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Review Article

Technological evolution of uniportal video-assisted thoracoscopic surgery in lung cancer: a comprehensive review

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ABSTRACT

In this review, we will examine how uniportal video-assisted thoracoscopic surgery (U-VATS) compares in the management of non-small cell lung cancer (NSCLC) in terms of effectiveness, safety, and advancements in technology, as supported by recent literature. The change from multiportal techniques to uniportal techniques has expanded the limits of minimal invasiveness in thoracic surgery. In all aspects evaluated in the literature included in this review, U-VATS is comparable to multiportal techniques in postoperative pain, drainage time, and oncologic outcomes. The learning curve criteria set by the ESTS consensus for the safe adoption of U-VATS provides a sound basis for promoting this technique. In essence, Uniportal VATS is an evolving technique that is equally minimally invasive and has great oncologic potential, given advancements in technology.

Keywords: uniportal VATS, lung cancer, minimally invasive surgery, sleeve resection

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Introduction

In the past three decades, the surgical approach to the treatment of NSCLC has witnessed a revolutionary change from the traditional and morbid approach of thoracotomy to the minimally invasive surgical approach. The minimally invasive approach, as described in the early 1990s by Roviaro et al., marked the beginning of a new era in the surgical treatment of thoracic malignancies [1]. Although the approach at the outset used the conventional three- and four-port "multiportal" technique, VATS rapidly gained acceptance as the gold standard in the treatment of early-stage NSCLC due to its proven benefits over the traditional approach of thoracotomy, including reduced postoperative pain, hospital stay, and immunological stress [2-4].

In parallel to the evolution of multi-portal techniques, the trend towards reduced port access was first seen in the early 2000s. While the initial attempt to perform minor video-assisted thoracoscopic surgery (VATS) procedures via a uniportal approach was made by Gaetano Rocco et al. in 2001, thereby indicating a significant learning curve for the specialty, the second landmark was seen in 2011 [5]. Following on from this, Gonzalez-Rivas et al. were successful in proving the viability of performing major pulmonary procedures via a single incision, thereby establishing the term Uniportal VATS (U-VATS) [6]. Although the approach follows the same principles as the traditional approach, U-VATS has proven to be a more refined approach in the treatment of NSCLC, in which the aim is to minimize the trauma and the injury to the intercostal nerves.

Although U-VATS has achieved worldwide popularity, controversy still exists with regard to technical difficulties and oncological outcomes compared with conventional M-VATS. M-VATS allows for a triangulated view with instruments moving parallel to each other within the thoracic cavity, whereas with U-VATS, the surgeon gets a direct cranio-caudal view, similar to that of conventional open surgery. In addition, with all instruments being inserted through one incision, a new set of ergonomics must be mastered by the surgeon, thus creating a steep learning curve. Current meta-analysis and randomized controlled trials involving thousands of patients have shown that U-VATS achieves better results with regard to chest drainage, hospital stay, and postoperative pain, with comparable results with regard to oncological outcomes compared with M-VATS.

The main objective of this review article is to assess the effectiveness of U-VATS in lung cancer surgeries with regard to its clinical outcomes, safety, and oncological adequacy based on recent comparative studies, systematic reviews, and meta-analyses. By combining the short-term benefits of U-VATS without compromising long-term oncological outcomes, this study aims to provide an updated perspective with regard to recent literature.

Uniportal surgical technique and ergonomics

The uniportal video-assisted thoracic surgery (U-VATS) technique marks an advanced level of achievement in the history of thoracic surgery, realized through the consolidation of the multiportal videothoracoscopic technique, which started in the 1990s, into a single incisional approach by 2011. Though initially considered to be more demanding than the multiportal technique in terms of the learning curve, the U-VATS technique provides a surgical view similar to the traditional open thoracotomy approach while offering direct access to the hilar structures. The technique allows for the excellent visualization of the whole hilar area, thus being considered a very effective technique. The major technical problem to be overcome by the surgeon is the problem of instrument collisions, i.e., the passage of the camera system and the instruments through a single incision, called the utility incision. Among the major solutions proposed to overcome this problem is the utilization of special instruments, which are longer and thinner than those used in the traditional VATS approach. These instruments have tips that allow for the manipulation of the instruments in different directions. This feature allows the hands of the operator to be located at a greater distance from the incision, thus reducing the incidence of hand collisions in the extracorporeal area while allowing for the manipulation of several instruments in a small space (Figure 1).

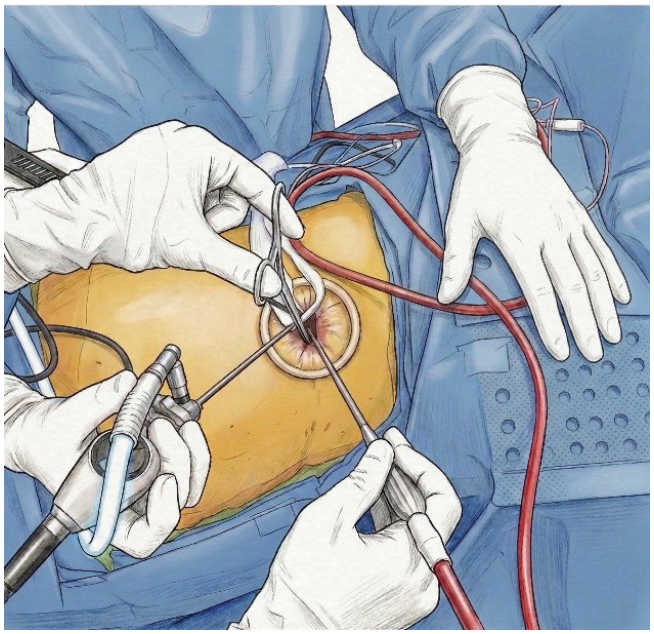


Figure 1. Uniportal video-assisted thoracic surgery.

A further factor in the determination of optimized ergonomics is the hierarchical placement of the instruments within the incision site. To avoid obstruction of the visual field and instrument overlap, the camera is best placed at the most superior (posterior) aspect of the incision site, while the surgical instruments are placed inferior to the camera (anterior). This placement allows for a natural working angle, analogous to the hand-eye coordination phenomenon observed during open procedures. This placement also reduces the fulcrum effect between the instrument's angle of insertion and the hand position. During the dissection of deep hilar structures such as vascular elements and the bronchus, maneuvers that either draw the lung tissue towards or away from the incision site using a cautery device or dissector are particularly useful in improving depth perception and comfort during the procedure. In cases of peripheral nodules, manipulation of the lung tissue towards the incision site allows for digital palpation in some cases, thereby improving diagnostic accuracy.

The use of a stapler in uniportal video-assisted thoracoscopic surgery (U-VATS) requires more sophisticated movements compared to multiportal VATS. To overcome this limitation of using a stapler, the concept of "mobile tissue against a fixed stapler line" is used. Dynamic traction of the lung tissue in the anterior, posterior, or superior direction is used to achieve the desired angle of the vessel or bronchus. This technique helps to align the hilar structures parallel to the stapler line.

In the subxiphoid uniportal approach, a semi-lateral position with a 70° posterior tilt is used with the help of the operating table. The access for the uniportal VATS is obtained through a longitudinal incision in the infrasternal area. After the incision, the rectus abdominis muscle fibers are longitudinally sectioned to access the xiphoid process. Complete excision of the xiphoid process facilitates the approach by providing an optimal view of the surgical area without the need to retract the sternum. After the tunnel is created behind the sternum, the pleural layer is entered under thoracoscopic vision, followed by the placement of a wound protector retractor. To maintain ergonomic positions, a 30° angled 10-mm diameter videothoracoscope is inserted from the caudal (inferior) part of the incision, while the VATS instruments are inserted from the cranial (superior) part of the incision to avoid instrument conflicts (Figure 2).

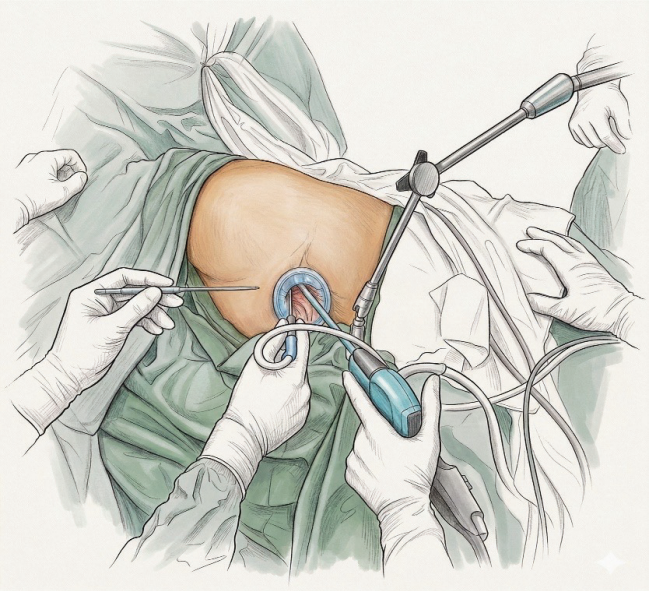


Figure 2. Subxiphoid uniportal approach.

Learning curve

Uniportal video-assisted thoracoscopic surgery (U-VATS) is believed to be technically challenging, as all the surgical manipulations are performed through a single incision. Even for thoracoscopic surgeons familiar with conventional multiportal video-assisted thoracoscopic surgery (M-VATS), the learning curve for the new technique involves improvements in depth perception and management of instrument interference.

The Cumulative Sum (CUSUM) analyses reported in the literature have evaluated the number of cases that need to be performed to acquire technical competence in the new technique of U-VATS lobectomy. The Consensus report from the ESTS Uniportal VATS Interest Group (UVIG) concluded that at least 50 cases need to be performed by the surgeon under mentorship/supervision to acquire competency in the technique of uniportal lobectomy [7]. Nachira et al. reported that the experienced team reached the technical proficiency threshold after 25 cases, with a reduction in the mean operative time from 191 to 164 min ($p = 0.04$) after the threshold cases [8]. Liu et al. divided the learning curve into three stages, with the initial 30 cases being the ascending phase, cases 30 to 60 being the plateau phase, and cases greater than 60 being the proficiency phase, with significant stabilization of the operative time and improvement in surgical safety from cases 30 to 60 [9].

Conversion Rates and Causes of ConversionConversion to open surgery is one of the key parameters used to evaluate the safety of U-VATS and the challenges associ-

ated with its learning curve. Meta-analyses conducted by Yan et al. and Magouliotis et al. demonstrated that there is no statistically significant difference in conversion rates between U-VATS and M-VATS ($p > 0.05$) [3,10]. The main causes of conversion are generally classified as pleural adhesions, calcified lymph nodes, and uncontrollable vascular injuries. Drevet reported that the majority of conversions occur during the first half of the learning curve, emphasizing the importance of surgical experience [11]. Table 1 summarizes the studies related to the learning process of Uniportal VATS.

At the early learning curve stage, particularly within the first 30 cases, the major problem encountered by the surgeon is the stapler's maneuverability. Liu et al. found that during the early learning curve phase, the attempts to insert the stapler had to be repeated in 73% of cases; however, the rate reduced to 5% once proficiency was achieved [9]. Recent research suggests that the learning curve for U-VATS does not have a negative effect on the length of stay and morbidity; the procedure can be safely performed with an appropriate training background.

A series of meta-analyses by Harris et al. has established that U-VATS is as safe as traditional M-VATS while also showing significant advantages in terms of postoperative recovery time [12].

Operative time was initially considered a limitation of U-VATS due to the steep learning curve required for surgeons. Indeed, data reported by Al-Ameri et al. [13] and more recently by Zheng et al. [2] demonstrated that operative times in the uniportal group were longer during the early phases compared with M-VATS. However, large-scale meta-analyses by Yan et al. [10] and Magouliotis et al. [3] have confirmed that as the surgical team's experience increases, this difference diminishes, and no statistically significant difference remains between the two techniques in terms of operative time or intraoperative blood loss.

The Uniportal VATS (U-VATS) method for major pulmonary resections has enjoyed significant popularity in the literature since the publication of the initial large case series by Gonzalez-Rivas et al. This initial study established the premise that the U-VATS method is a highly precise technique in terms of hilar dissection and does not violate any oncological principles [14].

The most consistently reported advantage of U-VATS in the literature is its ability to minimize thoracic tissue trauma, thereby reducing postoperative drainage volume and shortening the length of hospital stay. Nachira et al. demonstrated that these clinical advantages are much more pronounced when compared with open surgery (thoracotomy) [8]. Furthermore, when postoperative complication rates are evaluated, Magouliotis et al. [3] reported that the overall morbidity risk (arrhythmia, air leak, etc.) was significantly lower in the uniportal group compared with the M-VATS group (OR: 0.76), providing strong evidence supporting the safety of the technique (Table 2).

Table 1. Comparison of U-VATS learning curve and conversion data.

Study (Author)	Year	Threshold number of cases for learning	Conversion rate (%)	Key findings
Bertolaccin [7]	2019	50 cases	–	Training standard under mentorship.
Nachira et al. [8]	2018	25 cases	4.3%	Operative time decreases after 25 cases.
Liu et al. [9]	2018	30–60 cases	17% → 2%*	Stapler success increases after the first 30 cases.
Drevet et al. [11]	2016	~90 cases	15%	Rates stabilize after the first 10 months.

**In the study by Liu et al., the change between the first 30 cases and the subsequent 60 cases is presented.*

Table 2. Chronological comparison of perioperative outcomes between U-VATS and M-VATS.

No	Study (Author)	Year	Study Type	Patients (U/M)*	Operative Time	Drainage (Days)	Hospital Stay (Days)
1	Gonzalez-Rivas [14]	2013	Cohort	102 (U-VATS)	154 min (mean)	1.5 vs 2.3	2.5 vs 3.7
2	Harris et al. [12]	2016	Meta-analysis	1815 (total)	Similar	U-VATS <	U-VATS <
3	Al-Ameri et al. [13]	2019	Cohort	122 / 211	147 vs 133 min	2 vs 3	3 vs 4
4	Sihoe et al. [15]	2019	Review	–	Safe	Advantage	Advantage
5	Yan et al. [10]	2020	Meta-analysis	1869 / 2273	Comparable	3.8 vs 4.7	5.6 vs 6.5
6	Magouliotis et al. [3]	2021	Meta-analysis	1469 / 3231	Comparable	U-VATS <	U-VATS <
7	Nachira et al. [8]	2022	Comparative	115 / 115 (Open)	Comparable	4 vs 6	5 vs 8
8	Zheng et al. [2]	2024	Retrospective	60 / 68	U-VATS longer	3.5 vs 4.3	4.8 vs 6.0

** U: Uniportal VATS, M: Multiportal VATS.*

Oncological outcomes

The success of minimal invasive techniques in lung surgery for cancer is not only measured by the quick recovery of patients but also by the strict adherence to oncological principles, including lymph node dissection. One of the concerns regarding the extensive adoption of Uniportal Video-Assisted Thoracoscopic Surgery (U-VATS) for lung cancer has been the adequacy of exposure for all mediastinal stations through a single incision.

In fact, recent meta-analyses have demonstrated that U-VATS is equally effective as multiportal techniques (M-VATS) in lymph node dissection. In fact, in the meta-analysis by Yan et al., which included 20 studies, no significant difference was found between U-VATS and M-VATS in terms of the number of lymph nodes removed, with $p = 0.41$ for the comparison between the two techniques in terms of the total number of lymph nodes removed [10]. Magouliotis et al. have also demonstrated that with the uniportal technique, it is possible to adequately sample lymph nodes in both the hilar and mediastinal regions (N1 and N2) for staging purposes [3]. In their study comparing U-VATS for lobectomy with open thoracotomy, Nachira et al. [8] found that there was no difference in terms of the number of lymph nodes removed between the two techniques, thus demonstrating the oncological radicality of U-VATS for lung cancer surgery.

The ability to clear all the lymph nodes completely is of paramount importance to ensure the accuracy of the disease staging and the administration of adequate adjuvant treatment. The literature has shown that the incidence of upstaging of the lymph nodes with U-VATS is similar to that with M-VATS and even open surgery. The data from the ESTS Uniportal VATS Interest Group have shown that the use of the uniportal technique does not interfere with the en bloc dissection of the mediastinal fatty tissue and the lymph nodes [7].

Moreover, the data regarding the long-term results of U-VATS are emerging. Zheng et al. have shown that there were no significant differences in the rates of recurrence and metastasis between U-VATS and M-VATS during the postoperative period [2]. In the case of early-stage lung cancer, the rates of survival at 3 and 5 years are similar with the use of the conventional technique and the U-VATS, suggesting the oncological safety of the procedure.

Advanced techniques and extended resections

The evolution of Uniportal VATS (U-VATS) has gone beyond the initial indications, which were generally limited to simple resections, and has entered the extended phase, which allows for the execution of complex oncologic procedures safely. In this regard, the execution of bronchial and vascular sleeve resections for centrally located tumors has proven that such procedures can be fully executed in accordance with oncologic principles. Notably, the reliability of Uniportal VATS sleeve resections for locally advanced central-type non-small cell lung cancer (Stage IIB-IIIB) after the administration of neoadjuvant chemo-immunotherapy has been proven. Yang et al. have shown that, despite the fibrosis in the hilar region induced by the immunotherapy, the execution of sleeve resections with the aid of U-VATS has been technically possible and has been associated with satisfactory results with regard to the duration of the surgical procedures and the rates of complications [16]. These advanced techniques, with the simultaneous instrumentation ergonomics of the Uniportal technique, make it possible to avoid pneumonectomy in the case of pulmonary artery involvement.

The subxiphoid approach of the Uniportal SVATS, which has further enhanced the minimally invasive nature of the technique, has revolutionized the management of postoperative pain by avoiding the injury to the intercostal nerves. Studies by Pfeuty et al. and Sezen et al. have shown that the subxiphoid approach offers better perioperative results not only for routine lobectomies but also for complex operations like segmentectomy, which requires anatomical knowledge [17,18]. Sezen et al. have shown that the subxiphoid approach significantly reduces the hospital stay compared to the conventional intercostal approach (3.8 days vs. 4.8 days; $P = 0.004$) and significantly reduces the intensity of early postoperative pain, as measured by the VAS score [19]. One of the major strategic advantages of the subxiphoid approach is the ability to perform operations bilaterally, allowing for the treatment of lesions in both lungs through a single incision. Elkhayat et al. emphasized the advantage of the SVATS technique in improving the efficiency of the surgical procedure, especially for operations like the bilateral pulmonary metastasectomy, which allows for simultaneous access to

both hemithoraces through a single incision, avoiding the need for two separate operations. Thus, the minimally invasive nature of the technique has been taken to the next level by avoiding the need for two separate thoracotomies and the attendant increase in the duration of the surgical procedure [20].

In addition, the minimally invasive nature of the Uniportal VATS technique has been extended to the anesthetic management, as emphasized by Elkhayat and Gonzalez-Rivas, who have shown that the non-intubated (awake) approach to the Uniportal VATS technique could reduce the complications associated with endotracheal intubation and the use of muscle relaxants, allowing for tubeless surgery, which optimizes the recovery process [21]. Thus, the spectrum of operations, from the complex sleeve operations to the bilateral subxiphoid metastasectomy, and the non-intubated approach, clearly demonstrates that the Uniportal VATS technique is a dynamic and ever-expanding field.

Conclusion

In the field of minimal access surgery for lung cancer, Uniportal VATS surgery represents the pinnacle of minimal access surgery that has been achieved over the last decade. The advantage that is most consistently highlighted for U-VATS surgery is that it results in a significant reduction in postoperative pain, as measured by VAS scores, by limiting trauma to one intercostal space. This has significant benefits for postoperative mobilization, adherence to respiratory physiotherapy regimens, shorter durations of postoperative chest drainage, and shorter durations of postoperative stay in the hospital. With regards to lymph node dissection capabilities and nodal staging, which are critical for any oncologic surgery, U-VATS surgery is completely equivalent to multiportal techniques and open surgery. The future of uniportal surgery is likely to be even more closely aligned with advancements in technology and expertise, as represented by robotic uniportal VATS surgery (RUVATS) and advancements in artificial intelligence-based imaging.

In summary, Uniportal VATS surgery is a rapidly evolving field that is capable of providing minimal access surgery without compromising oncologic principles, improving quality of life for patients, and increasing its applications in parallel with advancements in technology.

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Authors' contribution

Both authors contributed equally to the concept, design, supervision, data collection, literature search, writing, and critical review of the manuscript. all authors have read and approved the final version of the manuscript.

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