Nonintubated Thoracoscopic Anatomical Segmentectomy for Lung Tumors

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**Background.** Intubated general anesthesia with one-lung ventilation is considered mandatory for anatomical pulmonary resections. Nonintubated thoroscopic segmentectomy for management of lung tumors, which is technically challenging, has not been reported previously. The goal of this study was to evaluate the feasibility and safety of thoracoscopic anatomical segmentectomy without endotracheal intubation.

**Methods.** From August 2009 to December 2012, 21 patients with lung tumors were treated using thoracoscopic anatomical segmentectomy without endotracheal intubation using a combination of thoracic epidural anesthesia, intrathoracic vagal blockade, and target-controlled sedation.

**Results.** There were 16 patients with primary or metastatic lung cancers and 5 patients with nonmalignant tumors. Left upper lobe apical trisegmentectomy was most commonly performed (n = 6), followed by superior segmentectomy of the right lower lobe (n = 4) and left lower lobe (n = 4). One patient required conversion to intubated single-lung ventilation because of vigorous mediastinal and diaphragmatic movement. No patient required conversion to a thoracotomy or lobectomy. Operative complications developed in 1 patient who had an air leak for more than 3 days postoperatively. The mean duration of postoperative chest tube drainage and mean hospital stay were 2.5 days and 6.0 days, respectively. Anesthetic induction and the operation required a mean 26.5 minutes and 148.0 minutes, respectively.

**Conclusions.** Nonintubated thoracoscopic segmentectomy is technically feasible and safe. It can be an alternative to intubated single-lung ventilation for management of lung tumors in selected patients.

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review of their medical records and discussion with the patients. Patients considered appropriate for nonintubated thoracoscopic segmentectomy included those with clinical stage I lung cancer with tumors smaller than 2 cm, those with centrally located benign lung tumors, and those with marginal cardiopulmonary function who were not suitable for a lobectomy (elderly patients with a New York Heart Association functional classification of II or higher, patients with a history of congestive heart failure, or those with a preoperative forced expiratory volume in 1 second <70% predicted). Patients with an American Society of Anesthesiologists status of 4 or greater, a bleeding disorder, sleep apnea, evidence of pleural adhesions, and unfavorable airway features or spinal anatomical characteristics were excluded from nonintubated operative procedures. Consent was obtained after explaining the type of anesthesia and the surgical procedure to the patients.

**Anesthetic Setting, Induction, and Maintenance**

Anesthetic management of nonintubated thoracoscopic operations has been described in previous studies [14, 17, 18, 24, 25]. All patients were premedicated with intravenous fentanyl (50 to 100 μg/mL). Standard monitoring of the electrocardiogram, noninvasive blood pressure monitoring, and pulse oximetry was applied for establishing thoracic epidural anesthesia. With full sterile preparation, an epidural catheter was inserted into the T5–6 thoracic interspace to achieve and maintain a sensory block between the T2 and T9 dermatomes using 2% lidocaine. After confirmation of working epidural anesthesia, patients were sedated with intravenous propofol 1% using a target-controlled infusion method. The level of sedation aimed to achieve a bispectral index value between 40 and 60, and incremental intravenous injections of fentanyl 25 μg were given to maintain a respiratory rate between 12 and 20 breaths/min. Meanwhile, continuous monitoring of the arterial blood pressure, urine output, and end-tidal carbon dioxide by insertion of a detector into 1 nostril was done. The patients were placed in the lateral decubitus position.

During the procedure, patients spontaneously breathed oxygen through a ventilation mask to keep the oxygen saturation at more than 90%. A chest wall incision was made to place a 28F chest tube was placed through the lowest incision. An air leak was detected after insertion of a chest tube to reexpand the lung. The wounds were sealed with transparent waterproof dressings (Tegaderm Film, 3M Health Care, Neuss, Germany) after insertion of a chest tube to reexpand the lung. The trachea was then intubated under bronchoscopic guidance, followed by insertion of a bronchial blocker for one-lung ventilation without a change in the patient's position.

**Surgical Technique for Anatomical Segmentectomy of Lung Tumors**

All patients underwent a complete anatomical segmentectomy. Meanwhile, mediastinal lymph node dissection was also performed in patients with confirmation of primary lung cancer. Thoracoscopic segmentectomy was performed using a 3-port method, as described by McKenna [26]. In brief, the patient was placed in the full lateral decubitus position, with slight flexion of the table at the level of the midchest. The thoracoscope was placed in 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- to 5-cm utility incision was placed anteriorly in the fifth intercostal space.

After collapse of the lung, interlobar fissures, pulmonary vessels, bronchi, and the pulmonary parenchyma to the affected segment were divided and sectioned with endoscopic stapling devices. The resected lung segment was removed in an organ retrieval bag through the utility incision. For patients with primary lung cancer, staging mediastinal lymph node dissection was performed, and the rough pleural surface of the lung was sutured using 4-0 Prolene (Ethicon, Somerville, NJ). After the operation, a 28F chest tube was placed through the lowest incision. Rib spreading, rib cutting, and retractor use were avoided in all patients.

**Anesthetic Conversion**

The attending surgeon and anesthesiologist decided whether to convert from nonintubated anesthesia to intubated one-lung ventilation in cases of ineffective epidural anesthesia, profound respiratory movement, massive pleural adhesions, persistent hypoxemia (oxygen saturation on pulse oximetry <80%), unstable hemodynamic status, or intraoperative bleeding requiring a thoracotomy [14, 17, 18, 25]. For conversion, the surgical wounds were sealed with transparent waterproof dressings (Tegaderm Film, 3M Health Care, Neuss, Germany) after insertion of a chest tube to reexpand the lung. The trachea was then intubated under bronchoscopic guidance, followed by insertion of a bronchial blocker for one-lung ventilation without a change in the patient's position.

**Postoperative Analgesics and Care**

Postoperative analgesia was administered with a continuous epidural infusion of bupivacaine 0.1% and fentanyl (1.25 μg/mL) for 3 days. Additional analgesics included oral nonsteroidal analgesics and acetaminophen once patients resumed oral intake 2 to 4 hours after operation. On postoperative days 1 and 2, patients were asked to evaluate the intensity of postoperative pain using a visual analog scale (VAS) in which 0 represented no pain and 10 represented intractable pain. Chest radiography was performed immediately postoperatively or the next morning. The chest tube was removed if no air leak was present and drainage was less than 200 mL in a 24-hour period. An air leak was defined as prolonged...
when it lasted longer than 3 days [14]. All postoperative complications were recorded.

Data Collection and Analyses
The clinical data, operative findings, operative and anesthetic results, treatment outcomes, side effects and complications, and pathologic characteristics of the lung tumors were collected from the medical records. The arterial blood gas analyses were performed before skin incision (preoperative), after segmentectomy (intraoperative), and after wound closure (postoperative). The VAS data were collected from the nursing records.

Results
The algorithm for patient selection is shown in Figure 1. From August 2009 through December 2012, nonintubated VATS was performed in 309 patients with lung tumors. Among them, 21 patients underwent segmentectomy without endotracheal intubation for management of their lung tumors, and their data are reported in Table 1. The median patient age was 61.0 years, and 16 patients (76.2%) were women. The median body mass index of the patients was 22.2 kg/m². The median tumor size was 1.5 cm. The pulmonary function of the patients was generally good, with a mean forced vital capacity of 105.4% predicted and forced expiratory volume in 1 second of 105.5% predicted. At the time of the procedure, the American Society of Anesthesiologists physical status was 1 in 2 patients, 2 in 11 patients, and 3 in 8 patients. The lung tumors were malignant in 16 patients (76.2%) and included primary non–small-cell lung cancer (NSCLC) in 13 patients, mucosa-associated lymphoid tissue lymphoma in 1 patient, and metastatic lung cancer in 2 patients. The remaining 5 patients (23.8%) had benign diseases, including atypical adenomatous hyperplasia, aspergilloma, hamartoma, organizing pneumonia, and sclerosing hemangioma. Four of 13 patients with primary lung cancer underwent compromised segmentectomy because of advanced age or marginal cardiopulmonary function (median, 77 years; range, 70–83 years), although their tumors were larger than 2.5 cm (range, 2.5–3.5 cm). The remaining 9 patients received intentional segmentectomy because their tumors were small and peripheral (median, 0.78 cm; range, 0.5–2.2 cm).

The anatomical locations of the VATS segmentectomies are reported in Table 1. Left upper lobe apical trisegmentectomy was most commonly performed (Fig 2), followed by superior segmentectomy of the right lower lobe and left lower lobe.

The operative and anesthetic results are reported in Table 3. The mean duration of anesthesia induction was 26.5 minutes, and the mean operative duration was 148.0 minutes. The mean intraoperative ratio of arterial oxygen tension to inspired oxygen fraction (PaO₂/FiO₂) during one-lung breathing was significantly lower (223 ± 60) when compared with preoperative or postoperative PaO₂/FiO₂ ratio (p < 0.001). During the operation, the mean lowest oxygen saturation was 95.5% (range, 88% to 100%), and the mean highest partial pressure of arterial carbon dioxide during one-lung ventilation was 51.8 mm Hg (range, 34.1–68.4 mm Hg). Conversion to intubated one-lung ventilation was required in a 69-year-old woman with a body mass index of 30.0 kg/m² because of vigorous mediastinal and diaphragmatic movement during the operation. The conversion was accomplished within 20 minutes without any sequelae.

Fig 1. Flow chart of 21 patients screened during the study period.
thoracotomy or lobectomy and no blood transfusion was required in any patient.

Complications after anesthesia occurred in 1 patient who had a sore throat, headache, and vomiting requiring medication. The mean postoperative VAS pain score was 1.8 on the first postoperative day and 1.9 on the second postoperative day. The mean duration of postoperative chest tube drainage was 2.5 days, and the postoperative hospital stay was 6 days. One patient had air leaks lasting more than 3 days after operation. No deaths or major complications occurred (Table 4).

Comment

This is the first report showing that VATS anatomical segmentectomy is feasible and can be safely performed without endotracheal intubation in highly selected patients with lung tumors. Because enhanced computed tomography screening protocols have identified increasing numbers of small lung tumors in patients with high surgical risk [20], there is increasing interest in minimally invasive surgical approaches, including thoracoscopic incisions, parenchyma-sparing resection, and less invasive anesthesia for management of lung tumors.

Lobectomy, either by thoracotomy or thoracoscopy, is currently considered the standard operation for early-stage NSCLC [22, 27, 28]. The role of thoracoscopic segmentectomy for NSCLC is still limited and controversial [20, 21]. Traditionally, it is used as a parenchyma-sparing procedure in high-risk patients with significantly reduced pulmonary function or a compromised medical condition. However, it is being increasingly reevaluated for the management of small NSCLC (tumor < 2.0 cm), and has shown oncologic results comparable with the well-established lobectomy [19]. In addition, thoracoscopic segmentectomy may also be the choice of operation for patients with metastatic disease or undiagnosed pulmonary nodules that are not amenable to wedge resection because of their proximity to large bronchovascular structures. In our cohort, compromised VATS segmentectomy was performed in 4 patients with NSCLC because of advanced age or marginal cardiopulmonary function, although their tumors were larger than 2.5 cm (range, 2.5–3.5 cm). The remaining 17 patients received intentional VATS segmentectomy because of small NSCLC (<2.0 cm) or centrally located benign or malignant lesions.

In this study, 76% of the patients were women, with a median body height of 158 cm. We believe that nonintubated thoracoscopic surgical procedures are most applicable in small-bodied female patients. These patients are prone to have a small tracheal caliber and are susceptible to intubation-related complications such as hoarseness, subglottic stenosis, and airway injuries, especially when double-lumen endotracheal tubes are used [29].

Although patient satisfaction with nonintubated thoracoscopic segmentectomy was not assessed, the operative and anesthetic results were satisfactory in this study. Our previous study showed that patients who underwent nonintubated lobectomy had lower rates of sore throat and earlier resumption of oral intake compared with their intubated counterparts [17]. Because muscle relaxants were not used, the patients resumed water and food intake between 2 and 4 hours postoperatively. Only
1 patient experienced minor side effects of vomiting, sore throat, and headache. The postoperative VAS pain scores were low, probably because of routine use of patient-controlled epidural analgesics. The mean postoperative hospital stay was relatively long in our patients (6 days) because of our National Health Insurance policy. Copayment is not required for patients with malignant diseases in Taiwan.

Conversion to intubated general anesthesia was necessary in only 1 patient with a body mass index of 30.0 kg/m² because of a vigorous diaphragmatic breathing pattern and significant mediastinal movement that made bronchovascular dissection difficult and dangerous. The anesthesiologist and the surgeon both agreed on tracheal intubation and the patient was intubated and extubated smoothly. The conversion rate to intubation was 4.8% in patients undergoing segmentectomy, which was similar to our nonintubated VATS lobectomy cases[17, 18]. Our experience suggests that patients with a body mass index of 30.0 kg/m² or more frequently experience vigorous diaphragmatic and mediastinal movement, and non-intubated thoracoscopic segmentectomy or lobectomy is not suitable for them.

Although none of our patients in this study required emergency conversion to intubation or a thoracotomy because of uncontrolled bleeding, it happened in our early experience and it is important to be aware of the possibility[17]. We suggest that proper patient selection, accumulated experience from performing minor nonintubated thoracoscopic procedures, and conversion to intubated general anesthesia without hesitation are mandatory to decrease the risk of emergency

### Table 3. Operative and Anesthetic Results

<table>
<thead>
<tr>
<th>Variable</th>
<th>Frequency (N = 21)</th>
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<tbody>
<tr>
<td>Anesthetic induction duration, min</td>
<td>20 (10–50) 26.5 ± 12.4</td>
</tr>
<tr>
<td>Surgical duration, min</td>
<td>156 (78–209) 148.0 ± 43.2</td>
</tr>
<tr>
<td>Global operating room duration, min</td>
<td>210 (140–290) 209.3 ± 41.3</td>
</tr>
<tr>
<td>Perioperative PaO₂/FiO₂ ratio</td>
<td></td>
</tr>
<tr>
<td>Preoperative (n = 13)</td>
<td>406 (229–512) 408 ± 78</td>
</tr>
<tr>
<td>Intraoperative (n = 21)</td>
<td>237 (131–349) 223 ± 60</td>
</tr>
<tr>
<td>Postoperative (n = 9)</td>
<td>379 (305–434) 380 ± 34</td>
</tr>
<tr>
<td>Perioperative PaCO₂ mm Hg</td>
<td></td>
</tr>
<tr>
<td>Preoperative (n = 13)</td>
<td>40.9 (29.5–44.9) 39.0 ± 4.6</td>
</tr>
<tr>
<td>Intraoperative (n = 21)</td>
<td>52.4 (34.1–68.4) 51.8 ± 9.0</td>
</tr>
<tr>
<td>Postoperative (n = 9)</td>
<td>40.5 (34.5–43.4) 39.7 ± 2.8</td>
</tr>
<tr>
<td>Lowest SpO₂ during operation, %</td>
<td>97 (88–100) 95.5 ± 4.2</td>
</tr>
<tr>
<td>Peak ETCO₂ during operation, mm Hg</td>
<td>42 (35–53) 42.0 ± 6.2</td>
</tr>
<tr>
<td>Lymph nodes dissected, no.d</td>
<td>5 (0–18) 6.5 ± 5.9</td>
</tr>
<tr>
<td>Conversion to intubation</td>
<td>1 (4.8%)</td>
</tr>
<tr>
<td>Conversion to lobectomy</td>
<td>0</td>
</tr>
<tr>
<td>Conversion to thoracotomy</td>
<td>0</td>
</tr>
</tbody>
</table>

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* Continuous data are shown as median (range) and mean ± standard deviation, and categorical data are shown as number (%).  
  ** Intraoperative PaO₂/FiO₂ ratio was significantly lower when compared with preoperative or postoperative PaO₂/FiO₂ ratio (p < 0.001).  
  ** Intraoperative PaCO₂ was significantly higher when compared with preoperative or postoperative PaCO₂ (p < 0.001).  
  ** Performed in 13 patients with non-small-cell lung cancer.

ETCO₂ = end tidal carbon dioxide; PaO₂ = partial pressure of arterial carbon dioxide; PaCO₂/FiO₂ ratio = ratio of arterial oxygen tension to inspired oxygen fraction; SpO₂ = oxyhemoglobin saturation by pulse oximetry.
conversion, especially at the beginning of the learning curve.

There are concerns about using the nonintubated technique for VATS segmentectomy. One major anesthetic concern is how respiratory function is maintained in a spontaneously breathing patient with an open pneumothorax (ie, in severe hypoxemia and hypercapnia), especially when the surgical duration is usually as long as a VATS lobectomy. To our surprise, our patients tolerated the procedure well, and supplemental oxygen by facemask was enough to maintain satisfactory oxygenation. Although carbon dioxide rebreathing might occur, these patients had only mild hypercapnia, which was not clinically relevant and resolved soon after terminating sedation. Atelectasis of the dependent lung during mechanical ventilation has been demonstrated to be a major contributing factor in ventilation-perfusion mismatch during one-lung ventilation and predisposes patients to severe hypoxemia [30]. Therefore, an alveolar recruitment strategy with application of positive end-expiratory pressure during one-lung ventilation was shown to be substantially effective in decreasing both a right-to-left shunt fraction and dead space ventilation from the dependent lung to improve oxygenation [30, 31]. We believe that preservation of diaphragm function is pivotal in a single-lung spontaneous breathing scenario, and the lower rate of atelectasis in the dependent lung compared with that in the intubated technique may explain the satisfactory oxygenation results in our patients.

The other major concern is whether it is feasible and safe to perform a surgical procedure on a nondependent lung, especially when intense pulmonary manipulation during segmentectomy might trigger coughing in spontaneously breathing patients. With intrathoracic vagal blockade to abolish the cough reflex, we previously demonstrated that this procedure was effective during nonintubated lobectomy [14, 17, 18] and was also effective during nonintubated segmentectomy. Empirically, retraction of the ipsilateral upper lobe is necessary to expose the intrathoracic vagal nerve. Before lung retraction and injection of local anesthetics, the level of sedation is transiently deepened to prevent triggering a cough reflex. After vagal blockade with bupivacaine, the level of sedation was returned to moderate and invasive pulmonary dissection was permitted for more than 3 hours. Transient recurrent laryngeal nerve palsy is occasionally noted after vagal blockade, but it resolves spontaneously after operation. Dissection of the subcarinal lymph nodes occasionally contacts or irritates the contralateral main bronchus, which might induce transient coughing.

To our satisfaction, nonintubated patients reported less postoperative nausea and vomiting, early recovery of oral intake and clear consciousness, and better postoperative analgesia in comparison with intubated patients. In addition, intubation-related complications are essentially avoided [14, 17, 18]. Most of our patients were satisfied with their own choices of what they wanted during operation.

We acknowledge that this study was limited by its retrospective design and a small number of patients. Meanwhile, the lack of a control group who received intubated general anesthesia makes differentiation of specific benefits of the nonintubated technique for VATS segmentectomy difficult. However, the low conversion rate from nonintubated to intubated general anesthesia and the low complication rate indicate that nonintubated VATS segmentectomy can be safely performed in selected patients. Further investigation is encouraged to clarify the applicability and benefits of nonintubated VATS segmentectomy for specific patient groups.

In summary, our experience showed that a VATS segmentectomy without tracheal intubation is technically feasible and clinically safe for management of lung tumors. In selected patients with NSCLC, it can be an attractive alternative both in compromised patients and for intentional purposes. The true benefits of nonintubated VATS segmentectomy should be further verified in larger prospective studies.

### References

INVITED COMMENTARY

In this issue of The Annals, Hung and coworkers [1] explore the feasibility of nonintubated thoracoscopic segmentectomy in 21 selected patients, 16 of whom had a malignant lesion. The eligibility criteria included peripheral stage I non-small cell lung cancer, central malignant lesions in marginal surgical candidates, and central benign lesions. The most frequent type of resection was left upper lobe apical trisegmentectomy, followed by superior segmentectomy of the lower lobes.

The current study corroborates and extends the findings of other groups on regional anesthesia strategies used to perform several lung surgical procedures, including wedge resection, lobectomy, lung volume reduction, and bullectomy. It also adds to previous findings coming from the same group on the feasibility of nonintubated lobectomy.

The anesthesia protocol proposed by Hung and coworkers differs somewhat from that reported by others in recent years and may have benefited from some historical work by pioneer surgeons such as Buckingham [2], who first reported in 1950 on major lung resections performed through sole thoracic epidural anesthesia, and Vischnievski [3], who reported on a multistep local anesthesia protocol including vagal blockade.

In their modern protocol, Hung and coworkers not only adopted selective vagal blockade to temporarily abolish the cough reflex and thus avoid unexpected and as yet dangerous lung movements during surgical maneuvering, but also used a bispectral index monitoring to keep the level of sedation at an optimal level while assuring the maintenance of spontaneous ventilation.

By this particular strategy, the authors achieved satisfactory results, inasmuch as optimal oxygenation was maintained for more than 2 hours during the operation, 1 obese patient only required conversion to general anesthesia because of excessive diaphragmatic movements, and operative morbidity was limited to one case of prolonged air leaks.

Nonetheless, it is conceivable that this article will reinvigorate criticism from those who may consider it somewhat hazardous to perform major lung procedures entailing fine vascular dissection in mildly sedated,