Thoracotomy, video-assisted thoracoscopic surgery and robotic video-assisted thoracoscopic surgery: does literature provide an argument for any approach?

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Abstract: Over the past two decades, video-assisted thoracoscopic surgery (VATS) has emerged as a safe and feasible alternative approach to conventional open thoracotomy in the treatment of non-small cell lung cancer (NSCLC). More recently, robotic VATS (RVATS) has gained increased interest as another minimally invasive option for selected patients. The objective of this review was to examine the current literature to compare the short- and long-term clinical outcomes of VATS and RVATS with open thoracotomy. Endpoints included long-term survival, perioperative complications, length of stay, operating time, cost of procedure and quality of life. From our review, we found that VATS offer similar, if not superior, long-term survival outcomes as the traditional thoracotomy approach for selected patients with NSCLC. Perioperative complication rates and length of hospitalization appear to be lower in minimally invasive (VATS and RVATS) approaches when compared with thoracotomy. Similarly, patients reported improved quality of life outcomes after minimally invasive surgery. Operative times were longest in the RVATS groups, but cost analyses were less robust. Although the ideal approach for an individual patient is dependent on the complexity of the patient's disease, the surgeon's experience, and the available instrumentation, the current trend towards minimally invasive approaches appears justified according to best available evidence.

Keywords: Thoracotomy; video-assisted thoracoscopic surgery (VATS); robotic video-assisted thoracoscopic surgery (RVATS); lobectomy; non-small cell lung cancer (NSCLC)

Received: 04 March 2017; Accepted: 27 March 2017; Published: 13 April 2017.
doi: 10.21037/vats.2017.03.08
View this article at: http://dx.doi.org/10.21037/vats.2017.03.08

Introduction

Over the past two decades, video-assisted thoracoscopic surgery (VATS) has emerged as a safe and cost-effective alternative to open thoracotomy for selected patients undergoing resection for non-small-cell lung cancer (NSCLC) (1). More recently, a heightened interest for this minimally invasive approach has extended lung surgery to encompass robotic VATS technology (RVATS). However, in global clinical practice, anatomical lobectomy by thoracotomy has remained the standard treatment for early stage NSCLC due to a number of logistic and clinical reasons (2,3). The present article provides a brief overview of the minimally invasive approaches and summarizes their current clinical evidence. The primary endpoint was long-term survival, considered as a surrogate for oncological efficacy. Secondary endpoints included perioperative complications, length of hospital stay, operating time, cost of procedure and quality of life (4).

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VATS

Since the introduction of VATS lobectomy in the 1990s, there has been increasing evidence to suggest fewer complications, less post-operative pain, and faster recovery associated with this minimally invasive approach in comparison to thoracotomy (5). Despite encouraging clinical evidence, VATS lobectomy currently accounts for approximately one in four lobectomy procedures in the United States, and even less in most European countries (6). Challenges to the popularization of the VATS technique include its steep learning curve and cost concerns (7).

RVATS

Interest in RVATS has continued to grow since the initial landmark reports by pioneering surgeons such as Melfi and Park (8-12). Potential advantages of RVATS include the ability to filter intention tremor along with stability of equipment, seven degrees of movement, wide operative fields and superior 3D imaging (13). However, reports comparing RVATS lobectomy with VATS have not identified statistically different lengths of hospital stay, or morbidity or mortality outcomes (4,14-16). In addition, concerns have been raised by some members of the thoracic community regarding its learning curve and its cost (8,17,18).

Endpoint Comparisons

Long-term survival

There is now considerable evidence within the current literature to suggest similar or better long-term survival outcomes for VATS lobectomy compared to the thoracotomy approach. A recent 12-year retrospective study involving 560 propensity score-matched NSCLC patients demonstrated no significant difference between the VATS and open approaches in long-term survival (19). In addition, Taioli *et al.* presented a meta-analysis including 20 articles, reporting a survival advantage for the VATS group compared with thoracotomy at 5 years (meta-difference in survival: 5%; 95% CI: 3–6%) (20). Similarly, Yan's meta-analysis involving two randomised and nineteen non-randomised studies reported superior overall 5-year survival after VATS compared to open thoracotomy (21).

In regards to RVATS, there is a relative paucity of long-term clinical data, but a multi-institutional retrospective review by Park *et al.* reported an overall 5-year survival of 80%, which was comparable to historical outcomes from VATS and thoracotomy (11). A more recent study in 2017 reported similar long-term survival outcomes for all surgical approaches to treat NSCLC, including 5-year survival rates of 77.6% for RVATS, 73.5% for VATS, and 77.9% for open thoracotomy (16).

Yang *et al.* analysed the American National Cancer database to evaluate outcomes in over 30,000 lobectomies, including 7,824 VATS lobectomies and 2,025 RVATS lobectomies from 2010 to 2012 (6). Their analysis found no statistically significant survival differences between RVATS and VATS in the treatment of NSCLC.

Previously, concerns have been raised regarding the capability of minimally invasive approaches to achieve adequate lymph node dissection or sampling, which may hinder long-term oncological efficacy and survival, particularly for more advanced stage NSCLC (22). However, these concerns have been addressed by recent studies that suggested the rates of nodal upstaging are improved with minimally invasive techniques (6).

Perioperative complications

Common post-operative complications in lobectomy patients include pain, bleeding, prolonged air leak, arrhythmia and infections, all of which contribute to the length of hospital stay, overall procedural costs and patient satisfaction (16).

A meta-analysis of propensity score-matched patients undergoing VATS and open thoracotomy demonstrated lower incidences of post-operative complications in VATS lobectomy (23). This analysis reported significantly lower rates of prolonged air leak (8.1% *vs.* 10.4%, P=0.02), pneumonia (3.2% *vs.* 5.0%, P=0.008), tachyarrhythmia (7.3% *vs.* 11.7%, P<0.001) and renal failure (0.9% *vs.* 3.0%, P=0.03) after VATS compared with open thoracotomy.

Analyses of post-operative complications following RVATS have recorded similar complications to VATS (4,14). A systematic review and meta-analysis involving 18 articles from 12 institutions found tachyarrhythmias to be the most commonly recorded complication (3–19%), followed by prolonged air leak (4–13%), pneumonia (1–5%) and acute respiratory distress (1–4%) (8).

Length of hospital stay

A number of studies have reported reduced length of stay in minimally invasive approaches compared with thoracotomy (23,24). A meta-analysis comparing VATS and thoracotomy

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reported length of stay to be significantly less in the VATS group when compared with thoracotomy (standard mean difference −0.37, 95% CI: −0.51—0.22, P<0.001) (23).

Recently, Yang *et al.* analysed the American National Cancer database and found significantly shorter stays for patients who underwent RVATS compared with thoracotomy (5.9 versus 8.2 days, P≤0.001) (6). However, no significant differences were identified between VATS and RVATS.

Operating time

A recent cohort study of over 6,000 patients comparing open lobectomy to VATS reported similar operative times between the two surgical approaches (1). However, a retrospective analysis by Deen *et al.* reported that VATS required 22 minutes longer to perform than open lobectomy (P=0.02) (25).

In regards to RVATS, Deen *et al.* found the robotic approach to be 43 minutes longer compared to open thoracotomy (P<0.001) (25). This finding was consistent with other studies that reported more than 65 minutes of operating time for RVATS (26).

Deen's comparison of operative time for RVATS versus VATS found a 21 minute difference in favour of VATS (P=0.045) (25). This was similar to Bao's reported difference of 25 minutes (136 *vs.* 111 mins, P<0.001) (24).

A steep learning curve for both VATS and RVATS techniques has also been well documented in the literature (2,4,8). This was demonstrated in a systematic review that reported average operative times for RVATS that differed as much as 106 minutes between institutions (8). This difference has been partially attributed to the early period of developing surgical mastery with robotic technology, which was substantially bridged after 20 cases (8).

Cost of procedure

A major hurdle in implementing new surgical techniques is their cost. The overall cost of a procedure include direct costs such as instrumentation, as well as indirect costs, which takes into consideration the lengths of hospital stay, rates of post-operative complications, and re-admissions.

The up-front costs of robotic surgical systems as well as their maintenance means RVATS begins from a higher cost base than its alternatives (25,27). However, all-in cost comparisons for the three approaches need to adjust for down-stream factors like relative operating time and materials, post-operative intensive care stays and laboratory expenses (25). Using this broader rubric, Augustin *et al.* calculated a cost differential of over 44% when comparing RVATS lobectomy with conventional VATS lobectomy (2). A multi-hospital database review also found RVATS procedures were more expensive compared to VATS ($4,565 greater for RVATS lobectomy and $2,992 greater for RVATS wedge resection) (4).

Park and Flores reported that RVATS was on average $3,981 more expensive than VATS, but $3,988 cheaper than thoracotomy (27). They proposed that the decreased costs of minimally invasive approaches could be attributed to reduced overall length of hospital stay. However, after including costs related to "amortized cost" of using the robot, a further $1,715 was added to total cost of each RVATS patient.

Quality of life

Shi *et al.* compared quality of life outcomes following VATS and open lobectomy using the MD Anderson Symptom Inventory (28). They found that patients who underwent VATS returned to their baseline activity, mood and enjoyment of life at a significantly faster rate than patients who underwent open lobectomy. Cerfolio *et al.* also conducted a medium-term quality of life assessment using the Short Form Health Survey (29). This was administered at 3 weeks and 4 months post lobectomy for RVATS and thoracotomy patients. At 3 weeks, scores for the RVATS group reflected significantly better mental and physical health and less pain. These differences were not maintained at 4-month follow-up.

Conclusions

The present article presented a number of recent systematic reviews, meta-analyses and large retrospective series that compared the various surgical techniques to resect NSCLC. Current clinical evidence suggests that VATS offers similar, if not superior, survival outcomes as the traditional thoracotomy approach for selected patients with NSCLC. In addition, it has been shown that VATS is associated with significantly lower perioperative morbidities, shorter hospitalization and improved quality of life compared to the open approach. Similarly, RVATS has also demonstrated encouraging short- and long-term clinical outcomes from specialized centres. However, there remains a relative paucity of robust long-term clinical

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data for this approach, and further studies are required to elucidate any potential superiority over VATS, as well as addressing persistent concerns regarding its overall cost. Ultimately, the ideal approach for a patient is dependent on the complexity of disease, the experience of the surgeon, and the available instrumentation. However, the current trend towards minimally invasive approaches appears to be justified according to best available evidence. With an aging population and a changing patient profile with increased co-morbidities, it is hoped that minimally invasive surgical techniques will increase the operability of candidates who were once considered inoperable. This is particularly relevant in the current clinical practice, in view of emerging alternative treatment modalities such as stereotactic body radiotherapy (30).

Acknowledgments

Funding: None.

Footnote

Provenance and Peer Review: This article was commissioned by the Guest Editor (Dominique Gossot) for the series "Video-assisted major thoracic procedures: Approaches" published in *Video-Assisted Thoracic Surgery*. The article has undergone external peer review.

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at http://dx.doi.org/10.21037/vats.2017.03.08). The series "Video-assisted major thoracic procedures: Approaches" was commissioned by the editorial office without any funding or sponsorship. The authors have no other conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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doi: 10.21037/vats.2017.03.08
Cite this article as: Clark A, Ozdirik J, Cao C. Thoracotomy, video-assisted thoracoscopic surgery and robotic video-assisted thoracoscopic surgery: does literature provide an argument for any approach? Video-assist Thorac Surg 2017;2:21.

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