Contraindications of video-assisted thoracoscopic surgical lobectomy and determinants of conversion to open

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ABSTRACT Since the introduction of anatomic lung resection by video-assisted thoracoscopic surgery (VATS) was introduced 20 years ago, VATS has experienced major advances in both equipment and technique, introducing a technical challenge in the surgical treatment of both benign and malignant lung disease. The demonstrated safety, decreased morbidity, and equivalent efficacy of this minimally invasive technique has led to the acceptance of VATS as a standard surgical modality for early-stage lung cancer and increasing application to more advanced disease. However, only a minority of lobectomies are performed using the VATS technique, likely owing to concern for intraoperative complications. Optimal operative planning, including obtaining baseline pulmonary function tests with diffusion measurements, positron emission tomography and/or computed tomography scans, bronchoscopy, and endobronchial ultrasound or mediastinoscopy, can be used to anticipate and potentially prevent the occurrence of complications. With increasing focus on operative planning, as well as comfort and experience with the VATS technique, the indications for which this technique is used has grown. As such, the absolute contraindications have narrowed to inability to tolerate single lung ventilation, inability to achieve complete resection with lobectomy, T3 or T4 tumors, and N2 or N3 disease. However, as VATS lobectomy has been applied to more advanced stage disease, the rate of conversion to open thoracotomy has increased, particularly early in the surgeon's learning curve. Causes of conversion are generally classified into four categories: intraoperative complications, technical problems, anatomical problems, and oncological conditions. Though it is difficult to anticipate which patients may require conversion, it appears that these patients do not suffer from increased morbidity or mortality as a result of conversion to open thoracotomy. Therefore, with a focus on a safe and complete resection, conversion should be regarded as a means of completing resections in a traditional manner rather than as a surgical failure.

KEY WORDS Video-assisted thoracoscopic surgery (VATS); lobectomy; contraindications; positron emission tomography (PET)

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Introduction

Since the introduction of anatomic lung resection or lobectomy for lung cancer by video-assisted thoracoscopic surgery (VATS) in the 1990s, VATS has experienced major advances in both equipment and technique and has subsequently been demonstrated to be safe and effective for the treatment of early-stage lung cancer (1-5). It is associated with decreased morbidity and length of stay and offers equivalence in terms of survival and recurrence rates (6,7). As such, VATS lobectomy is now accepted as a standard surgical modality for early-stage lung cancer and has been gradually applied to more advanced disease (8). However, only a minority of lobectomies are performed using the VATS technique, as only approximately 45% of lobectomies registered in the Society of Thoracic Surgeons database are performed thoracoscopically (9). Its adoption has been variable, likely due to perceived technical challenges when compared to an open approach and the concern for intraoperative complications, especially during a surgeon's learning curve, discouraging smaller centers from adopting VATS lobectomy (10).

Operative planning

As with most surgical procedures, the optimal strategy for managing complications of VATS pulmonary resections is to prevent their occurrence. VATS represents a new approach and not a new procedure. Therefore, the preoperative evaluation and indications

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for VATS major resections remains the same as for conventional resection. Avoiding complications is dependent on appropriate preoperative workup and patient selection. Planning for as safe a VATS resection as possible involves consideration of patient characteristics, the radiographic appearance of the area of lung to be removed, and the anticipated technical aspects of the case.

All patients have a preoperative examination with a positron emission tomography (PET), computed tomography (CT) scan, bronchoscopy, and endobronchial ultrasound/mediastinoscopy for preoperative staging (unless it is benign lung disease or a peripherally-located T1 tumor on PET) (11). Additionally, preoperative evaluation and staging for thoracoscopic resection should include pulmonary function tests (PFTs) with diffusion measurements. The performance of thoracoscopic procedures is usually dependent on the ability to achieve and maintain single-lung ventilation, which involves careful consideration of the patient's contralateral lung status. Obtaining quantitative ventilation-perfusion scans can help in determining the ability of a patient with marginal functional status to tolerate pulmonary resection. The lowest limits in lung function parameters that would still be considered acceptable for VATS lobectomy have not been scientifically studied (12), but this would depend upon, among other factors, the surgeon's judgment, experience, and technique; the contribution of the excised lobe to overall lung function; and the exact location of the pathology. Additionally, VATS resections have been shown to be able to be accomplished in patients with lung function who have typically been thought to be too poor to undergo more conventional resection via thoracotomy (13,14). We have performed lobectomies on selected patients whose forced expiratory volume in 1 second (FEV_1) was less than 30% predicted with excellent outcomes (15). In fact, one major advantage of VATS resection is that it allows recruitment of older and sicker patients with multiple comorbidities who would otherwise not be suitable candidates for resection through a conventional thoracotomy approach (13,16). Moreover, aggressive preoperative pulmonary rehabilitation can be considered in patients initially considered not to be candidates for resection owing to poor PFTs (17). Finally, patients who are not candidates for an anatomical resection could still be considered for VATS wedge resection (18). In all such cases, it is imperative to consider that conversion to thoracotomy is possible for all patients for whom VATS resection is planned.

Contraindications to VATS lobectomy

Since major lung resection by VATS was first introduced in the early 1990s, the indications and contraindications of these procedures have changed over time. Thus, whereas initially a history of prior surgery, endobronchial lesion, or even the administration of induction chemotherapy were regarded as contraindications, the experience that has since been gained, together with improvements in instrumentation and thoracoscopic imaging, have now changed this situation in most hospitals with experience in VATS. As such, recent studies have shown that lobectomy by VATS in cases of bronchogenic carcinoma with prior chemotherapy can be carried out safely and effectively without an increase in the rate of complications (19). And although endobronchial lesions were previously considered a contraindication for VATS, some authors do not consider this issue a contraindication at present (20). Furthermore, there are publications reporting on thoracoscopic sleeve resections (21).

Nevertheless, in addition to the general contraindications, such as recent myocardial infarction and severe coagulopathy, there remain a few absolute contraindications that are specifically applicable to VATS major resections. Apart from the inability to tolerate single lung ventilation, which is relatively uncommon, absolute contraindications to thoracoscopic lobectomy include the inability to achieve complete resection with lobectomy, lobectomy, T4 tumors, and N3 disease (22). Absolute tumor size criteria that would preclude VATS resections have not been defined, though large specimens (tumors greater than 6 cm in diameter) may not be amenable to removal without rib spreading; this tends to negate the benefit of minimal access surgery. Despite these previously cited absolute contraindications, the ideal patient for thoracoscopic lobectomy, particularly early in a surgeon's experience performing the operation, is one with a peripheral T1 or T2 lesion without nodal disease.

It remains controversial as to whether VATS lobectomy is justified for lung cancer patients with lymph node metastasis (23). It was generally considered that patients with lymph node metastasis were not suitable candidates for VATS lobectomy (8,24). Additionally, it has been suggested that if a suspicious looking mediastinal lymph node is detected, it should be biopsied and a frozen section examination performed; confirmation of N2 disease mandates conversion to open surgery for complete mediastinal lymphadenectomy or induction chemotherapy depending on the exact circumstances (25). These guidelines have stemmed from a concern over incomplete lymph node dissection during VATS lobectomy. However, Watanabe *et al.* reported that the outcomes of VATS lobectomy were comparable to those of thoracotomy in clinical N0 but postoperative pathological N2 patients (26). Additionally, previous studies have compared the efficacy of a lymph node dissection of a VATS lobectomy with standard thoracotomy and have demonstrated that the results are similar (23,27,28). Nevertheless, it remains that in some institutions, preoperative or intraoperative lymph node metastasis is a contraindication for a VATS lobectomy and mandates conversion if discovered intraoperatively (29).

True pleural symphysis that leads to abandonment of the VATS approach is uncommon in our experience, but it may represent a contraindication for surgeons without extensive experience. Once a space is created when the correct plane in the pleural space is entered, endoscopic adhesiolysis can proceed quickly and safely using a combination of sharp and blunt dissection under videoscopic vision. VATS has the advantage over conventional thoracotomy in visualizing, with high resolution for details, the apex and base of the hemithorax.

Relative contraindications include tumors that are visible at bronchoscopy and the presence of hilar lymphadenopathy that would complicate vascular dissection (benign or malignant). Tumors visible in the bronchus by bronchoscopy within 2 cm of the origin of the lobe to be resected and where a possible sleeve resection might be needed are likely not amenable to a VATS approach. Calcified hilar adenopathy, such as with histoplasmosis, can likewise complicate vascular dissection (30).

The use of prior thoracic irradiation and induction therapy have previously been considered relative contraindications, but thoracoscopic lobectomy has been shown to be both safe and effective for patients who received induction therapy for non-small cell lung cancer (NSCLC) (19,31). Prior thoracic surgery, incomplete or absent fissures, and benign mediastinal adenopathy should not be considered contraindications. Redo-VATS surgery has been reported, and prior surgery is no longer considered an absolute contraindication to VATS resection (32). Though fused fissures present a technical challenge to VATS lobectomy, with experience and proper operative planning, successful lobectomy can be accomplished—the fused fissure should be divided last following the pulmonary vasculature and the bronchus. Finally, though chest wall involvement requires thoracotomy for resection, VATS can be used to perform the lung portion of the surgery and allow placement of the incision better situated for the area of the chest wall to be removed.

It is important to note that with improving surgeon experience and comfort with VATS lobectomy, just as several indications have been modified and expanded, the number of contraindications has been reduced. However, there remains some institutional variability in contraindications for this same reason. In a high-volume tertiary care institution experienced in the technique of VATS lobectomy such as our own, contraindications evolved to include a narrow patient population. Other institutions cite chest wall invasion, tumor infiltration beyond the fissure, invasion of the pericardium or diaphragm, centrally placed tumors in the hilum and adherent to vessels, as well as induction radiotherapy or chemotherapy as contraindications (11,33). Nevertheless, we do not consider these absolute contraindications. Additionally, evidence from our institution has shown VATS lobectomy to be safe and technically viable in patients receiving induction chemotherapy (19,31). As such, these additional institutional contraindications likely represent surgeon comfort and experience with VATS techniques rather than those deemed necessary for patient safety, anatomical reasons, and complete oncological resection.

Conversion to open thoracotomy

Conversion rates for thoracoscopic lobectomy to open thoracotomy have been reported to range from 2% to as high as 23%, with these higher rates stemming from patients with more advanced NSCLC (34-40). Krasna *et al.* reported an 8% conversion rate in 321 patients undergoing VATS procedures for various indications (41). Most commonly the conversion to thoracotomy was deemed necessary because of oncological reasons, such as centrally located tumors requiring vascular control or sleeve resection, or unexpected T3-T4 tumors that infiltrate to the chest wall, diaphragm, or superior vena cava. These authors concluded that abnormal hilar nodes with granulomatous or metastatic disease adherent to the superior pulmonary vein may be better evaluated and more safely resected with thoracotomy. However, about 30% of thoracotomy conversions in this series were for non-oncological reasons, such as pleural adhesions (41). In the series of the Memorial Sloan-Kettering Cancer Center Thoracic Service, conversion to open thoracotomy because VATS was not "technically adequate" occurred in 44/410 patients (11%) (42). In a recent institutional study, our conversion rate was 4% (36/916) when patients had an attempted VATS lobectomy for lung cancer, with patients with clinically node-positive disease (N1-N3) having statistically significantly higher conversion rates than clinical N0 patients (43).

Overall, causes of conversion can generally be classified into four categories: intraoperative complications (e.g., bleeding from vascular injury, usually to branches of the pulmonary artery and occasionally injury to the pulmonary vein; bronchus injury by the endotracheal tube), technical problems (e.g., equipment or stapler malfunction, failure to progress, poor visualization), anatomical problems (e.g., absent or thick fissure, calcified peri-arterial lymph nodes, diffuse pleural adhesions, chest wall invasion, tumor size precluding removal through the utility incision, need for sleeve resection), and oncological conditions (e.g., intraoperative discovery of N2 tumors, invasion of the artery, invasion of the parietal pleura, positive margins that need to be extended). However, the ability to predict which patients are more likely to require conversion to thoracotomy has not been thoroughly addressed to date. Given that studies have demonstrated that emergent conversion to open thoracotomy has been found to be significantly correlated with VATS-associated complications during the first 30 postoperative days (44), the ability to anticipate patients that may be high-risk for conversion may prevent this unexpected eventuality and its associated morbidity.

One of the most dreaded complications for surgeons is massive bleeding from pulmonary vessels. Dense adhesive disease often increases the risk of vascular injury, necessitating conversion to an open procedure. It is important to note that even in such cases, dissection of vessels can generally be difficult, and risk of vessel injury and bleeding can be high even by thoracotomy. Both Craig *et al.* and Yim *et al.* have reported mechanical failure of the staplers that resulted in massive bleeding (45,46). In these cases, bleeding was controlled by pressing on the bleeder with a sponge stick and conversion to thoracotomy. It should be pointed out that these are anecdotal cases, and the mechanical staplers available now are generally very reliable, and while stapler malfunction may occur, it is relatively rare. Certain avoidable conditions have been incorrectly associated with the stapler. For example, the use of metal clips in the hilar dissection is discouraged, as the stapler will not function if a clip is included in the stapler's jaw. Additionally, attention to the amount of tension when retracting during the stapling of pulmonary artery branches is essential. If excess retraction is applied during the stapling process, the arterial branch may tear before the completion of the stapling when the linear strength of the artery is reduced with the initiation of this process. Additionally, several technical developments have avoided the bleeding problems and consequent conversion to thoracotomy that are pitfalls of VATS techniques (46). These include us of visceral pleura to buttress staple lines, routine use of vertically apposed staplers, and expertise in extracorporeal and intracorporeal knot tying with fine suture.

Nevertheless, these results highlight the fact that even in the event of significant bleeding from a major pulmonary vein or artery branch injury that cannot be repaired thoracoscopically, the source of bleeding can usually be identified and controlled with a thoracoscopic instrument to allow controlled and stable conversion to thoracotomy. However, these injuries are usually managed successfully without conversion by the experienced thoracoscopic surgeon. With advanced skill and experience in endoscopic suturing, in the event of minor to moderate bleeding from the pulmonary vasculature, conversion can often be avoided.

Video equipment malfunctions are unique to VATS compared with open thoracotomy. The surgeon must be prepared when video equipment failures occur to prevent complications from taking place as a result. The operating room team must have someone familiar with the set-up of the camera, light source, and monitors present at all times as well as the ability to obtain back-up equipment or contact an expert in the event of equipment failure. Additionally, the surgeon and the entire operative team must always be prepared with the instruments needed to convert to thoracotomy in the event of patient instability or non-recoverable video equipment problems.

An additionally described cause of conversion to open lobectomy is particular to areas in which histoplasmosis is endemic, specifically states bordering the Ohio River valley and the lower Mississippi River, making the hilar dissection challenging (30). In a recent study by Samson *et al.*, patients with evidence of calcifications specifically involving the hilum of resection had a 37% risk of conversion, and those with evidence of calcifications along the bronchial tree, but not along the hilum of resection had an intermediate rate of conversion at 25% (47). In fact, calcification score was the only predictor of conversion to open thoracotomy in multivariable modeling including lobe resection, race, gender, reoperation status, age, body mass index, tumor size, baseline PFTs, and time since first VATS lobectomy case to factor in the possible learning curve effect. In another study examining unplanned conversion for VATS lobectomy by Park and colleagues, 41% of conversions were due to hilar nodal anthracofibrosis and hilar adhesions, and were associated with increased operative time and length of stay (48). When the authors retrospectively reviewed the CT scans, hilar calcifications were seen in 71% of these patients. In these cases, careful review of the preoperative chest CT scan is essential, focusing on calcifications in the hilum, especially at the origin of the lobar bronchus that is to be divided. To date, however, there are few studies evaluating the role of imaging studies in selecting the surgical approach for lobectomy, and those that do are limited to the size and location of the tumor. Mason and colleagues evaluated the role of imaging studies in predicting complications associated with VATS and demonstrated that pleural thickening and calcifications on CT or chest X-ray predicted difficulties (49). However, this study included all VATS procedures with only a small number of lobectomies.

Samson and colleagues additionally demonstrated, not surprisingly, that when compared with completed VATS, converted VATS operations were significantly more likely to result in postoperative atrial fibrillation, increased length of stay, increased duration of chest tube drainage, longer surgery time, and increase in estimated blood loss (47). Interestingly, on comparison of converted VATS to planned open thoracotomy, VATS conversion was only an independent predictor of longer length of stay, and combined mortality and morbidity were similar. In fact, several studies have examined the implications of unplanned conversion from VATS to thoracotomy. One study evaluated the outcomes in 26 patients who underwent a converted VATS procedure and compared them with the outcomes of 52 patients who underwent a planned thoracotomy. There were no significant differences between the groups in perioperative (30-day) or long-term outcomes (50). Sawada and colleagues found that VATS conversion was associated with increased blood loss, perioperative complications, and length of surgery compared with completed VATS, similar to the recent data of Samson and colleagues (47,51). Nevertheless, these authors concluded that patients with evidence of calcifications involving the hilum of resection can undergo attempted VATS lobectomy, but perhaps this should not be attempted during the learning curve or by surgeons who are not as experienced with open pulmonary resection in these patients.

The number of patients undergoing VATS lobectomy as opposed to an open procedure has significantly increased over recent years but conversion rates have fallen (52). The anticipated learning curve for an advanced minimally invasive procedure can be clearly tracked. Cause of conversion initially was for a variety of reasons, but with experience and as confidence levels increased, reason for conversion for anatomical reasons has also increased, possibly reflecting bolder patient selection or discomfort with a perceived anatomical problem, such as chest wall adhesions. In addition, there are oncological reasons a decision to convert may be taken, with tumor size and location and extranodal invasion by a metastatic node being obvious markers. However, apart from the latter case, the decision of conversion depends solely on the surgeon's preference. Several reports have supported the use of VATS for complete lymph node dissection and showed no significant differences in survival or recurrence between VATS and thoracotomy (8,53-55). Thus, in cases of gross lymph node metastasis, the decision to convert must be carefully weighed.

But as programs developed, despite increasing numbers of VATS resections, conversions for anatomical reasons have tended to fall as have conversions for vascular injury (53). This is explained by the experience gained in vascular dissection and in the management of the fissure, particularly in complex cases, post-chemotherapy patients and even reoperations. The nature of the conversion and whether conversion is controlled is important both for the obvious safety aspects of the patient but also for how smoothly the minimally invasive approach is perceived amongst colleagues as well as the confidence of the surgeons performing the VATS lobectomy.

Generally, high conversion rates have declined as surgeons became more familiar with advanced thoracoscopic lobectomy, an operation with a challenging learning curve. This trend has been demonstrated previously, with a decreasing proportion of conversions as an increasing number of thoracoscopic lobectomies were performed for advanced-stage disease (35). And although conversion to thoracotomy should always be considered as a tool available to manage any unexpected situation, conversion rates have been shown to be as low as 1.6% to 2.5% in large series by experienced thoracoscopic surgeons (35,56). Further, though it is clear that the accumulation of experience has improved the surgical team's skill, allowing them to avoid and/or manage problems, resulting in a reduced conversion rate, these results also suggest that there remains a patient population in which VATS lobectomy is difficult to perform. It is generally accepted that dense hilar lymphadenopathy, pleural symphysis and fused fissure make VATS lobectomy difficult, and increase the likelihood of conversion to an open procedure. Specifically, persistent air leak beyond seven days was the most common morbidity seen in earlier experience and almost certainly related to hilar dissection when the fissures were incomplete (57).

Ultimately, the decision for conversion is left to each surgeon's skills and patience. It is difficult to establish any guideline for the conversion; however, our approximate timing of the decision for conversion is as follows: in cases with bleeding, as previously described, a sponge stick is first applied in order to tamponade the bleeding. Once the bleeding is controlled, a decision about whether or not the repair can be performed under VATS is made. When the bleeding cannot be controlled or repair seems to be difficult under VATS, conversion to thoracotomy is considered. In cases with a fused fissure or dense hilar lymphadenopathy, if the pulmonary artery cannot be isolated, conversion is considered.

Finally, although it may ultimately be difficult to predict who will require conversion from VATS to open surgery, there are a few important considerations regarding this matter. First, one of the advantages of VATS lobectomy is the magnified visualization it affords, which is useful for dissecting vessels or identifying small bleeders and makes this technique useful even in cases where conversion to an open procedure may be considered likely preoperatively. Secondly, after the surgeon's learning curve with advanced VATS techniques is surpassed and the conversion rate presumable reaches its nadir, attempts at decreasing conversion rates may only serve to delay the timing of conversion and increase the risks. The first objective of the operation is to perform a safe and complete resection. Once problems arise, repair takes a longer time, and the risks are increased. It is important not only to plan safe maneuvers to avoid problems, but also to have the courage to convert if there is any sense of discomfort experienced by the surgeon with VATS. Finally, long-term outcome is an important parameter to evaluate the safety and feasibility of converted VATs lobectomy. Jones *et al.* reported that the long-term outcome of converted VATS lobectomy for lung cancer was equivalent to that of successful VATS lobectomy (50). Therefore, it is reasonable to conclude that VATSs lobectomy is feasible for lung cancer surgery even from the viewpoint of the safety rate of converted VATS.

Conclusions

VATS was introduced nearly 20 years ago. Since then, VATS has experienced major advances in both equipment and technique, especially for the treatment of benign lung disease (58). With the accumulation of experience for the treatment of benign diseases, VATS has gradually begun to be employed for radical resection of lung cancer (3,4). VATS lobectomy is now considered standard in thoracic surgery, with acceptable safety and efficacy for both lung cancer and benign lung diseases (59,60). Several investigators have reported that the outcomes of VATS lobectomy for lung cancer are comparable to those of thoracotomy (35,38,61,62). While no large, controlled studies have been conducted to compare VATS with thoracotomy, it is now generally accepted that the outcomes of VATS are not inferior to those of thoracotomy. However, another concern is the safety of VATS lobectomy. Subsequent to VATS lobectomy, perioperative complications and mortality have been reported to occur at rates of approximately 5-32% and 0-7%, respectively; these rates are also generally accepted to be comparable to those reported for thoracotomy (35,38,63,64).

However, VATS lobectomy sometimes requires, for a variety of reasons, emergency conversion to thoracotomy. There are difficulties with the procedure, including a narrow view angle, complicating conditions such as pleural adhesions and dense hilar lymphadenopathy, oncologic problems if the disease is lung cancer, and the surgeon's discomfort with VATS instruments. As such, even though the technical safety of VATS lobectomy is widely accepted, there remains a range of situations that can result in unplanned conversion to open thoracotomy during the procedure, especially during a surgeon's training period (30).

The most important concern with unplanned conversions is the possible increased risk of mortality, morbidity, and cancer recurrence. Patients who undergo unplanned conversion to open thoracotomy most likely experience a longer operating time, extra lung manipulation, increased risk of injury to adjacent tissue, and increased blood loss, which may all adversely affect the outcome. And although the safety and efficacy of successful VATS lobectomy has been documented by many authors, there are fewer data regarding failed VATS lobectomy. The few studies regarding this problem report no significant increase in mortality or morbidity (50,51). Apart from vascular and bronchial injuries, which result from technical problems, the other causes of conversion may be predictable preoperatively. For example, in light of clear hilar calcifications on preoperative CT, conversions due to anthracofibrosis may be able to be anticipated. Certain vascular anomalies resulting in conversion are often visible on preoperative enhanced CT. Finally, preoperative PET scans can show a high probability of lymphatic metastasis in cases converted because of gross metastasis of these lymph nodes. Although unexpected conversion to thoracotomy during VATS does not appear to compromise prognosis, the decision to convert must be made promptly to reduce the operating time, blood loss, and possible complications. Accordingly, when attempting a VATS procedure, access ports must be placed to facilitate immediate conversion to open thoracotomy and to support instrument manipulation and anatomic accessibility of the stapler to close vessels and the bronchus. And in the context of narrowing contraindications for VATS lobectomy and surgeons overcoming the learning curve associated with increasingly complex resections, conversion should not be regarded as a surgical failure but rather as a way to safely complete resections in a traditional manner.

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