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Review article

Application of uniportal video-assisted thoracoscopic surgery for segmentectomy in early-stage non-small cell lung cancer: A narrative review

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A B S T R A C T

Uniportal video-assisted thoracoscopic surgery (UVATS) segmentectomy has emerged as an effective approach for managing early-stage non-small-cell lung cancer (NSCLC). Compared to conventional open and thoracoscopic surgeries, this minimally invasive surgical technique offers multiple benefits, including reduced postoperative discomfort, shorter hospital stays, expedited recovery, fewer complications, and superior cosmetic outcomes. Particularly advantageous in preserving lung function, UVATS segmentectomy is a compelling option for patients with compromised lung capabilities or limited pulmonary reserve. Notably, it demonstrates promising oncological results in early-stage NSCLC, with long-term survival rates comparable to those of lobectomies. Skilled thoracic surgeons can ensure a safe and effective execution of UVATS despite the potential technical challenges posed by complex tumor locations that may hinder visibility and maneuverability within the thoracic cavity. This study provided a comprehensive review of the literature and existing studies on UVATS segmentectomies. It delves into the evolution of the technique, its current applications, and the balance between its benefits and limitations. This discussion extends the technical considerations, challenges, and prospects of UVATS segmentectomy. Furthermore, it aimed to update advancements in segmentectomy for treating early-stage NSCLC, offering in-depth insights to thoracic surgeons to inform more scientifically grounded and patient-specific surgical decisions.

1. Introduction

Lung cancer remains one of the primary causes of cancer-related deaths worldwide, with non-small cell lung cancer (NSCLC) being the most prevalent. Surgical resection, particularly lobectomy, has been established as the gold standard treatment for early-stage NSCLC [1]. However, the ongoing advancements in minimally invasive technologies have led to significant shifts in surgical approaches. Among these techniques, uniportal video-assisted thoracoscopic surgery (UVATS) segmentectomy has garnered considerable attention in recent years [2–4].

UVATS segmentectomy stands out as a paradigm for minimally invasive surgery, distinguished by its ability to conserve a large portion of the healthy lung tissue. Unlike lobectomy, which involves a more extensive resection, UVATS segmentectomy is

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meticulously designed to excise only tumor-bearing segments, aiming to strike an optimal balance between oncological effectiveness and lung function preservation [5–7]. The underlying principle is to match the oncological outcomes of traditional lobectomy while reducing the functional impact on the patient. Additionally, UVATS has potential benefits such as reduced surgical trauma, decreased postoperative pain, quicker recovery, cosmetically favorable incisions, and enhanced patient satisfaction [8–10].

The main controversies surrounding UVATS for lung segmentectomy include surgical indications, intraoperative safety and technical difficulty, comparison of effectiveness between segmentectomy and lobectomy, comparison with traditional thoracoscopic surgical methods, identification of intersegmental planes, and the learning curve for UVATS. This study was aimed to provide thoracic surgeons with detailed information about UVATS to enable them to make more scientific and objective choices regarding surgical methods based on the specific clinical characteristics of early-stage lung cancer. Thus, we reviewed the developmental history of UVATS, focusing on its techniques and applications, as well as the advantages and disadvantages of UVATS segmentectomy and its oncological effects to provide future perspectives.

1.1. The development of UVATS segmentectomy

Lobectomy has been the preferred treatment modality for lung cancer for an extended period. However, as our understanding of lung anatomy and surgical techniques has advanced, sublobar resection has emerged as a viable alternative, delivering comparable oncological outcomes in early-stage NSCLC [11]. Sublobar resection involves a segmentectomy and wedge resection. This technique primarily aims to preserve the optimal health of the lung tissue, in order to minimize the impact on lung function, reduce postoperative complications, and maintain the option for future surgical resection in cases of secondary primary lung tumors without compromising the initial lesion treatment. Segmentectomy, guided by precise anatomical considerations, entails meticulous separation of the segmental veins, arteries, and bronchi, facilitating excision of the diseased tissue. Unlike wedge resection, segmentectomy ensures a sufficient margin between the lesion and resection site, thereby reducing the risk of lung tumor recurrence [12].

While open thoracotomy pneumonectomy has been a surgical procedure with a history dating back to the 1930s and 1940s, it is important to note that the historical emphasis within thoracic surgery has predominantly centered on lobectomy rather than segmentectomy. Churchill and Belsey [13] were the first to articulate segmentectomy in their advocacy for the use of tongue segmentectomy for bronchiectasis treatment and championed the bronchopulmonary segment as a surgical unit replacement for the lobe. Over time, the lung segments have gained recognition as distinct anatomical entities. The advent of endoscopic instruments and VATS has propelled minimally invasive techniques to the forefront [14,15]. Specifically, VATS facilitates direct access to the thoracic cavity through small incisions, enabling segmentectomy [16]. With continuous advancements in endoscopic technology, UVATS has gained significant attention for its minimally invasive single-incision approach. Compared to traditional VATS techniques, UVATS maintains a clear field of vision and high precision even in constrained surgical spaces. Moreover, it significantly reduces surgical trauma and postoperative pain, expedites patient recovery, and effectively shortens hospital stays [17]. In 2012, Gonzalez-Rivas et al. [18] pioneered the concept of UVATS anatomical segmentectomy, highlighting its potential to minimize surgical trauma and enhance patient outcomes. This groundbreaking concept sparked a global uptake, with thoracic surgeons performing UVATS segmentectomy procedures [19–22]. Recent research has focused on innovative techniques such as non-intubated UVATS segmentectomy and subxiphoid UVATS segmentectomy, specifically targeting early cell lung cancer, and these approaches have demonstrated excellent long-term results [23,24]. Cumulatively, the evidence supports the safety and practicality of UVATS segmentectomy, showcasing its ability to accommodate more complex and advanced surgical interventions [25].

Several factors have contributed to the development of UVATS segmentectomy. UVATS involves a single small incision, significantly reducing postoperative pain and accelerating recovery compared to traditional surgical methods, thereby substantially shortening hospital stays. Additionally, this technique has shown a lower complication rate, including reduced risks of surgical site infections and postoperative pneumonia, significantly improving overall patient recovery and health status. UVATS segmentectomy also allows for more precise tumor identification and removal while preserving more healthy lung tissue, which is especially important for patients with limited lung function. Advances in technology and the development of new surgical tools have greatly enhanced the safety and effectiveness of this procedure. Consequently, UVATS segmentectomy has gradually gained widespread attention in the treatment of lung cancer and has become an important treatment option.

1.2. Technique and application of UVATS segmentectomy

1.2.1. Identification of pulmonary nodules

Common techniques for identifying pulmonary nodules include preoperative three-dimensional bronchial angiography, computed tomography (CT)-guided localization, bronchoscopic localization, indocyanine green fluorescence staining, and the application of artificial intelligence (AI). Each method offers unique advantages in terms of precision and efficacy and caters to different aspects of nodule detection and surgical planning.

(1) Three-dimensional Bronchial Angiography: Merging 3D-CT with contrast-enhanced angiography, this method offers vital preoperative insights, aids in arterial analysis and bronchial anatomy assessment, and guides segmentectomy [26,27]. However, it is crucial to be mindful of risks, such as contrast agent allergies and possible differences between preoperative and intraoperative findings due to individual anatomical variations.
(2) CT-Guided positioning: CT imaging is instrumental in accurately localizing lesions for needle placement. Various localization materials, such as hookwires, microcoils, color dyes (e.g., methylene blue), fluorescent agents (e.g., indocyanine green), and

lipiodol, have been utilized. Despite its precision, percutaneous puncture carries inherent risks such as bleeding, pneumothorax, and other potential complications [28,29].

(3) Bronchoscopy positioning: Bronchoscopy is adept at identifying nodules near or within airways. Its effectiveness is further enhanced by advanced technologies, such as ultrasound bronchoscopy and virtual electromagnetic navigation, offering reduced trauma and heightened precision. However, this method involves specific patient selection criteria and faces challenges in achieving spatial precision [30,31].

(4) Indocyanine green fluorescence staining: The use of indocyanine green (ICG) fluorescence staining in pulmonary segmentectomy represents a significant technological advancement. This technique guides surgeons in performing meticulous resections, ensuring accurate removal of the targeted segment while conserving adjacent segments and vital structures [32]. Moreover, fluorescence imaging offers additional benefits for confirming resection adequacy and evaluating resection margins. Nonetheless, limitations exist, including diminished contrast in some cases, relatively short effective duration, and possible ICG allergies [33].

(5) AI: AI is revolutionizing thoracic surgery by significantly enhancing the precision in detecting and characterizing nodules within lung segments, thereby improving the effectiveness of segmentectomy procedures [34]. AI achieves this by utilizing specific patient data, such as detailed nodule characteristics and extensive medical histories, to aid surgeons in making informed decisions. Additionally, AI is crucial in the postoperative stage as it facilitates accurate comparisons between preoperative and postoperative images for a comprehensive assessment. However, the application of AI is not without challenges, including limited data availability, the possibility of false diagnoses, and variability in nodule characteristics owing to different ethnic and demographic factors.

1.2.2. Indications of segmentectomy

The application of segmentectomy for the treatment of early-stage peripheral NSCLC remains a subject of ongoing debate within the medical community. The CALGB140503 study [35], an international clinical trial, conducted a comprehensive comparison between sublobar resection and lobectomy for NSCLC, revealing that, specifically for NSCLC tumors with a size of 2 cm or less and negative lymph nodes, no significant disparities were observed in terms of complications and mortality. Remarkably, sublobar resection exhibited superior preservation of lung function compared with lobectomy. Turning our attention to the JCOG0802 study [36], which centered on lung cancer cases characterized by a size of ≤2 cm and a high consolidation-to-tumor ratio, a direct comparison between lobectomy and segmentectomy was made. The findings from this study demonstrated that while segmentectomy improved overall survival, it also exhibited a higher recurrence rate, particularly in terms of local recurrence, than did lobectomy. Interestingly, the lung cancer mortality rates remained comparable between the two groups; however, the lobectomy group exhibited a higher mortality rate related to other malignancies. It is imperative to underscore that for a comprehensive assessment of lung function and long-term prognosis, an extended follow-up period of five years or more is warranted. Furthermore, the JCOG1211 study [37] focused on evaluating the effectiveness of segmentectomy in treating Stage Ia lung cancer characterized by a size of ≤3 cm and a low consolidation-to-tumor ratio, particularly when ground-glass opacity (GGO) was present. The results of this study revealed a notably high 5-year recurrence-free survival rate and a 5-year overall survival rate of 98.0 %. Remarkably, pulmonary function exhibited significant improvements compared with the findings of the JCOG0802 study, particularly at 6- and 12-month post-segmentectomy intervals. Moreover, the perioperative safety profile of the segmentectomy group was favorable. The decision to opt for segmentectomy hinges on a multitude of factors, including the patient's overall well-being, attributes of the lung ailment, and the potential merits of lung conservation. This choice is prompted by several criteria, including [38].

(a) Cases where the patient's functional capacity could not withstand lobectomy.

(b) Peripheral nodules with a tumor diameter of 2 cm or smaller, meeting one of the following conditions: carcinoma in situ, GGO component exceeding 50 %, with extended monitoring demonstrating a doubling time exceeding 400 days.

1.2.3. Precise identification of the intersegmental plane in segmentectomy

Accurate identification of the intersegmental plane is crucial in segmentectomy, particularly in UVATS, to ensure precise removal of the targeted lung segment while protecting nearby healthy tissues. This process involves the careful localization and dissection of specific bronchi, arteries, and veins. Preserving the intersegmental veins and accurately identifying and incising the intersegmental plane are especially vital in lung cancer to achieve proper surgical margins. Inaccuracies in identifying the intersegmental plane may lead to resection of the wrong lung segment or damage to the adjacent tissue, potentially causing complications such as air leaks, pneumonia, hemoptysis, or reduced lung function [39,40].

Several techniques have been proposed to establish an intersegmental plane accurately. Pioneering work by Tsubota et al. [41] introduced the "selectively resected segmental inflation" approach, which departs from conventional inflation-contraction techniques. This method involves isolating the bronchus of the target segment after lung lobe inflation, keeping the resected segment inflated while the retained segment remains vented. Okada et al. [42] introduced a hybrid VATS approach that utilized intraoperative fiberoptic bronchoscopy for selective segmental ventilation, optimizing the surgical field of view. However, this technique places considerable demand on anesthesiologists and can be influenced by patient positioning. Kamiyoshihara et al. [43] adopted a method involving the inflation of the segmental bronchi using a butterfly needle, although this approach carries risks such as air embolism and incomplete ventilation of the resected segment. Oizumi et al. [44] introduced a monofilament slippage knot technique for bronchial ligation and intersegmental plane identification; however, its effectiveness can be affected by factors such as pleural adhesion and emphysema. Wang et al. [45] proposed a "modified inflation-deflation approach," which involves inflating the lung with 100 % oxygen to create a discernible intersegmental plane. Additionally, ICG and methylene blue have been employed as contrast agents for the real-time visualization of intersegmental planes [46,47]. After dissecting and ligating the arteries, veins, and bronchi of the target lung segment, 20 mL of 0.1 % methylene blue was injected slowly (0.2 mL/s) into the target lung segment bronchus using an intravenous needle, or 3–5 mL of ICG (2.5 mg/mL concentration) was injected rapidly through the peripheral vein. However, ICG fluorescence imaging has a short display time and is associated with potential risks. Fu et al. [48] advocated a straightforward arterial ligation method to ascertain the intersegmental plane during segmental resection, aiming to prevent inadvertent cutting of the preserved bronchi and veins in subsequent operations. Furthermore, Zhang et al. [49] proposed unidirectional occlusion of the pulmonary circulation for intersegmental plane recognition, achieving promising results through the targeted occlusion of the pulmonary arteries or veins during surgery.

1.3. Advantages and drawbacks of UVATS segmentectomy for early-stage NSCLC

UVATS segmentectomy is a cutting-edge, minimally invasive surgical method that involves removing specific lung segments through a single incision of approximately 3–4 cm, offering a multitude of benefits compared to traditional thoracoscopic or open surgeries.

(1) Reduced Intraoperative Blood Loss: Studies indicate that UVATS is associated with significantly less intraoperative blood loss compared to multiportal approaches. Chen et al. indicated that patients undergoing UVATS experienced lower average blood loss than those undergoing three-port VATS [50].
(2) Shorter Operative Times: The evidence on operative times is somewhat mixed. Meta-analyses show no significant differences in operative times between UVATS and multiportal VATS [51], while Cheng et al. suggest that uniport VATS showed less blood loss, a shorter duration of postoperative drainage [52].
(3) Reduced Trauma and Pain: This technique causes significantly less tissue and muscle damage, resulting in markedly lower postoperative pain due to minimized nerve stimulation and inflammatory responses [53]. Tian and colleagues found that uniportal VATS for anatomical segmentectomy is not only safe and feasible, but compared to traditional VATS, this method can reduce postoperative pain and minimize surgical trauma [54].
(4) Quicker Recovery and Shortened Hospitalization: The small incision and minimal tissue disruption inherent to UVATS segmentectomy facilitate a more rapid recovery process and decrease the risk of postoperative complications, leading to a notably reduced hospital stay for patients. Chen et al. utilized the Propensity score matching (PSM) method to compare the perioperative outcomes of uniportal versus multiportal VATS segmentectomy. The study revealed that after PSM adjustment, the uniportal VATS approach significantly reduced postoperative drainage time and hospital stay [55].
(5) Superior Cosmetic Outcome: The discreet, small incision limits muscle and tissue disruption, which not only diminishes the risk of postoperative infections but also results in less noticeable scarring, thereby enhancing cosmetic results for patients. By comparing UVATS with two-port and three-port VATS, Wang et al. observed that the UVATS approach offers superior cosmetic effects at the incision site and facilitates a quicker postoperative recovery [56].
(6) Preservation of Lung Function: By precisely targeting the affected lung segments while conserving healthy tissue, UVATS segmentectomy is especially advantageous for patients with pre-existing lung conditions or compromised respiratory function, reducing the likelihood of complications such as pulmonary infections and respiratory distress [57]. Wang and colleagues noted that patients undergoing UVATS segmentectomy experience less postoperative pain, better recovery of lung function, and higher quality of life [58].
(7) Optimized Visual Clarity: The unique single-port approach of UVATS segmentectomy provides surgeons with an unobstructed, direct view of the operative field, significantly improving the precision of tumor resection and dissection. This method effectively eliminates complications related to torsion or dihedral angles, often encountered in conventional multiport thoracoscopic surgeries [7].

Although UVATS has numerous advantages, it also has drawbacks and challenges. First, it is imperative to emphasize that this technique may not be applicable to all patients. This technique can pose challenges in cases characterized by intricate anatomical features, such as lung segments situated deep within the pulmonary parenchyma or those with complex vascular and bronchial structures. Secondly, there are limitations associated with the surgical instruments used in UVATS segmentectomy. In contrast to conventional VATS or thoracotomy approaches, the confined space of a single incision can lead to instrument conflict, thereby restricting the range of motion and maneuverability of instruments. Third, it is crucial to underscore the need for specialized skills and training in UVATS segmentectomy. The associated learning curve can pose a challenge, potentially impeding the widespread adoption of this technique and increasing the likelihood of complications, particularly in the early stages. Fourth, there exists the possibility of incomplete resection in UVATS segmentectomy. The inherent constraints of this approach may increase the risk of residual tissue, particularly when managing tumors located in challenging or hard-to-reach anatomical areas. Fifth, it is essential to acknowledge the presence of an element of uncertainty concerning nodal staging in UVATS segmentectomy. This approach may offer a more limited assessment of nodal involvement than lobectomy, potentially introducing ambiguity into the staging of the lymph nodes. Sixth, it is worth noting that the availability of UVATS segmentectomy is limited. The adoption of single-port surgery necessitates access to specialized instruments and training. Unfortunately, not all surgical centers possess the required resources or expertise to perform UVATS, thereby reducing its widespread availability. Finally, it is crucial to recognize the potential necessity for conversion to open surgery. Situations characterized by procedural complexities or unexpected challenges may mandate a transition from UVATS segmentectomy to an open surgical approach. These conversions can result in increased postoperative discomfort and extended recovery periods.

1.4. Surgery technique of UVATS segmentectomy for early-stage NSCLC

For UVATS segmentectomy, the patient is placed in the lateral decubitus position and intubated with a double-lumen endotracheal tube for general anesthesia. The surgeon and assistant stand on the abdominal and dorsal sides of the patient, respectively. The surgical instruments used in the single-port approach are similar to those used in conventional VATS, including double-jointed long-curved endoscopic instruments, curved aspirators, and a high-resolution 30° thoracoscope. A skin incision of about 3.0–4.0 cm is made in the fourth or fifth intercostal space along the anterior axillary line, where an incision protector is placed. The thoracoscope is usually positioned in the upper channel, whereas the instruments are placed in the lower channel. The positions of the thoracoscope and instruments can be flexibly changed. The intersection of all instruments after insertion should be as close to the incision site as possible to avoid mutual interference and combat, which affect the actual operating experience and increase the difficulty of the surgery. Initially, the entire pleural cavity is examined, followed by the use of an electrocautery hook to remove adhesions. The surgical procedure involves the individualized anatomy of the target segment, veins, arteries, and bronchi. Moreover, an automatic stapler is used to sever blood vessels and bronchi. For small vessels, ligation with silk sutures and division with an ultrasonic scalpel is used. If intraoperative frozen pathology suggests lung cancer, mediastinal lymph node sampling or dissection is performed.

Performing a UVATS segmentectomy for early-stage NSCLC involves several technical considerations.

(1) Patient selection: A meticulous evaluation of variables encompassing tumor location, dimensions, and adjacency to vital anatomical entities, such as major vasculature and bronchial structures, coupled with the patient's holistic medical condition, assumes paramount significance in ascertaining procedural suitability.
(2) Preoperative planning and imaging examination: When tumors are located deep in the lung or close to major blood vessels and bronchi, precisely locating the tumor and ensuring adequate resection margins present significant challenges. Utilizing 3D-CT scans aids in visualizing the lung anatomy, blood vessels, and bronchial structures, enabling accurate localization of the target segment for resection while also identifying any potential anatomical variations.
(3) Tumor localization: For small tumors that cannot be directly seen or palpated, tumor localization technologies help ensure that the tumor is completely removed while preserving as much normal lung tissue as possible. A spectrum of methodologies for tumor localization can be harnessed, encompassing preoperative CT-guided markers, intraoperative ultrasound, or advanced image-guided techniques such as electromagnetic navigation and indocyanine green staining.
(4) Instrument selection: Since UVATS is performed through a single small incision, it limits the operational space and angle of the surgical instruments, especially in narrow or complex surgical areas. Procurement of specialized tools, including a 30° thoracoscope, extended dissector, stapling devices, and energy instruments.
(5) Incision location: Judicious choice of the incision site holds critical significance in achieving optimal access to the target lung segment. Generally, the fourth or fifth intercostal space of the anterior axillary line is selected. This not only facilitates precise instrument manipulation but also safeguards neighboring structures from inadvertent injuries.
(6) Anatomy and hemostasis: A comprehensive understanding of the pulmonary anatomy is paramount, coupled with meticulous ligation of the segmental bronchi, arteries, and veins to avoid hemorrhage and ensure complete resection of the pulmonary segment. Depending on the clinical scenario, vascular staplers, clips, or ligatures can be used to isolate vessels and bronchial structures safely.
(7) Lymphadenectomy or sampling: Assessment of lymph nodes is a pivotal aspect of surgical procedures. Lymph nodes situated within the drainage territory of the segment must undergo either dissection or sampling, with subsequent pathological analysis aimed at identifying potential metastatic involvement.
(8) Conversion to open surgery: Surgeons must maintain readiness to transition to open surgical approaches when confronted with technical complexities or complications such as intraoperative vascular variation and uncontrollable bleeding, which cannot be adequately resolved through the single-port approach. Conversion of UVATS to thoracotomy can lead to elevated surgical risks and complications. These factors include an increased likelihood of infection, bleeding, respiratory or circulatory difficulties, and impaired lung function. Additionally, this procedure typically results in extended operative and recovery times, increased postoperative pain and discomfort, and more pronounced scarring from the incisions.
(9) Surgeon expertise and training: Due to the limited access and space provided by a single incision, surgeons may encounter difficulties in manipulating instruments, which requires high technical skill and experience. Mastering thoracoscopic surgical techniques, particularly the uniportal approach, is crucial. The learning curve for this procedure is generally divided into initial and proficiency stages. Recent studies [59] suggest that a minimum of 50 operations are required to become familiar with UVATS lung segment resection and achieve high-quality surgical outcomes. Furthermore, the guidance and proper supervision of experienced surgeons [60], as well as effective teamwork, are integral to this learning process. Surgeons should also engage in comprehensive training programs, learn from surgical videos and animal experiments, and continuously refine their skills to enhance their proficiency in advanced surgical techniques. Currently, notable contributions in UVATS segmentectomy have been made by Professors Gonzalez-Rivas D, Qun Wang, and Lunxu Liu, among others. By following established learning pathways, surgical proficiency can be significantly enhanced.

1.5. Oncological efficacy of UVATS segmentectomy for early-stage NSCLC

The oncological efficacy of UVATS in the management of early-stage NSCLC is of paramount importance. Studies have demonstrated that UVATS yields oncological outcomes comparable to those of conventional VATS. The study conducted by Zhou et al. [61] provided compelling evidence that UVATS segmentectomy can yield comparable OS and progression-free survival outcomes when patients are appropriately selected. These findings underscore the robust capacity of UVATS to manage cancer effectively in patients with early-stage NSCLC. Chan et al. [62] showed that the 5-year recurrence-free survival (68.6 % vs. 75.8 %) and overall survival (57.8 % vs. 61.0 %) were similar after segmentectomy vs lobectomy in patients with clinical T1cN0M0 NSCLC. Furthermore, a recent study by Gioutsos et al. [63] investigated the clinical and oncological outcomes after single-port anatomical segmentectomy for stage IA NSCLC and showed that the 3-year overall survival rate was 87.9 %, with 90.5 %, 93.3 %, and 70.1 % in groups IA1, IA2, and IA3, respectively. This technique has good short-term clinical efficacy and a low incidence of postoperative complications (within 30 days). In the context of resection margins and lymph node dissection, UVATS segmentectomy excels in achieving tumor removal with negative resection margins while also ensuring a thorough assessment of lymph nodes [64]. Studies conducted by Xiang et al. [65] consistently demonstrated that UVATS achieves OS and disease-free survival outcomes that closely resemble those obtained with multiportal VATS. Notably, UVATS is most suitable for patients with small peripheral tumors, intact pulmonary anatomy, and no evidence of lymph nodes or distant metastases. In addition, Sachs and colleagues compared the early postoperative clinical outcomes of 833 patients (232 undergoing segmentectomy and 601 undergoing lobectomy) and confirmed that the outcomes of UVATS segmentectomy were similar to those of lobectomy [66]. Currently, there is no direct literature evidence supporting the comparison of long-term survival rates between UVATS segmentectomy and lobectomy for the treatment of NSCLC. Therefore, more clinical trials are needed to further investigate this issue. Consequently, the decision to proceed with UVATS necessitates a comprehensive evaluation of the patient's overall health status and tumor characteristics.

1.6. Future prospects and outlook

UVATS has gained widespread recognition because of its minimal invasiveness, characterized by a small incision, negligible postoperative pain, and a brief hospital stay. Its potential applications are expanding, encompassing not only NSCLC but also a variety of other pulmonary conditions such as tuberculosis, diverse lung tumors, and infections. The ongoing development of surgical instruments and methods has significantly enhanced the accuracy and safety of UVATS. In particular, the emergence of robot-assisted UVATS has infused a new life into surgical practice. Advances in this technology, leveraging the precision and flexibility of robotics, have enhanced the capabilities of UVATS, making complex surgeries more manageable and minimally invasive. With precise manipulation and improved visual capabilities, robotic systems enable surgeons to perform delicate operations through smaller incisions, not only shortening patient recovery time but also potentially improving surgical outcomes. In their comparative study, Zhou et al. [67] demonstrated a reduced rate of perioperative complications and mortality in robotic segmentectomies, highlighting the efficacy of robotic platforms in executing complex anatomical segmentectomies. Gonzalez-Rivas explored the techniques and skills related to uniportal robot-assisted thoracic surgery and confirmed that robot-assisted UVATS segmentectomy is feasible [68]. Electromagnetic navigation Bronchoscopy (ENB)-guided UVATS is a rapidly emerging technique that combines UVATS with image navigation technology to produce an intricate three-dimensional lung map. This map accurately directs the bronchoscope to a specific lung segment, enabling surgeons to excise only the affected area while conserving the healthy lung tissue. This method not only enhances surgical safety and effectiveness but also minimizes patient recovery time and postoperative discomfort. Shi et al. emphasized the efficacy of this technique [69] in their study on the learning curve for preoperative ENB-assisted lung lesion localization. Furthermore, Zeng et al. [70] confirmed the safety and accuracy of localizing pulmonary nodules using methylene blue staining guided by ENB. Future research should delve deeper into the combination of ENB with UVATS segmentectomies. With the continuous evolution of these innovative techniques, the safety and efficacy of UVATS segmentectomy are expected to increase.

2. Conclusions

With improvements in imaging and surgical techniques, UVATS segmentectomy is expected to become a key method in thoracic surgery, especially for early-stage NSCLC. It offers benefits such as smaller incisions, less postoperative pain, shorter hospital stays, and faster recovery. However, it is crucial to conduct more comprehensive, high-quality clinical studies to evaluate the differences in clinical outcomes and oncological metrics between UVATS, open surgery, traditional VATS, and robot-assisted UVATS segmentectomies. Understanding the learning curves associated with these surgical techniques is equally important. Furthermore, advances in techniques, such as fluorescent staining and ENB, are likely to enhance the role of UVATS segmentectomy in treating early-stage NSCLC.

Ethics declarations

Review and/or approval by an ethics committee was not required for this study because it was a literature review and did not address the ethical considerations of animal, cell, and human experimentation.

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Data statement

No data was used for the research described in the article.

CRediT authorship contribution statement

Linlin Wang: Writing – review & editing, Writing – original draft, Conceptualization. **Jiandong Cao:** Writing – review & editing, Supervision. **Yong Feng:** Writing – review & editing, Supervision. **Renxiang Jia:** Writing – review & editing, Supervision. **Yi Ren:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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