most cases in comparison of VATS and open chest lymph node dissection, the origination of data from several studies with surgeons of varying thoracoscopic technical levels may have contributed to certain data deviation. Secondly, this study only analyzes two surgical procedures only in terms of the number of lymph node dissection and related postoperative complications, without comparing the differences in the prognosis. Therefore, a more comprehensive prospective study will be needed to further determine the safety and effectiveness of VATS lymph node dissection.

In conclusion, for patients with resectable NSCLC, VATS systematic lymph node dissection is safe and effective with acceptably low incidences of postoperative complications, and significantly faster postoperative recovery compared with traditional open chest surgery.

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Original Article

Video-assisted thoracoscopic surgery for postoperative recurrent primary spontaneous pneumothorax

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Objectives: Postoperative recurrent primary spontaneous pneumothorax (PSP) is a troublesome complication and an important issue to be discussed. This study is to determine whether Re-video assisted thoracoscopic surgery (VATS) should be performed for postoperative recurrent PSP (PORP).

Materials and methods: Patients who had underwent needlescopic VATS for PSP between Jan. 2007 and Dec. 2011 were reviewed.

Results: VATS was initially performed on 239 patients with PSP in total. Eleven patients were found to have PORP during a follow-up period of 36.95 months. Nine patients received Re-VATS and only two patients receiving conservative treatment had no further recurrence. No conversion to thoracotomy, blood transfusion and prolong air leak were recorded.

Conclusions: Even for smaller size cases, Re-VATS, which is technically feasible, safe and effective with better cosmetics and minor postoperative pain, should be a strong contender as priority treatment.

Keywords: Postoperative recurrent primary spontaneous pneumothorax; video-assisted thoracoscopic surgery

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Introduction

Surgical procedure, thoracotomy or video-assisted thoracoscopic surgery (VATS), can effectively reduce the recurrence rate of primary spontaneous pneumothorax (PSP) after the first episode, from 23-50% (1-3) to 3-7% (4-6). When it was first implemented for PSP, VATS seemed to have a higher postoperative recurrence rate than thoracotomy (4-6), but with gradual advancement of instrumentation and improvement of surgeon dexterity, results from both approaches are now comparable (7-9). From reports worldwide, the recurrence rate after operation for PSP is as mentioned above. Although the percentage does not seem high, any postoperative recurrence remains the embarrassment of every surgeon. Even now, there is no standard treatment principle for postoperative recurrence, and related discussions in the literature are few.

In this article, we will discuss the feasibility of re-operation and share our limited experience of implementation of Re-VATS for postoperative recurrent pneumothorax (PORP).

Materials and methods

Patients who had underwent needlescopic VATS for PSP between Jan 2007 and Dec 2011 were reviewed, with those aged 40 years and above excluded to avoid the possibility of secondary pneumothorax. Reviewed patients were followed-up once a week after discharge at our out-patient clinic for several weeks until they were satisfied with their condition. They were advised to contact us immediately in the event of any discomfort. Telephone counseling was the method of choice prior to the composition of this article.

Operative technique

Needlescopic VATS (first operation) (8).

Patients were placed under general anesthesia in the lateral decubitus position with double lumen endotracheal tube. A 10-mm camera port was inserted through the sixth or seventh intercostal space (ICS) along the mid-axillary line after lung deflation. Two 3.0-mm working ports were inserted over the 3rd ICS anterior axillary line and fifth ICS posterior axillary line, respectively. With a 10 mm 30° thoracoscopy, blebs, if identified, were grasped with an endograsper. The camera was retrieved and a 3.0 mm needlescope (Karl Storz Gmb H and Co. Tuttlingen Germany) was then inserted through the other 3-mm port for viewing. Endo GIA endoscopic linear stapler (U.S. surgical Corporation: Norwalk, CT) was then inserted through the 10 mm port for blebectomy. Any air leak and bleeding was checked. The whole parietal pleura was rubbed with marlex mesh (Bard limited, Crawly, UK). The procedure was concluded with the placing of a 28 Fr chest tube.

Diagnosis of postoperative recurrent pneumothorax (PORP)

PORP is defined as pneumothorax occurring seven days or more after removal of chest tube, all confirmed by chest computed tomography and chest radiography. The size of pneumothorax was calculated by the formula designed by Collins *et al.* (10). Patients diagnosed with recurrence were routinely admitted into the ward for treatment. Depending on the size of pneumothorax, treatment was either observation with O_2 inhalation for pneumothorax of volume 15% or less; pleural drainage under CT guide for 16% to 30% or Re-VATS for over 30% volume.

Operative technique of Re-VATS

Patients were placed under general anesthesia in the lateral decubitus position under double lumen endotracheal intubation. A 10-mm camera port was placed through the sixth or seventh ICS or over the area of pneumothorax, avoiding the sites of old ports in case of possible pleural adhesions underneath. Two other 10-mm ports were then created under direct thoracoscopic vision, usually in the upper thorax. With ring forceps and harmonic scalpel, adhesions could be lysed if necessary. The entire lung was meticulously inspected. Blebs, if found, were resected with Endo GIA. Warm saline was then instillated to check for air leak. The pleura was then rubbed meticulously with marlex mesh. Finally, three rubber drainage tubes were placed, one at each incision, overlying different aspects of the pleural cavity. Low suction was used in the ward. The tubes were gradually retreated by 3 to 5 cm on the seventh day, and again on the ninth day. They were completely removed on the eleventh day. Patients were all followed-up in the clinic after discharge.

Results

VATS was initially performed on 239 patients with PSP in total. Eleven patients, all male, were found to have postoperative recurrence during a follow-up period of 36.95 months. Demographic data, time to postoperative recurrence, treatment, and operative data are shown in *Table 1*.

Three patients were treated under observation. One showed improvement and was discharged five days later. He reported no further recurrence. The remaining two recurred 12 and 9 months following, and received Re-VATS. Unfortunately, one of the two recurred again 17 days after the procedure. Since the volume was small, CT guide drainage was administered, and he was then treated with blood patch. No further recurrence was reported. Two patients received initial treatment of CT guided pleural drainage with sclerosing agent instillation afterwards. One recurred 14 days later. He then received Re-VATS and no further recurrence was reported. Six patients received Re-VATS straight off, with no further recurrence following. There was no conversion to thoracotomy, blood transfusion, prolong air leak or other complications.

Discussion

Recurrence of PSP after a first episode is a troublesome complication, and postoperative recurrence even more so. Though the latter is seemingly a minor problem in thoracic surgery, it is however, an important issue to be discussed, owing to the fact that every thoracic surgeon would face such patients during his medical practice. There is a misconception that reoperation for post-VATS recurrent pneumothorax would be quite complicated. This is because of (I) the previous pleurodesis adhesions; (II) uncertainty when looking for leakage sites. Thus many surgeons would prefer a conservative approach. Even if surgery was unavoidable, open thoracotomy would be the procedure of choice. This study found evidence of the contrary, with the authors discovered that the adhesions caused by previous

Table 1 Operative and demographic data

	Age	Sex	Operative time/min	post-treatment stay (days)	Operative bleeding (mL)	Bleb	Time to recurrence from first VATS
1	23	M	110	11	20	⊕	30 mo
2	40	M	80	11	50	–	40 mo
3	17	M	120	11	100	⊕	18 days
4	18	M	90	11	10	–	27 mo
5	29∗	M	N/A	4	N/A	N/A	31 mo
6	16	M	75	11	5	⊕	24 mo
7	16△	M	100	11	10	–	9 mo
8	17	M	65	11	10	–	20 mo
9	21 (obs)	M	N/A	5	N/A	N/A	29 mo
10	20◎	M	85	11	20	–	12 mo
11	23	M	78	11	30	–	15 mo

∗, CT guide drainage with no further recurrence; △, recurrence after Re-VATS, followed by blood patch; obs, operation for recurrence after O_2 inhalation; ◎, only O_2 inhalation with no further recurrence; N/A, not applicable.

abrasions in those patients with post-operative recurrence were usually mild. Some even presented with no adhesion. The reason is still unknown. (In other words, patients with fine adhesions would have no recurrence.) In this series, nine patients received Re-VATS. Only one had further recurrence of small volume, ultimately resolved with blood patch. Sixty percent (three out of five) of patients with conservative treatment finally required VATS. Only two patients receiving conservative treatment had no further recurrence indicating Re-VATS could possibly yield a more effective result.

Thoracotomy seems to be the better way to treat PORP because it allows better inspection and examination of the entire lung, and also creates greater pleural adhesions. In fact, the adhesions in the PORP would be very little for thoracoscopy as we mentioned above. In addition, inspection is much clearer with today's high resolution video system, that even narrow hidden spaces can be carefully examined. Moreover, VATS has its benefit of better cosmetics and less pain. Usually, re-operation causes more bleeding and longer operative time. In this series, the average intra-operative bleeding was 28.33±15 mL, and operative time was 85.22±25 min (*Table 1*). Compared to our first VATS reported in 2009 (11), these are statistical insignificant. The hospital stay would also be longer due to deliberately lengthening the tube drainage time for pleural irritation.

The authors do not advocate performing Re-VATS with needlescopy. The reason is the poorer resolution and narrower video-field (8,11,12). Since they are postoperative recurrent patients, a clearer video-field is essential. Moreover in our series, at the end of the procedure, rubber drains 1.0 cm in diameter, were placed in each incision, which is the reason for the three 1-cm incisions made at the start of the procedure, and a 10-mm camera is certainly superior to needlescopy.

Three patients were found to have blebs. No leakage or lesions were found for the remaining six patients. All patients received meticulous pleural abrasions, and rubber tubes over three different areas of the pleural cavity, were placed and retained for a week before slowly retreated. Rubber drains cause great tissue reaction, resulting in reliable pleural adhesions. Only one patient with leakage site not found after Re-VATS recurred, showing that good pleurodesis is a crucial part of the operation (13).

Some surgeons (7,14) perform pleurectomy during Re-VATS for greater adhesion, a step the authors in this series would not advocate, since the resulting dense adhesions would certainly be barriers to subsequent thoracotomy should the patient need it in the future. Emphasis should be placed on performing the abrasions of pleura as the last procedure of the operation after all resections and testing of leakage, as blood clots, produced by the abrasions would be an ideal sealing material, covering almost the entire lung surface, stopping even minute leakage and resulting in a satisfactory pleural symphysis.

The size of pneumothorax still guides the initial approach, however, as we can see in this series, nine out of the eleven patients received Re-VATS, showing (I) failure rate of conservative treatment is high; (II) Re-VATS could be performed with no difficulty; and (III) the results of Re-VATS were satisfactory.

Finally, we note that all of the recurrent patients were male, with five smokers among them possibly indicating that smoking is still a risk factor for pneumothorax and subsequent recurrence after surgery.

The drawback of this study is the small number of cases due to the low postoperative recurrence rate (4.6%) of PSP. Also it is a retrospective one.

In this series, all nine patients were operated on by the same surgical team. With the praising results of the present series, the authors suggest discarding the conservative treatment for PORP which many surgeons are still implementing. Even for smaller size cases, Re-VATS, which is technically feasible, safe and effective with better cosmetics and minor postoperative pain, should be a strong contender as priority treatment.

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Original Article

Robotic mitral valve repair in infective endocarditis

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Background: Robotic mitral surgery is the most common robotic cardiac procedures. However, in mitral endocarditis the repair become more challenging especially in minimally approach. We applied robotic surgery in mitral endocarditis repair and reviewed our surgical methods and results.

Patients: From January 2012 to December 2013, 12 patients with mitral endocarditis in National Taiwan University Hospital were operated via robotic assisted repair. Age of them was among 21 to 65 years old, mean 43.

Results: The vegetation involves anterior leaflet in 3, posterior leaflet in 8 and commissural leaflet in 4. Mean cardiopulmonary bypass time is 124 minutes and cross clamp time is 89 minutes. There was no stroke and no operation death. Mitral valve repair technique including anterior leaflet patch augmentation in 2, direct closure of rupture hole on anterior leaflet in one, plication commissural leaflet in 2, and artificial chordae in 10. There was no mitral regurgitation detected immediately after weaning of cardiopulmonary bypass. All of them got free-from-regurgitation or -stenosis rate was 100% at one-year follow.

Conclusions: Although mitral infective endocarditis is complex and difficult to repair, robotic mitral repair in infective endocarditis is feasible. Even in the complex repair group, the cardiopulmonary bypass time is not prolonged and the result is good.

Keywords: Robotic mitral valve surgery; infective endocarditis

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Background

The first robotic mitral valve repair was performed by Carpentier in 1998 using a prototype of the da Vinci™ surgical system (Intuitive Surgical, Inc., Sunnyvale, CA, USA) (1), since then the concept of robotic mitral valve surgery became reality, and now robotic mitral surgery is the most common robotic cardiac procedures. Mitral valve repair in degenerative disease is the evidence-based care standard, not only in traditional sternotomy approach but also in robotic surgery. However, in mitral endocarditis the repair become more challenging especially in minimally approach.

Infective endocarditis is a serious disease of the endocardium of the heart and cardiac valves, caused by a variety of infectious agents. Treatment of endocarditis includes prolonged appropriate antimicrobial therapy and in selected cases, cardiac surgery. The techniques in mitral endocarditis repair are much more challenging than degenerative disease not only in standard sternotomy but also in minimal incision. The benefit of minimally invasive incisions is well documented in the literature (2). Several large health care delivery systems have embraced minimally invasive surgical approaches aiming to replicate the "gold standard" results of a trans-sternal cardiac surgery aiming to improve patient acceptance and facilitate earlier referral. With more and more experience in handling robotic surgical system, we applied robotic surgery in mitral endocarditis repair.

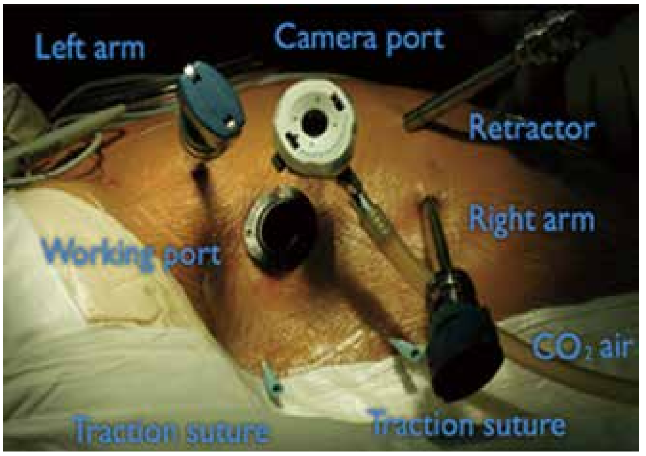

Figure 1 Working port incision is made in the 4th intercostal space anterior to the anterior axillary line (AAL). Camera port is inserted at 4th intercostal space, just around right nipple areola line. Right robotic arm trocar is introduced in the 5th or 6th intercostal space at the AAL and left arm in the 2nd or 3rd intercostal space. The atrial retractor is inserted in the 5th intercostal space three fingerbreadths medial to the nipple.

Patients

From January 2012 to December 2013, we operated 12 patients with mitral endocarditis operated via robotic assisted in National Taiwan University Hospital were analyzed. Age of them was among 21 to 65 years old, mean 43. Among them eight are operated in active endocarditis phase and four of them had been treated with antibiotics for three weeks. The diagnosis of infective endocarditis was documented on cardiac echogram findings and infection specialist's judgments. All of them had vegetation on mitral valve and causing severe mitral regurgitation.

Description of operation technique

Anesthesia preparation

Patients are intubated with either a double lumen endotracheal tube or a bronchial blocker to allow for right lung isolation. All patients were put on transesophageal echocardiogram for valve lesion study.

Position

The patient is positioned with the right side up thirty degrees from horizontal. Bilateral femoral area and right neck should be disinfected and wrapped for further peripheral cannulation.

Cardiopulmonary bypass setting

Usually right side femoral artery and femoral vein are used for bypass route. Right side internal jugular vein is also cannulated for drain. Negative pressure system is routinely used in our minimally invasive surgery.

Ports

A 3 cm working port incision is made in the 4th intercostal space anterior to the anterior axillary line (AAL). Camera port is inserted at 4th intercostal space, just around right nipple areola line. Robotic arm trocars are introduced, one in the 5th or 6th intercostal space at the AAL for the right arm, one in the 2nd or 3rd intercostal space anterior to the AAL for the left arm. The dynamic atrial retractor is inserted in the 5th intercostal space three fingerbreadths medial to the nipple (*Figure 1*). The da Vinci™ system is then docked.

Myocardial protection

The ascending aorta is occluded using the Chitwood transthoracic aortic cross clamp, and antegrade crystalloid cold cardioplegia is used to arrest the heart. The preoperative chest computed tomography is routinely used to evaluation the calcification of ascending aorta.

Surgical strategies in mitral endocarditis

Check the lesion and resected the infected area

After arrest, Sondergaard's groove is dissected, and the entry of the pulmonary veins into the left atrium is identified. A left atriotomy is performed and the dynamic atrial retractor is used to expose the mitral valve. The valve lesion is inspected segmentally (*Figure 2A*). The infected area should be removed to ensure the curative of infected vegetation (*Figure 2B*). After all the infected tissue resected, re-check the valve again to decide further treatment plan (*Figure 2C*).

Evaluate the valve condition

The valve leaflet is checked again to ensure good size for coaptation. If there is any hole in the anterior leaflet, patch repair of the leaflet first. If any chordae lossing, we use CV-4 Goretex™ suture to reconstructe new chords (*Figure 2D*).

After reconstruction of valve, the annulus is always support with Cosgrove-Edwards band for all of them (*Figure 3*).

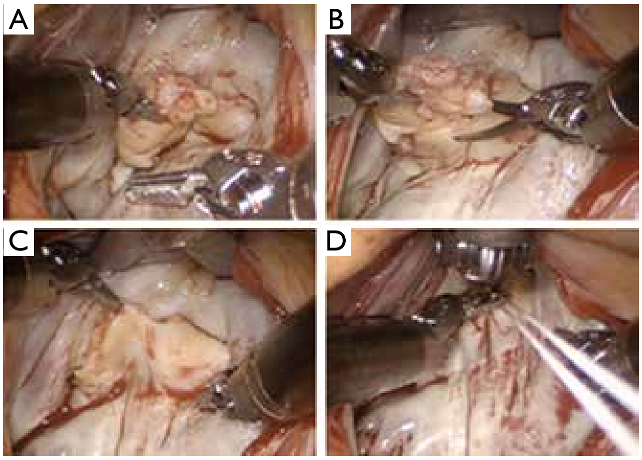

Figure 2 (A) Expose the mitral valve by left atrial dynamic retractor. The valve lesion is inspected segmentally; (B) Resect all the vegetation, the injured leaflet should be debrided; The infected area should be removed to ensure the curative of infected vegetation; (C) Reevaluate the valve after complete debridement of infected tissue; (D) CV-4 Goretex™ suture is used to reconstructe new chords.

Antibiotics and medical treatment

All patients receive a 4-6-week antibiotics course treatment. The C reactive protein is monitored in all of them. Besides no fever, before discharged home, the C reactive protein should be normal in range. Cardiac echography follow is performed in all of them before discharged home.

Results

Among January 2012 to December 2013, 12 patients underwent robotic mitral repair for their mitral endocarditis. Preoperative, all of them have severe mitral regurgitation and vegetation detectable by cardiac echography. The vegetation involves anterior leaflet in 3, posterior leaflet in 8 and commissural leaflet in 4 (*Figure 3*).

Mean cardiopulmonary bypass time is 124 minutes and cross clamp time is 89 minutes. There was no stroke and no operation death. Mitral valve repair technique including anterior leaflet patch augmentation in 2, and direct closure of rupture hole on anterior leaflet in one. We closed two

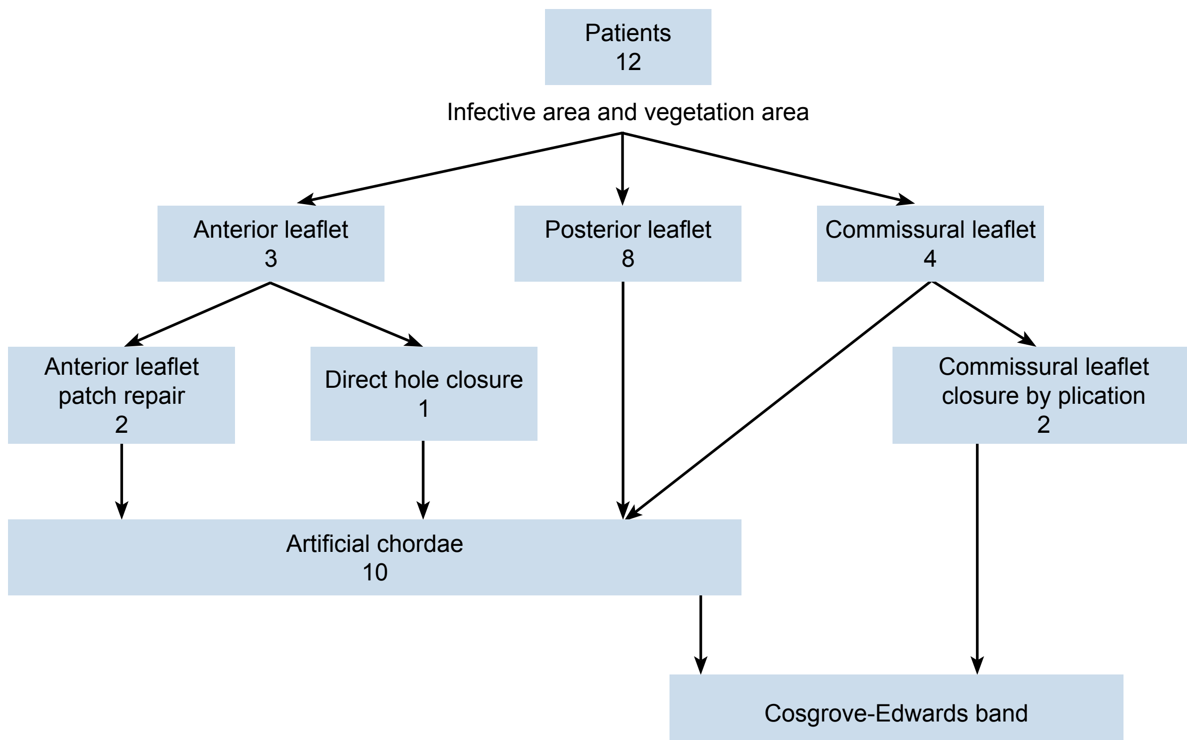

Figure 3 Twelve patients underwent robotic mitral repair for their mitral endocarditis. The vegetation involves anterior leaflet in 3, posterior leaflet in 8 and commissural leaflet in 4.

commissural leaflets by plication commissural leaflet. Ten of them require artificial chordae to regain the coaptation height (*Figure 3*).

Mitral valve condition

Valve insufficiency was defined as more than mild grade valve dysfunction on cardiac echography. There was no mitral regurgitation detected immediately after weaning of cardiopulmonary bypass in ten of them, and two with trace to mild mitral regurgitation. All of them got free-from-regurgitation or -stenosis rate was 100% at one-year follow. There was no recurrent fever or vegetation noted on cardiac echography finding.

Discussion

Robotic cardiac surgery is still evolving despite being deployed for over a decade. Iterative advancements in device technology suggest to many of us that tissue telemanipulation and the least invasive methods will become a major part of our surgical field in the future (3). Mitral repair in degenerative disease is described much more than infective endocarditis in the literature and in real practice (3-5). Infective mitral endocarditis is complex, for the variation of disease severity and variety of valve condition. Many surgeons remain so concerned with the complexity and the procedure cost that they will not adopt this platform (3).

The surgical principles applicable in the treatment of infective endocarditis including debride infected tissues and all vegetation then restoration of damaged structures (6). Debride the infected tissue is mandatory in the surgical treatment for infective endocarditis followed by restore of leaflet function and size (7). Anterior leaflet size is important for the good long term coaptation, if the defect over anterior leaflet is big enough to influent the area of anterior leaflet, we will use the patch to augment anterior leaflet size. For the posterior leaflet lesion, in our practice, we favored using artificial chordae to preserve as much leaflet tissue as possible. Based on the above principles and the surgical techniques, described by A. Carpentier (7) in recent years, a high rate of success of such complex mitral valve repair procedures has been attained in mitral valve infective endocarditis, with some centers having a success rate of 75-80% (2,6). In United States, about 25% of mitral valve operations were done using minimally invasive techniques, and that only half of them using robotic mitral surgery (8). There is only few report of repair mitral endocarditis by robotic system. For the complexity of the lesion and surgeons are afraid of adopting robotic system on difficult cases. However, with the benefit of minimally invasive technique become more well known and there should be more and more patients and surgeons prone to robotic assisted mitral operation (4,5). We demonstrated robotic mitral repair in this complex lesion and complicated patient group. The result is good and could apply all mitral repair techniques on mitral repair. With more familiar with the robotic system application, the surgery will become more reliable and the result will be constant.

Conclusions

Although mitral infective endocarditis is complex and difficult to repair, robotic mitral repair in infective endocarditis is feasible. We have no operation mortality and all the patients can free from mitral regurgitation and infection after complete course of treatment. Even in the complex repair group, the cardiopulmonary bypass time is not prolonged and the result is good.

Limitation

The study limitation was that it was single-institution case series and did not have a comparative group to the robotic technique. It exist patient selection bias in disease severity and surgeon's preference.

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Visualized Surgery

Natural orifice surgery in thoracic surgery

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Since Kallo *et al.* reported the first transgastric peritoneoscopy in 2004, several studies have shown the safety and benefits of natural orifice surgery (NOS) in abdominal surgery in human studies. The feasibility of NOS thoracoscopy has been reported using different natural orifice access (transvesical, transesophageal, transtracheal, transoral, and transumbilical) in porcine and canine models. However, only a minority of thoracic procedures (myotomy for achalasia, sympathectomy for palmar hyperhidrosis) are performed using the NOS technique (1-9). This paper presents the development and current status of our work, and provides an overview of the questions that still need further investigation, regarding NOS in thoracic disease and future plans.

Animal studies for natural orifice surgery

Transvesical approach (2)

In 2007, Lima *et al.* demonstrated the feasibility and safety of transvesicle thoracoscopy and lung biopsy via transvesical and transdiaphragmatic incision in six female pigs. There were no postoperative complications or respiratory distress. The lack of relatively long rigid endoscopic instruments to reach the overall thoracic cavity is a major barrier to the transvesicle approach.

Transgastric approach (3)

In 2010, De Palma *et al.* evaluated the feasibility and safety of the transgastric approach in accessing the thoracic cavity in four female pigs. Lung biopsies were successfully performed via the gastric wall combined with diaphragmatic wall incision without complications in the first 15 days after surgery. The incisions were closed with endoscopic clips. However, owing to the absence of direct comparative data with current video assisted thoracic surgery, further studies are necessary to clarify the utility of the transgastric approach in thoracic surgery.

Transesophageal approach (4,10)

The transesophageal approach is the most frequently utilized platform in the exploration of the thoracic cavity. This is in likelihood due to the familiarity with the transesophageal endoscopy procedure and the proximity of the esophagus and thoracic cavity. Thoracic procedures performed via the transesophageal approach include lymphnode dissection, pleural biopsy, pericardial window creation, and lobectomy. Postoperative complications (tension pneumothorax and descending aortic injury) following the transesophageal thoracic procedure were encountered in 10 out of 56 animals (17.8%). The exact role of this approach in thoracic surgery remains to be elucidated.

Transtracheal approach (5)

The first successful approach to the thoracic cavity via tracheal incision was reported by our research group. We performed pleural biopsy, lung biopsy, and pericardial window creation using a needle knife via one or two small tracheal incisions. The tracheal wound was closed

Video 1 Transumbilical right upper, middle, and lower lobectomy.

with a silicone airway stent. Although the transtracheal approach is, feasible, lung injury and bleeding led to the intraoperative death of three of the 14 animals. We believe that life-threatening complications and limited work-space via the small tracheal incision prohibits further investigation into transtracheal thoracoscopy.

Transoral approach (6)

Another novel approach described by our research team is the transoral approach. Surgical lung biopsy and pericardial window creation were completed via a 12 mm incision over the vestibulum oris region. We demonstrated that the transoral approach was comparable to thoracoscopic surgery in terms of procedure success rate, hemodynamic impact, and inflammatory changes. Further, the transoral approach achieves better cosmetic outcome compared to the thoracoscopic approach.

However, the shortcoming of the transoral approach is the size of lung specimen removed from a 1.2-cm wound over the vestibulumoris region.

Transumbilical approach (7) (Video 1)

Many researchers have reported on the safety and efficacy of approaching the thoracic cavity via an abdominal wound and a good outcome can be achieved via the transumbilical approach. We investigated the feasibility of transumbilical thoracoscopy in a canine model. We demonstrated that pericardial window creation and large lung wedge resection could be performed via a 3 cm vertical transumbilical incision. More recently, we also found that anatomic lobectomy could be performed with the current approach but was associated with intraoperative complications. However, we strongly believe that increased familiarity with the surgical approach and refinement of endoscopic instruments might clarify the role of transumbilical surgery in thoracic disease.

Human clinical applications for natural orifice surgery

Transesophageal approach (9)

In 2009, Inoue and colleagues developed an innovative procedure to perform therapy for achalasia in 17 consecutive patients with achalasia. The procedure consisted of creating an esophageal submucosal tunnel via the lower esophagus, and extending to the oesophagogastric junction and beyond, onto the gastric cardia. Endoscopic myotomy of circular muscle bundles and the lower esophageal sphincter was then completed under direct vision. The short-term outcome of transesophageal myotomy for achalasia was excellent and it can be used in routine clinical practice. The long-term efficacy and comparative study with other interventional therapies will clarify the role of transesophageal myotomy in achalasia. However, results of transesophageal NOS performance of mediastinal and thoracic therapeutic procedures in humans has not yet been published.

Transumbilical approach (8)

In 2013, Zhu and colleagues reported the first series of performance of sympathectomy by natural orifices transumbilical technique for women with palmar hyperhidrosis without thoracotomy. The procedure was successfully completed with an ultrathin flexible endoscope via a 5-mm umbilical incision combined with a 5-mm diaphragmatic incision in all patients. There were no intraoperative or postoperative complications. All patients were satisfied with the cosmetic outcome of the incision. A retrospective comparison of transumbilical with conventional video assisted thoracoscopic surgery (VATS) sympathectomy in 66 patients with severe palmar hyperhidrosis, further demonstrated that the transumbilical approach offers apparent advantages over conventional VATS with regard to postoperative pain, chest wall paresthesia, and better cosmetic results.

Future perspective

With no well-established NOS platform available for surgery within the thoracic cavity, our research teams have demonstrated that transumbilical thoracoscopy is a practical approach for evaluating intrathoracic structure. Further experimental investigations with clear evidence-based information will clarify the possible role of the transumbilical approach in the surgical treatment of thoracic disease. Current projects pursued by our research group include (I) comparative study of safety and efficacy between transumbilical and transthoracic anatomic lobectomy in a canine survival model; (II) comparative study of safety and efficacy between hybrid transumbilical (transumbilical combined with a minithoracoscopic wound) versus pure transumbilical anatomic lobectomy in a canine survival model; (III) feasibility study of transumbilical anatomic lobectomy in a cadaveric model. We believe that all these investigations are important before this technique can be used in clinical practice in humans.

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