The evolution of vats and minimally invasive techniques in the treatment of lung cancer: a narrative review

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Background and Objective: Video-assisted thoracoscopic surgery (VATS) has undergone rapid evolution and has become standard practice in recent decades. Understanding how VATS developed from open approaches can help shed light on how minimally invasive surgical techniques will continue to evolve in the future. This narrative review serves to provide readers with a synopsis of the origins of minimally invasive thoracic surgery; the rapid adoption of minimally invasive surgery (MIS); and the outcomes of these new techniques, as compared to one another and conventional thoracotomy.

Methods: A review of past literature on PubMed and Google Scholar was conducted using MeSH terms and key words, respectively, between November 2022 to July 2023. Selected articles were written in English and either focused on the evolution of minimally invasive techniques for lung resection or compared post-operative outcomes and prognosis between techniques. The reference lists of retrieved articles were also explored, and additional papers were included by expert reviewer suggestion to add to the depth of the paper.

Key Content and Findings: Since the advent of VATS, the thoracic subspecialty has seen many new minimally invasive techniques including robotic assisted thoracic surgery (RATS), subxiphoid excisions, and uniportal approaches. There is sufficient evidence to suggest VATS is favourable to thoracotomy in terms of perioperative and postoperative outcomes while maintaining similar 5-year survival rates. There is evidence that RATS is either equivalent or superior to VATS in regard to perioperative outcomes while possibly conferring a shorter learning curve. Uniportal intercostal and subxiphoid incisions may reduce postoperative pain when compared to multiportal VATS, but further research is warranted.

Conclusions: The evolution of VATS begins with the conception of the early endoscope and does not seem to have an end in sight. It is clear that these MIS approaches offer advantages to conventional thoracotomy; however, there is conflicting evidence regarding how they compare to one another. This narrative review suggests further randomized trials and meta-analyses are required to confirm which minimally invasive approach is most favourable in the resection of lung cancer.

Keywords: Video-assisted thoracoscopic surgery (VATS); minimally invasive surgery (MIS); history; evolution; comparative outcomes

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Introduction

Background

The surgical removal of cancer has ancient roots that can be dated back to first century Rome (1). Nonetheless, the surgical removal of lung cancers was long deemed impossible and was not popularized until the 20th century (2). French surgeon Jules Emil Pean was able to perform the first lung cancer removal in 1861; however, pulmonary resections of tumours produced high mortality rates prior to the advent of general anesthesia and positive-pressure lung ventilation in the early 1900s (2,3). After the first successful pneumonectomy in 1933 by Dr. Evarts A. Graham, lung cancer resection approaches quickly evolved to lobar and sub lobar resections that would soon become more amenable to minimally invasive surgery (MIS) (3). To date, these MIS approaches have included multiportal video-assisted thoracoscopic surgery (VATS), uniportal VATS, robot-assisted thoracic surgery (RATS), muscle-sparing thoracotomy (MST), and subxiphoid incisions.

Rationale and knowledge gap

An understanding of the evolution of MIS in resection of lung cancer can help current and aspiring thoracic surgeons better understand how to advance the field. Current literature on the evolution of MIS approaches to lung cancer are succinct and often provide key information on the timeline of one or two techniques. However, to our knowledge, there has yet to be an article that details the evolution and compares post-operative outcomes for each of the MIS approaches.

Objectives

The two main objectives of this paper are to: (I) provide a detailed history on the past evolution and milestones in MIS techniques for resection of lung cancers; and (II) synthesize the existing literature that outlines the advantages and disadvantages, as well as compares the outcomes between, MIS approaches. We present this article in accordance with the Narrative Review reporting checklist (available at https://vats.amegroups.com/article/view/10.21037/vats-22-63/rc).

Methods

A narrative review was conducted using the PubMed database and Google Scholar from November 1st, 2022 to July 27th, 2023. Each category of study design was considered, and no restrictions were placed on the date of publication. Article titles and abstracts were screened and included based on relevance to the objectives of this narrative review. Articles that appeared to have low reliability and/or were not written in English were excluded. Additional articles were suggested by the manuscript reviewers and were subsequently added to increase the depth of the narrative review. Most of the formulas used in the search of PubMed are included in *Table 1*, and the search strategy summary and most of the key terms used for Google Scholar are included in *Table 2*.

The history of VATS

The first record of a device capable of visualizing the internal structures of the human body was published by Dr. Bozzini, a German Urologist, in 1806 (4). This device, known as the Lichtleiter, used a beeswax candle and a silver mirror to allow for inspection of the vagina, urethra, female bladder, rectum, and upper air passages (5). In 1853, Antonin Desormeaux built on Bozzini's work and developed a lens that could focus direct light on the internal structures of the body, rendering images with more clarity (6). This lens was subject to further improvement by Maximilian Nitze in 1879 when he introduced the cystoscope—a device consisting of a working channel, a light source, and an optical lens to allow for better visualization of body cavities (6). George Kelling took these concepts and devised instruments to allow for laparoscopic surgeries of the pelvis and abdominal cavities, with the first laparoscopic procedure on a human being performed in 1929 (6).

With the development of the endoscope, the road was paved for Hans Christian Jacobeus, a professor of internal medicine in Sweden, to apply Kelling's procedures to the visualization of the thorax (6). In 1910, Jacobeus was able to use endoscopic instruments to visualize the lung and lung cavity, pioneering what is now known as modern thoracoscopy (6). Jacobeus noted that these procedures were quite effective in the lysing of pleuritic lesions resulting from tuberculosis to prevent pneumothorax (6,7). He also introduced the concept of cancer staging, working closely with thoracic surgeon Einar Key to provide thoracoscopic descriptions of lung tumours prior to resection (7).

The introduction of antituberculotic chemotherapy in the 1950s saw the use of thoracoscopy decline, and it was only used sparingly in Europe for the diagnosis of

Table 1 The search terms used for PubMed

("endoscopy"[MeSH] OR "thoracoscopy"[MeSH] OR "laporoscopy"[MeSH]) AND "history"[MeSH]
("endoscopy"[MeSH] OR "thoracoscopy"[MeSH] OR "laporoscopy"[MeSH]) AND "adenocarcinoma"[MeSH]
("thoracic surgery, video-assisted"[MeSH]) AND ("prognosis"[MeSH] OR "postoperative complications"[MeSH])
("thoracic surgery, video-assisted"[MeSH] OR "robotics"[MeSH) AND "pneumonectomy"[MeSH]
("thoracic surgery, video-assisted"[MeSH] OR "robotics"[MeSH]) AND "treatment outcome"[MeSH]
("thoracotomy"[MeSH]) AND "muscles"[MeSH]
("thoracic surgery, video-assisted"[MeSH] OR "robotics") AND "learning curve"[MeSH]

Table 2 The search strategy summary

Items	Specification
Date of search	2022/11/01 to 2023/7/27
Databases and other sources searched	PubMed and Google Scholar
Search terms used	For the PubMed strategy, see *Table 1*
	For Google Scholar, a combination of the following words was used: "video-assisted thoracic surgery", "VATS", "robot-assisted thoracic surgery", "robotic surgery", "RATS", "subxiphoid", "muscle-sparing thoracotomy", "pneumonectomy", "lung resection", "history", "evolution", "outcomes", "prognosis", "minimally invasive surgery", "learning curve"
Timeframe	Any year
Inclusion and exclusion criteria	No restriction was placed on the type of article. Inclusion criteria: focus was placed on articles that either (I) outlined the history and evolution of minimally invasive surgery in lung resection, or (II) compared outcomes and prognoses between the different approaches to lung resection, whether they be open or minimally invasive surgical techniques. Exclusion criteria: articles were excluded if they were either (I) not written in English or, (II) considered to have low reliability
Selection process	David Sahai conducted the selection process
Any additional considerations, if applicable	Articles in the reference section of papers returned by the search were also occasionally explored for inclusion in the study

VATS, video-assisted thoracoscopic surgery; RATS, robot-assisted thoracic surgery.

pleuropulmonary diseases (7). However, thoracoscopy soon found its place in the treatment of pleural effusions and resection of metastatic lung cancer (6). Despite the use of thoracoscopy in Europe in the early 1920s, it was not until the 1970s that it was widely adopted in North America (6). New endoscopic instruments, such as the surgical stapler, allowed for what is now modern VATS (8). It was Giancarlo Roviaro who completed the first VATS lobectomy in Milan, Italy, in 1991 on a 71-year-old man to remove an adenocarcinoma from the right lower lobe (9). To this day, thoracoscopy is increasingly used in the treatment of lung cancer for formal oncologic lobectomies and segmentectomies, allowing a minimally invasive window to the thorax without the need to complete a thoracotomy.

VATS outcomes and prognosis compared to thoracotomy

Compared to thoracotomy, the VATS technique has demonstrated clear perioperative and postoperative advantages. A meta-analysis and systematic review by Cheng *et al.* [2007] synthesized findings from 205 patients in 36 randomized trials and 3,589 patients in 33 nonrandomized trials (10). The authors evidence many advantages of VATS compared to open thoracotomy including: decreased blood loss; pain reduction at one day, one week, and 2–4 weeks; reduced need for analgesics post-operatively; an improved vital capacity at 1-year follow-up; a reduced length of hospital stay by 2.6 days; and a reduction in the amount of time between operation and receiving chemotherapy (10).

Bendixen *et al.* [2016] compared VATS lobectomy (n=102) with anterolateral thoracotomy (n=99) in stage I non-small cell lung cancer (NSCLC) to evaluate differences in postoperative pain and mean quality of life scores (11).

Researchers found pain was significantly lower in the VATS group at 24 hours and, further, that this group experienced shorter length of stay and lower incidence of moderate-to-severe pain at 52 weeks (11). Quality of life scores were significantly higher in the VATS group when using the EuroQol 5 Dimensions questionnaire; however, it should be noted no significant differences existed when using the European Organization for Research and Treatment of Cancer Core Health-related Quality of Life Questionnaire (EORTC QLQ-C30) (11).

The VIOLET trial is the most recent randomized controlled trial comparing VATS to open lobectomies for early-stage lung cancer (12). In this trial, 503 participants were randomly assigned to either a VATS approach (n=247) or an open lobectomy (n=256) (12). VATS patients experienced superior physical function outcomes at 5 weeks compared to open lobectomy as measured by the EORTC QLQ-C30 (12). The VATS group also had shorter length of stay, fewer severe adverse events following discharge, and less time with pain at the point of incision (12). It is worth noting that the type of thoracotomy performed was not controlled for and was chosen by surgeon preference.

In addition to the perioperative and postoperative benefits conferred by VATS, it also demonstrates comparable survival rates with open approaches. The aforementioned meta-analysis by Cheng *et al.* [2007] showed no difference in stage-specific survival at 5 years when comparing VATS to open lobectomy (10). Another pertinent multi-institutional study by Shigemura *et al.* [2006] compared outcomes from 145 patients with clinical stage IA disease in three treatment groups: complete VATS (c-VATS), assisted VATS (a-VATS), and open lobectomy (13). At a mean follow-up of 38.8 months post-surgery, no significant differences were found in 5-year survival, with Kaplan-Meier probabilities of survival of 96.7% for c-VATS, 95.2% for a-VATS, and 97.2% for open approaches (13). A more recent retrospective study by Higuchi *et al.* [2014] studied the long-term outcomes of VATS lobectomy and found no statistically significant difference in 5-year disease-free survival or 5-year overall survival when compared to open lobectomy (14).

Broadened implications of VATS

The introduction of VATS provided more than simply another avenue for lung resection. One implication was the creation of dedicated VATS teams in the operating room that allowed for shared mental models (15). Importantly, research has since demonstrated that stronger mental models within surgical teams can shorten the duration of VATS lobectomies and also decrease intra-operative bleeding (16).

The VATS technique also allowed for non-intubated anesthesia (NIA) techniques to eliminate the need for double-lumen endobronchial intubation (17). Nezu *et al.* [1997] were one of the first to implement NIA using a VATS approach for wedge resection in the treatment of spontaneous pneumothorax (18). Specifically, these surgeons used 0.5% lidocaine as local anesthetic and IV butorphanol tartrate and diazepam as systemic agents to eliminate the need for general anesthetic (18). A meta-analysis and systematic review by Yu *et al.* [2019] has since confirmed that NIA in VATS lobectomy, metastasectomy, and segmentectomy is associated with shorter hospital stay, lower estimated cost of hospitalization, decreased chest tube duration, and shorter postoperative fasting time when compared to intubated general anesthesia (17).

The advent of VATS approaches also allowed for surgical intervention in situations where thoracotomy was conventionally deemed too high-risk. Donahoe *et al.* [2017] conducted a retrospective review to see if high-risk patients with subpar lung function tests could undergo VATS lobectomies without increasing postoperative complications (19). This review included 608 patients who received a lobectomy between 2002–2010 and classified them as either high risk [forced expiratory volume in one second (FEV1) or diffusion capacity of the lungs for carbon monoxide (DLCO) ≤50% predicted] or standard risk (19). In those undergoing thoracotomy, high risk patients were more likely to have pulmonary complications when compared to standard risk patients (19). Interestingly, no significant difference in pulmonary complications existed between high and standard risk groups when a VATS approach was taken (19).

History of robotic surgery and outcomes compared to VATS

The word robot stems from the Czech word “robota”, which translates directly in English to the word “labor” (20).

The history of robotic apparatuses can be dated back to 1495, when Da Vinci constructed a "Metal-Plated warrior" with structures that resembled a human jaw, arms, and neck (20). However, it was not until 1921 that the notion of a robot was introduced in Karel Capek's play "Rossom's Universal Robots" (20). The first published use of robotics in surgery was seen half a century later in 1988 when Kwoh *et al.* conducted very precise biopsies of the brain using the Unimation Puma 200 robot (21). Shortly after, this same robotic system was used to perform a transurethral resection of the prostate (20). Eventually, Dr. Marescaux was the first to perform a completely remote telesurgery from New York City on a patient undergoing a laparoscopic cholecystectomy in Strasbourg, France in the year 2001 (22).

In the early 2000s, thoracic surgeons began using robotics to assist with lung resections in a technique now known as RATS (23). The robotic apparatus used was the Da Vinci System, which consists of a surgical manipulator connected to two instrument arms, as well as a central arm equipped with an endoscope (24). It should be noted that this system is a telemanipulation system, meaning that the instrument arms are controlled by the surgeon at a distant location (24). The first references to the use of RATS in anatomical lung resection were reported by Melfi *et al.* [2002], Morgan *et al.* [2003], and Bodner *et al.* [2004] (24-26). These surgeons used the Da Vinci System to complete a variety of thoracic surgeries including lobectomies, tumour enucleations, excisions, bulla stitching procedures, esophageal dissections, and fundoplication (24-26). They noted relatively uneventful postoperative courses in patients and highlighted the potential benefits of robotic technology in the future of thoracic surgery (24-26).

Robert Cerfolio continued to refine previous robotic techniques used in RATS and, in the early 2000s, developed his own approach to robotic assisted lobectomy using 4 robotic arms (27). In this approach, the pleural space is entered in the mid-axillary line above the 7th rib, and a 5-mm video-assisted thoracoscopic camera is used to make the remaining incisions (27). Ramadan *et al.* [2017] have also recently outlined an approach in which 8 mm left and right robotic arm ports, a 12 mm camera port, a fourth 5 mm robotic arm, and a 12 mm assistant port are used to complete the operation (23).

Compared to the conventional two-dimensional images that VATS provides, the robot-assisted approach introduces a three-dimensional, magnified, high-definition image of the thorax (23). The use of robotic arms also allows for improved precision and maneuverability of surgical instruments (23). However, it is worth mentioning that the RATS approach does not allow for direct palpation of structures in the lung, as is possible in VATS techniques (23). Further, robotic procedures can have longer operation times, can be less cost-effective, and require extra incisions (28).

With the technical benefits of RATS, the question must be asked if outcomes are similar to conventional VATS techniques. A review of a national database by Kent *et al.* [2014] analyzed outcomes for RATS, thoracotomy, and VATS in the case of 33,095 patients (29). Compared to thoracotomy, robotic surgery reduced mortality, length of stay, and overall complication rates; however, when compared to VATS, robotic surgery did not provide any statistically significant differences (29). Conversely, a meta-analysis by Zhang *et al.* [2022] found that, when compared to VATS techniques, RATS procedures afforded less blood loss, a lower conversion rate to open, a shorter length of hospital stay, more lymph node dissection, and better 5-year disease-free survival (30). Thus, it is clear that more prospective trials are needed to clarify if true differences exist between these two techniques. It is worth mentioning that one recent narrative review by Rocha Júnior and Terra [2022] suggests RATS to offer equivalent oncological results to VATS while also providing a shorter learning curve and improved quality of lymphadenectomy (31).

Uniportal VATS and outcomes compared to multiportal VATS

While VATS procedures reduce the invasiveness that is inherent to thoracotomies, at least three or four incisions are needed for a multiportal approach (32). Thus, in an attempt to reduce the number of incisions made, a uniportal VATS technique has recently garnered popularity (32). One of the first descriptions of this technique was provided by Rocco *et al.* in 2004, wherein surgeons were able to successfully complete 15 wedge resections using a one-port approach in the diagnosis of interstitial lung disease (33).

While the potential advantages of uniportal over multiportal VATS procedures may seem plausible, there is inconclusive evidence in regard to improved outcomes in both randomized trials and meta-analyses. One randomized trial by Sano *et al.* [2021] compared pain scores in patients undergoing either uniportal or multiportal VATS lung resection and found that pain scores on post-operative day (POD) 2, 3, 5, and 10, were reduced in the uniportal group (34). On the contrary, Perna *et al.* [2016] found no significant differences between uniportal and multiportal groups when measuring postoperative pain or opioid consumption at POD 1, POD 2, or POD 3, and additionally noted no difference in time to removal of chest drain (35). Similarly, Yao *et al.* [2020] found no differences between uniportal and multiportal groups in regard to chest tube duration, length of stay, or lung function tests (36). Interestingly, researchers did conclude that mental and physical demands were less on surgeons in the uniportal approach (36).

Another randomized trial investigated two different uniportal VATS approaches, one using a 4 cm incision and the other an 8 cm incision (37). Here, Menna *et al.* [2020] found no significant differences in length of stay, respiratory complications, FEV1, or 6-minute walk test between groups (37). In fact, researchers found the 4 cm incision group to have longer operative times and suggested that a smaller incision may risk unnecessary time in the operating room (OR) (37).

Like the randomized trials, meta-analyses comparing uniportal to multiportal VATS approaches also display conflicting evidence. A meta-analysis by Harris *et al.* [2016] concluded that, compared to multiportal VATS procedures, uniportal techniques reduce postoperative pain and paresthesia and improve patient satisfaction (32). Xiang *et al.* [2023] also compared uniportal and multiportal VATS for segmentectomies of NSCLC and found that the uniportal group had shorter length of stay, decreased postoperative pain on day three, and fewer days with chest tube drainage (38). Similarly, Abouarab *et al.* [2018] found that uniportal VATS resulted in less postoperative pain, blood loss, hospital stay, and time of chest tube drainage (39). In contrast, Yan *et al.* [2020] analyzed 20 studies comparing uniportal and multiportal VATS and found no differences in operative time, blood loss, drainage duration, or length of postoperative stay (40).

Muscle sparing thoracotomy and outcomes compared to VATS

The first mention of an MST technique appears in the literature in 1973, where Noirclerc *et al.* described how one could avoid incising the latissimus dorsi muscle (41-43). Many approaches have since been devised; however, the first MST technique accepted as adequate in the resection of major pulmonary tissue was that of American surgeon Karwande in 1989 (44). This technique involves an incision from the anterior axillary line, continuing to the tip of the scapula, and travelling superiorly and posteriorly between the scapula and the spine (45). Skin flaps are then produced using electric cautery along the posterior aspect of the latissimus dorsi, and the latissimus dorsi and serratus anterior muscles are dissected from the chest wall without being incised (45).

Initial randomized trials, including one by Hazelrigg *et al.* [1991], confirmed that those undergoing MST had a decreased perception of pain as opposed to those undergoing standard thoracotomy (46). Another prospective, randomized trial concluded that narcotic usage in the first 24 hours was lower in the MST group when compared to standard posterolateral thoracotomy (47). With the endorsement of VATS approaches for pulmonary resection, a meta-analysis was conducted to see if an MST approach still held any benefits to a thoracoscopic approach (48). Wang *et al.* [2019] evaluated 10 studies with 1,514 patients and concluded that hospital stay, chest tube drainage time, and intraoperative blood loss were all decreased in the VATS group as compared to the MST group, suggesting that VATS may still be the preferred approach (48).

Subxiphoid incisions and their relative outcomes

While VATS approaches are less invasive when compared to thoracotomy, the port placement and removal of specimens through intercostal spaces results in a degree of rib spreading and possible intercostal nerve injury (49). Moreover, in the instance that lung tissue is too large to be removed all at once, the lung may sometimes be required to be removed in pieces (49). To avoid these potential difficulties of intercostal space incisions, subxiphoid approaches have gained attention (49). The theoretical advantages of this approach include reduced chronic and acute pain, as well as the ability to remove larger volumes of tissue without the limitations of the intercostal spaces (49). In this approach, a 3–5 mm incision is made to reveal the xiphoid process, followed by dissection of the Linea alba and blunt dissection above the level of the diaphragm (49). Research has shown that subxiphoid approaches to lung resection can result in decreased pain at 1 and 3 months, as well as an increased reported quality of life, when compared to VATS approaches (50).

It is worth noting that the subxiphoid approach is not without any risks or potential complications. Research by Chen *et al.* [2022] has recently found an increased risk of cardiac arrhythmia in subxiphoid procedures when compared to uniportal intercostal approaches (51). Still, there was less reported pain in the subxiphoid incision group as measured by a numerical rating scale at 24 and 48 hours (51). More prospective trials, preferably randomized controlled trials, are required to further evaluate the oncologic and perioperative outcomes compared to VATS.

Learning curves in MIS

While research has been conducted to standardize the learning curve for various MIS approaches, many experts report a different number of operations required for proficiency. It has been suggested that 50 VATS procedures are required to become sufficient in this technically demanding surgery; however, other experts claim that experienced surgeons can be proficient in this surgery in as little as 20 cases (52,53). A further exploration of the literature reveals that surgeons require anywhere from 18–32 surgeries with the robotic system to achieve proficiency in RATS (54). Andersson *et al.* [2021] suggest that the learning curve for VATS and RATS are similar and, perhaps, less steep for RATS if the surgeon has prior experience in VATS (55). Bedetti *et al.* [2017] suggest that a learning phase of 30 uniportal VATS lobectomies is sufficient to result in reduced conversion rate and complications, such as prolonged air leak, in subsequent surgeries (56).

Although researchers have done well to quantify the learning curve for different MIS techniques, there are several extraneous factors that dictate how long it will take to truly master each procedure. For instance, training programs with higher caseloads allow for trainees to practice this new technique many times in a shorter time frame (52). The learning curve can also be shortened when trainees have a truly deep understanding of the anatomy of the lung and its many anatomical variations (52). In the instance of VATS lobectomies, experience with other VATS procedures such as wedge resections can provide a strong foundation for port placement and help round the learning curve (52). In attaining proficiency of robotic surgery, robotic surgical simulators can be used to improve robotic performance when training surgeons (52). For instance, the da Vinci Skills Simulator provides a specific simulation with step-by-step guidance in performing a robotic lobectomy while providing postoperative feedback (57). It should also be noted that learning curves may differ depending on the lobe being operated on, as one single-center study found 21 uniportal VATS upper lobectomies was sufficient to stabilize operating time, while only 12 were required for lower lobectomy (58).

Strengths and limitations

The main strength of this narrative review is the breadth of minimally invasive techniques that are discussed. To our knowledge, this is the first narrative review that outlines the evolution and outcomes for each of multiportal VATS, uniportal VATS, RATS, MST, and subxiphoid approaches while also speaking to the associated learning curves of certain techniques.

There are fundamental limitations to this narrative review. First, pooled statistical analysis was not conducted and, thus, the relative patient group sizes of the included randomized controlled trials and meta-analyses are not reflected in our interpretations. Further, while our review of the literature focused on lung resections for lung cancer, findings were not stratified by specific type of resection (wedge *vs.* lobectomy *vs.* pneumonectomy *vs.* segmentectomy). Finally, while careful attention was made to include all relevant outcomes from the included articles, not all outcomes were discussed.

Conclusions

Minimally invasive thoracic surgery has expanded rapidly in the last decade. While multiportal VATS was the first MIS to replace open pulmonary resection via thoracotomy, many other approaches have evolved and include RATS, uniportal VATS, and subxiphoid approaches. The end goals of these innovations are multifold and include providing superiority or, at least, equivalence to current methods; improving oncologic efficacy and survival outcomes; ameliorating pain control; reducing length of stay; and reducing the rates of perioperative and postoperative complications.

VATS was the first approach demonstrated to be superior to thoracotomy and revealed myriad advantages at the cost of increasing intraoperative time. These advantages include decreased blood loss, acute and chronic pain reduction, reduced need for post-operative opioids, improved lung function tests, and reduced hospital stay. Since then, RATS has provided improved precision and maneuverability of surgical instruments with a relatively short learning curve. Compared to thoracotomy, RATS provides many of the same advantages as VATS, and may even be superior to VATS in regard to decreased blood loss, lower conversion to thoracotomy, shortened length of stay, and better 5-year disease free survival. While MST is superior to open surgery in reducing post-operative pain, it is still inferior to VATS in many areas. Uniportal VATS and subxiphoid approaches allow for less incisions than conventional VATS; however, further research is needed to confirm if there are true advantages in terms of perioperative and postoperative outcomes.

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Footnote

Reporting Checklist: The authors have completed the Narrative Review reporting checklist. Available at https://vats.amegroups.com/article/view/10.21037/vats-22-63/rc

Conflicts of Interest: Both authors have completed the ICMJE uniform disclosure form (available at https://vats.amegroups.com/article/view/10.21037/vats-22-63/coif). The senior author R.N. has previously received honoraria from Merck and Co. These honoraria are not related to any of the material discussed in this paper. The other author has no conflicts of interest to declare.

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