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MOLECULAR AND CLINICAL ASPECTS OF VIDEO-ASSISTED THORACOSCOPIC SURGERY FOR PERIPHERAL LUNG TUMORS

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ABSTRACT
The article examines the molecular and clinical features of video-assisted thoracoscopic surgery for peripheral lung tumors. VATS has become well established in the treatment of early-stage non-small cell lung cancer: the method allows anatomical resections to be performed through a low-trauma approach while maintaining the required oncological radicality. The epidemiological features of peripheral lung tumors are considered, including their more frequent detection at early stages due to the expansion of low-dose CT screening programs. The advantages of VATS over thoracotomy are analyzed separately: lower intraoperative blood loss, less pronounced postoperative pain, shorter hospitalization, and faster patient recovery. Modern types of anatomical resections are also discussed, including lobectomy, segmentectomy, sublobar resections, and wedge resections. Their role in small peripheral tumors less than 2 cm in diameter is shown. Methods of intraoperative navigation and localization of peripheral lesions are described, including CT-guided navigation, dye marking, hook wire placement, microcoils, and electromagnetic navigation bronchoscopy. Accurate localization of small and non-palpable nodules makes VATS resections safer: it reduces the probability of conversion and makes it possible to preserve a larger volume of functioning lung tissue. The molecular aspects of modern lung cancer therapy are considered separately, including the pathological response after neoadjuvant immunotherapy and the importance of targeted removal of the residual tumor focus. The presented data show that further development of VATS will be associated with the introduction of 3D modeling, fluorescence navigation, robot-assisted systems, and more precise selection of surgical tactics for each patient. Video-assisted thoracoscopic surgery remains one of the main areas of minimally invasive cardiothoracic surgery in the treatment of peripheral lung tumors.

KEYWORDS: video-assisted thoracoscopic surgery, VATS, peripheral lung tumors, non-small cell lung cancer, anatomical resection, intraoperative navigation, minimally invasive cardiothoracic surgery.

INTRODUCTION

Lung cancer remains one of the most common forms of malignant neoplasms and a leading cause of cancer-related mortality in many countries worldwide [1]. According to current oncological statistics, the disease is characterized by consistently high incidence and mortality rates, which defines its importance as a serious medical and social problem [2–5]. Peripheral lung tumors are quite common; many of them are now detected at early stages due to the expansion of screening programs and the wide availability of low-dose CT. Surgery remains the main method of radical treatment for early-stage lung cancer. International guidelines, including NCCN and ESMO, generally give preference to minimally invasive anatomical resections in patients with early-stage non-small cell lung cancer, provided there are no contraindications [6].

Over the past decades, minimally invasive technologies have significantly changed approaches to lung surgery. Video-assisted thoracoscopy (VATS) has taken its place in clinical practice: it allows anatomical resections to be performed through small incisions rather than through a large surgical wound [7, 8]. VATS has expanded the indications for organ-sparing interventions in peripheral tumors and has reduced surgical trauma compared with thoracotomy. VATS lobectomy and segmentectomy are usually associated with less pain, shorter hospitalization, and faster patient recovery [9, 10].

Further development of minimally invasive cardiothoracic surgery is closely linked to robotic systems, which make it possible to perform more precise dissection in areas where manual movements may be less stable. Interest is also shifting toward outcomes that better reflect the patient's actual recovery, not only the course of the operation itself but also how the patient lives afterward. One of the most illustrative indicators is days alive and out of hospital (DAOH), which reflects the number of days a patient spends outside the hospital after surgery [11, 12]. This measure combines length of hospitalization, readmissions, and mortality; although it may not cover every aspect of recovery, it provides a much broader picture of postoperative outcomes.

At the same time, an important problem remains unresolved: how to accurately localize small peripheral lung tumors during minimally invasive procedures. During VATS, deeply located and non-palpable nodules are often neither visible nor tactilely detectable, which complicates the choice of resection volume [13, 14]. Various marking techniques have been proposed, including dyes, hook wires, and microcoils placed under computed tomography guidance. These methods are useful, but not ideal: procedure invasiveness, additional stages of patient preparation, and the risk of marker displacement remain significant limitations.

In recent years, navigation technologies have been actively studied, including electromagnetic navigation bronchoscopy, which makes it possible to localize nodules directly in the operating room [15]. Data on its safety and effectiveness are accumulating, although they remain limited. The question is whether the available evidence is sufficient for confident conclusions. The aim of this review is to summarize and critically assess current possibilities of video-assisted thoracoscopic surgery in the treatment of peripheral lung tumors in cardiothoracic practice, as well as to evaluate prospects for further development of minimally invasive technologies and their clinical application.

Epidemiology and Clinical-Biological Features of Peripheral Lung Tumors

Lung cancer remains one of the most common malignant neoplasms and ranks among the leading causes of cancer-related mortality worldwide. According to international epidemiological studies, millions of new cases are diagnosed each year, which determines the high medical and social significance of this disease. A substantial proportion of tumors are located in the peripheral parts of the lung parenchyma, where they may remain asymptomatic for a long time and are often detected incidentally during radiological examinations. In clinical practice, such lesions are most often represented by adenocarcinomas and other types of non-small cell lung cancer, which have specific features of growth, staging, and surgical treatment.

In recent years, considerable attention has been paid to early lung cancer detection programs based on low-dose computed tomography. Large randomized studies have shown that regular screening in high-risk patients contributes to the detection of tumors at early stages and is associated with reduced mortality. Under conditions of early diagnosis, the role of surgical treatment increases, as it remains the main method of radical therapy for localized forms of the disease. In cardiothoracic surgery, minimally invasive lung resections are becoming increasingly important. Video-assisted thoracoscopy, for example, makes it possible to perform anatomical resections for peripheral tumors with less surgical trauma and a more favorable postoperative recovery [9, 11].

Epidemiological studies show marked regional variability in lung cancer incidence, which is usually related to the prevalence of smoking and local environmental risk factors. In several developed countries, incidence rates have declined, but the disease still remains one of the leading causes of cancer mortality in both men and women. Frequent late diagnosis largely explains low survival rates, especially in advanced stages [16–22]. When the disease is detected at an early stage and surgery is performed in time, the prognosis improves significantly.

The development of modern surgical technologies has expanded the possibilities for treating peripheral lung tumors. Video-assisted anatomical resections, including lobectomy and segmentectomy, are now being actively introduced; in terms of oncological effectiveness, they are comparable to traditional thoracotomy, while causing substantially less trauma. Clinical studies show that the use of VATS is associated with fewer postoperative complications, shorter hospitalization, and improved quality of life [23–25]. Russian studies also confirm that videothoracoscopic interventions in lung resections are safe and effective, with early outcomes appearing more favorable than those after open surgery [1, 5]. The key factor is the combination of early diagnosis and minimally invasive technologies, which creates new practical opportunities for effective treatment of peripheral tumors. The main question is how quickly and effectively these methods can be transferred into broad clinical practice.

The Role of Surgical Treatment in Modern Lung Cancer Therapy

Surgical treatment remains the main therapeutic method for non-small cell lung cancer, especially in the early stages of the disease [26–28]. According to the review by Sakoda L.C. and Henderson L.M. [29], the introduction of low-dose computed tomography screening programs over the past decade has increased the detection of early-stage lung cancer by more than 20–30%. This has been accompanied by a growing number of patients with peripheral tumors less than 2 cm in diameter who may be suitable for surgical resection. Early tumor detection has a major impact on prognosis: in stage I disease, five-year survival may exceed 70–80%, whereas in advanced stages this rate does not exceed 10–15%. Therefore, optimization of surgical strategy and the search for less traumatic but oncologically effective operative methods are becoming increasingly important [21].

One of the key directions in improving lung cancer surgery has been the introduction of minimally invasive technologies. The transition from traditional thoracotomy to video-assisted thoracoscopic procedures has made it possible to significantly reduce surgical trauma and improve postoperative recovery. Thus, the study by Porkhanov V.A., Danilov V.V., Polyakov I.S., Kononenko V.B., Zhikharev V.A., and Krygin S.A. [4] showed that video-assisted and robot-assisted lobectomies are associated with a lower rate of postoperative complications and shorter hospitalization. Similar results were obtained in the multicenter study by Kent M.S., Hartwig M.G., Vallieres E. et al. [7], which included 5,721 patients and found that minimally invasive procedures reduced hospital stay by an average of 1.5–2 days and decreased complication rates by 15–20% compared with open surgery.

Additional evidence supporting the advantages of the thoracoscopic approach is presented in clinical studies comparing different surgical techniques. In the study by Atyukov M.A., Zemtsova I.Yu., Petrov A.S., Zhemchugova-Zelenova O.A., and Yablonsky P.K. [1], VATS was associated with lower intraoperative blood loss and faster postoperative recovery. In particular, average blood loss during video-assisted thoracoscopic surgery was approximately 150–200 ml, whereas during thoracotomy it reached 300–400 ml. In addition, hospitalization after VATS resections usually lasts 5–7 days, compared with 8–10 days after open procedures, which represents a clinically noticeable difference.

Along with resection, adequate systematic lymphadenectomy is required to ensure oncological radicality. In the study by Skorokhod A.A., Petrov A.S., Nefedov A.O., Kozak A.R., Atyukov M.A., and Yablonsky P.K. [5], video-assisted mediastinal lymphadenectomy allowed removal of an average of 10–15 lymph nodes from several mediastinal stations, which is sufficient for complete disease staging. Additional safety aspects of thoracoscopic procedures are reflected in the work of Akhmadullin M.R., Vasiliev Ya.I., Marova N.G., and Koryachkin V.A. [3]. In their prospective randomized study, erector spinae plane block reduced postoperative pain intensity by 2–3 points on the visual analogue scale and decreased the need for opioid analgesics in the early postoperative period.

These clinical findings are also supported by international studies evaluating the long-term oncological effectiveness of different types of lung resections. In the study by Altorki N., Wang X., Kozono D. et al. [15], which included 697 patients with stage IA peripheral non-small cell lung cancer, five-year recurrence-free survival after sublobar resection was 63.6%, compared with 64.1% after lobectomy. Overall five-year survival reached 80.3% and 78.9%, respectively. A systematic analysis of minimally invasive procedures performed by Pan J.M., Watkins A.A., Stock C.T. et al. [9] also showed comparable overall survival and recurrence rates between VATS procedures and traditional thoracotomy. Thus, the accumulated evidence indicates that video-assisted thoracoscopic surgery provides not only better perioperative outcomes but also comparable oncological effectiveness in the treatment of peripheral lung tumors (Table 1).

Table 1: Key studies on video-assisted thoracoscopic surgery (VATS) for lung cancer

Authors	Year	Sample size	Surgical method	Main results
Atyukov M.A., Zemtsova I.Yu., Petrov A.S., Zhemchugova-Zelenova O.A., Yablonsky P.K. [1]	2024	Clinical series of patients undergoing anatomical resections	VATS vs thoracotomy	Blood loss was approximately 150–200 ml with VATS versus 300–400 ml with thoracotomy; hospitalization lasted 5–7 days versus 8–10 days.
Skorokhod A.A., Petrov A.S., Nefedov A.O., Kozak A.R., Atyukov M.A., Yablonsky P.K. [5]	2021	Patients after mediastinal lymphadenectomy	Video-assisted mediastinal lymphadenectomy	An average of 10–15 lymph nodes were removed from mediastinal stations; the technical feasibility of the method was confirmed.
Ryabov A.B., Pikin O.V., Glushko V.A. et al. [2]	2022	Patients older than 75 years	Surgical treatment of lung cancer	The possibility of radical resections in elderly patients was confirmed with proper patient selection.
Akhmadullin M.R., Vasiliev Ya.I., Marova N.G., Koryachkin V.A. [3]	2025	Prospective randomized study	Regional anesthesia during VATS	Erector spinae plane block reduced pain by 2–3 points on the VAS and decreased the need for opioids.
Kent M.S., Hartwig M.G., Vallieres E. et al. — PORTaL study [7]	2023	5,721 patients	Open, VATS, and robot-assisted lobectomy	Minimally invasive procedures reduced complications by approximately 15–20% and shortened hospitalization by 1.5–2 days.
Altorki N., Wang X., Kozono D. et al. [15]	2023	697 patients	Sublobar resection vs lobectomy	Five-year recurrence-free survival was 63.6% versus 64.1%; overall survival was 80.3% versus 78.9%.
Pan J.M., Watkins A.A., Stock C.T. et al. [9]	2024	Review of clinical studies	VATS and RATS	Comparable survival and lower postoperative trauma compared with thoracotomy were confirmed.
Sakoda L.C., Henderson L.M. [29]	2025	Review of screening programs	Low-dose CT screening	Detection of early-stage lung cancer increased by 20–30%; five-year

				survival in stage I disease reached 70–80%.

Table 1 shows that minimally invasive technologies are being used increasingly often in lung cancer surgery. Their clinical efficacy and safety have been confirmed. The development of video-assisted thoracoscopic surgery and the introduction of new technological solutions are of particular interest, as they make operations more precise and support oncological radicality. The key question remains how quickly these innovations can be integrated into routine clinical practice.

Development and Modern Technologies of Video-Assisted Thoracoscopic Surgery

The emergence of video-assisted thoracoscopic surgery (VATS) became a turning point in the treatment of lung cancer: minimally invasive technologies entered thoracic surgery and changed the approach to operative treatment. The first clinical reports on VATS lobectomy appeared in the early 1990s, after which the method gradually became widely used due to reduced surgical trauma and improved perioperative outcomes. At present, most anatomical lung resections for early-stage non-small cell lung cancer are performed using minimally invasive techniques; according to large registry data, more than 80% of lobectomies and segmentectomies are carried out with VATS or robot-assisted technologies.

The technical basis of the method involves performing anatomical resection through several small intercostal ports without rib spreading, which reduces postoperative pain and decreases trauma to the chest wall [30]. As a rule, 2–4 ports with a diameter of 5–12 mm and one auxiliary incision of approximately 3–5 cm are used for specimen extraction, while visualization of the operative field is provided by a high-resolution video camera with a 30° viewing angle. Comparative studies show that intraoperative blood loss during VATS lobectomy averages 100–200 ml, whereas in open thoracotomy it may reach 300–500 ml, and the average length of hospitalization is reduced to 4–6 days.

With the development of the technology, different variants of thoracoscopic procedures have been proposed, including multiport and uniportal VATS. In the uniportal approach, the operation is performed through a single incision approximately 3–4 cm long, usually in the IV–V intercostal space along the anterior axillary line, through which both the camera and surgical instruments are introduced. In a comparative study by Zhang K., Liu W., Zhao Y. et al. [26], which included patients with non-small cell lung cancer, uniportal VATS was associated with less pain and faster recovery of functional activity compared with multiport robot-assisted surgery, while postoperative complication rates were comparable.

In parallel with the development of thoracoscopy, robot-assisted thoracoscopic surgery (RATS) was introduced in the early 2000s. This method is based on the use of a robotic platform with three-dimensional visualization and articulated instruments. The robotic system provides 10–12-fold magnification of the operative field, eliminates physiological hand tremor, and allows more precise dissection of vascular-bronchial structures and mediastinal lymph nodes. According to clinical series, median blood loss during robot-assisted resections is approximately 20–50 ml, the average length of hospitalization is 2–4 days, and the conversion rate to thoracotomy does not exceed 8–10%.

VATS is increasingly moving toward the refinement of anatomical sublobar resections, including segmentectomy and even subsegmentectomy; the main idea is to operate more precisely while preserving lung function. In the study by Dai W., Chang S., Pompili C. et al. [21], which compared thoracoscopic segmentectomy and lobectomy for peripheral non-small cell lung cancer less than 2 cm in size, segmentectomy was associated with better early patient-oriented outcomes and faster recovery of physical activity, with comparable oncological effectiveness.

Modern technological tools, including three-dimensional visualization, indocyanine green fluorescence navigation, and preoperative 3D modeling of pulmonary vascular anatomy, improve the accuracy of segmental resections. Intraoperative fluorescence navigation with indocyanine green during segmentectomy allows clearer identification of intersegmental borders, more accurate resection, and reduced risk of vascular injury. These technologies make the planes between segments more precise and lower the risk of damage to vascular structures, which is especially important when removing small peripheral tumors. This approach helps preserve more lung tissue and reduce the number of complications. Further development of minimally invasive methods and improvement of surgical equipment continue to expand the possibilities of video-assisted thoracoscopic surgery in lung cancer treatment.

Video-Assisted Anatomical Resections for Peripheral Lung Tumors

Video-assisted anatomical lung resections are now regarded as an important tool in the treatment of peripheral tumors, especially in the early stages of non-small cell lung cancer. Accumulated clinical data show that operations performed through small incisions provide comparable oncological radicality with less surgical trauma. This is expected. The study by V.A. Porkhanov, V.V. Danilov, I.S. Polyakov, V.B. Kononenko, V.A. Zhikharev, and S.A. Krygin [4] analyzed the results of video-assisted thoracoscopic and robot-assisted lobectomies. The authors showed that the use of minimally invasive technologies is associated with lower intraoperative blood loss and a reduced rate of postoperative complications compared with open thoracotomy, while the average length of hospitalization was about 4–6 days, compared with 6–8 days after open procedures.

Lobectomy remains one of the most common types of anatomical resection and is traditionally considered the “gold standard” for the treatment of early-stage non-small cell lung cancer. However, in recent years, increasing attention has been paid to sublobar resections, primarily segmentectomy, especially for small peripheral tumors less than 2 cm in diameter. In the study by S. Shiono, M. Endo, H. Watanabe et al. [13], which compared lobectomy and sublobar resections in patients with PET/CT-detected hypermetabolic stage IA lung cancer, lobectomy was shown to provide more favorable long-term outcomes. In particular, overall survival rates were higher after lobectomy, whereas the rate of local recurrence after sublobar resections was somewhat higher. The authors associated this with the smaller volume of removed lung parenchyma and possible features of lymphatic tumor spread.

The development of thoracoscopic technologies has made it possible to significantly improve the technique of segmentectomy. Thus, H. Oizumi, T. Sasage, S. Takamori et al. [12] proposed a "vein-first" strategy for thoracoscopic segmentectomy using preoperative three-dimensional computed tomography reconstruction. The authors showed that 3D modeling allows more accurate visualization of segmental vessels and bronchi, which facilitates identification of intersegmental planes. In the clinical patient series, the use of this technique was associated with a lower risk of vascular injury and reduced intraoperative blood loss, which in most cases did not exceed 100–150 ml.

Special attention in modern thoracic surgery is given to wedge resection, which is mainly used in patients with limited pulmonary functional reserve or metastatic disease [31]. In such cases, wedge resection allows removal of the pathological lesion with minimal loss of lung tissue and may also be performed for diagnostic purposes when the nature of a peripheral nodule is uncertain. In brief, the clinical and surgical characteristics of different types of video-assisted lung resections, including lobectomy, segmentectomy, sublobar resection, and wedge resection, are summarized in Table 2.

Table 2: Characteristics of video-assisted resections in peripheral lung tumors

Type of resection	Main indications	Technical features of VATS	Typical extent of resection	Clinical advantages
Lobectomy	Early-stage NSCLC with satisfactory lung function	Anatomical lobar resection through 3–4 ports with dissection of the vascular-bronchial bundle	Removal of the entire lung lobe with systematic lymphadenectomy	High oncological radicality and low risk of local recurrence
Segmentectomy	Peripheral tumors ≤2 cm or patients with limited lung function	Isolation of segmental vessels and bronchus; use of 3D CT and fluorescence navigation	Removal of one or several anatomical segments	Preservation of a larger volume of lung parenchyma with comparable effectiveness
Sublobar resection	Small peripheral tumors or high surgical risk	Minimally invasive access with limited vascular dissection	Removal of part of the lobe without complete anatomical segmentation	Lower surgical trauma and faster recovery
Wedge resection	Diagnostic procedures, metastases, or benign nodules	Non-anatomical excision of the nodule using endoscopic stapling devices	Local removal of a parenchymal area around the tumor	Shorter operation time and minimal loss of lung tissue

Analysis of current clinical studies shows that the introduction of video-assisted technologies has significantly changed approaches to the surgical treatment of peripheral lung tumors. Minimally invasive resections, including lobectomy, segmentectomy, and wedge resection, provide comparable oncological outcomes while being associated with fewer postoperative complications and shorter hospitalization. VATS techniques continue to evolve: 3D visualization, navigation technologies, and robot-assisted systems are not merely technical innovations, but practical tools that improve the precision of anatomical lung resections.

Intraoperative Navigation and Methods for Localizing Peripheral Tumors

Intraoperative navigation and methods for detecting peripheral lung tumors are among the key tools in modern thoracic surgery, especially in minimally invasive procedures. Small nodules, often less than 10–15 mm in diameter, may be difficult to identify during VATS because they are not always visible or palpable. For this reason, various preoperative and intraoperative navigation techniques are used. The most common methods include CT-guided navigation, dye marking, hook wire placement, microcoils, and electromagnetic navigation bronchoscopy, all of which increase the accuracy of the intervention. However, even with a high success rate of 90–95%, complications may still occur, including pneumothorax, marker migration, and other technical problems, which indicates the need for further improvement of navigation technologies.

In the study by A.A. Skorokhod, A.S. Petrov, A.O. Nefedov, A.R. Kozak, M.A. Atyukov, and P.K. Yablonsky [5], devoted to the use of video-assisted technologies in mediastinal lymphadenectomy, it was shown that endoscopic visualization and precise anatomical navigation allow safe removal of an average of 10–15 lymph nodes from different mediastinal stations. The authors note that combining modern navigation methods with thoracoscopic access improves the accuracy of surgical maneuvers and reduces the risk of injury to vascular-bronchial structures. These data indicate that the development of intraoperative navigation contributes to more radical resections, although the speed of widespread implementation of these approaches remains an open question.

The main difficulty is associated with small pulmonary nodules that are almost non-palpable during minimally invasive procedures [32]. Therefore, emphasis is placed on preoperative localization, with CT-guided navigation being the most widely used tool. It allows accurate determination of the lesion's position and makes it possible to mark the tumor before surgery. Different techniques are used for marking: dyes may be injected, or a hook wire or microcoil may be placed;

these landmarks assist the surgeon during VATS resection. According to several clinical series, such methods increase the accuracy of peripheral nodule localization to 90–95% and reduce the risk of conversion to thoracotomy [33–35].

In recent years, electromagnetic navigation bronchoscopy has been increasingly used directly in the operating room to mark the tumor nodule in situ. This method is based on a three-dimensional navigation system and a bronchoscope equipped with a position sensor, which helps guide the instrument precisely to the peripheral lesion. According to current data, the success rate of navigational nodule localization using this technology reaches 92–100%, which substantially facilitates anatomical lung resections.

Accurate preoperative navigation is becoming increasingly important with the emergence of new drug-based treatment approaches. A clear example is the large CheckMate-77T trial [36], in which neoadjuvant immunotherapy combined with chemotherapy produced a marked pathological response in a substantial proportion of patients with resectable non-small cell lung cancer. In particular, among 214 patients, a complete pathological response was achieved in 32.4% of those receiving combination therapy, compared with 3.8% in patients receiving chemotherapy alone. In such clinical situations, precise localization of the residual tumor focus is especially important for performing radical surgical resection. The main navigation and localization methods for peripheral lung tumors used during video-assisted thoracoscopic procedures are schematically presented in Figure 2.

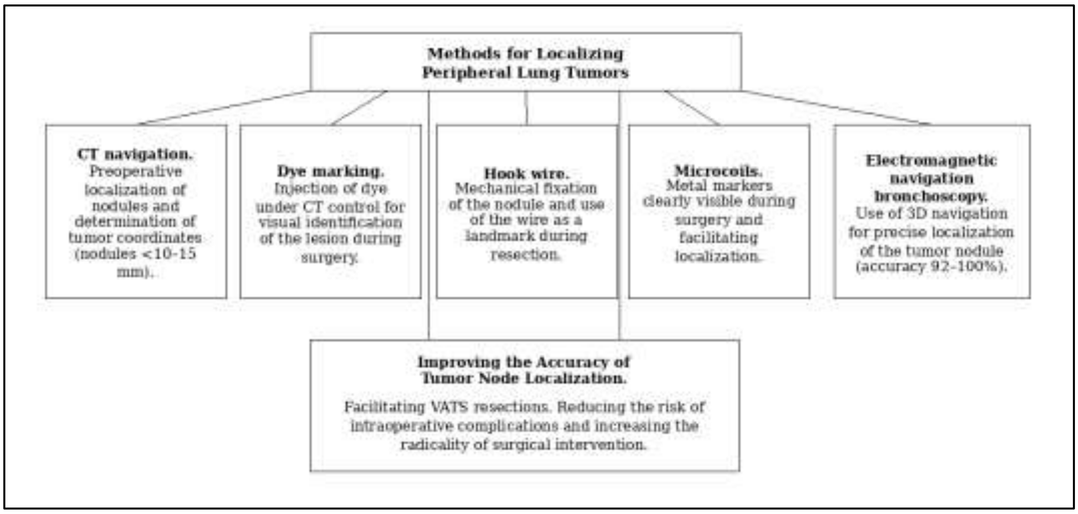

Figure 2: Methods of localization of peripheral lung tumors during VATS resections: a list of approaches with brief notes on application

CT navigation, different methods of tumor nodule marking, and navigational bronchoscopic technologies make the localization of peripheral lung lesions much more accurate and facilitate minimally invasive procedures. Sometimes the difference is measured in millimeters, but these millimeters determine how much tissue must be removed and how quickly the patient will recover.

Additional data on the role of immunotherapy in improving surgical outcomes for malignant tumors are provided by the study of R.J. Kelly, J.A. Ajani, J. Kuzdzal et al. [37]: adjuvant nivolumab after surgery significantly increases disease-free survival. These results show that oncology is increasingly combining therapeutic approaches with surgery. The key issue is how precisely intraoperative navigation and accurate localization of the lesion are performed, since this determines whether the tumor can be removed radically while preserving the maximum amount of functional lung tissue.

The introduction of modern technologies for navigation and localization of peripheral lung tumors expands the possibilities of video-assisted thoracoscopic surgery. CT navigation, bronchoscopic marking methods, and various navigation systems provide more accurate localization of tumor nodules, facilitate VATS resections, and reduce the risk of intraoperative complications. This changes the approach in the operating room: fewer assumptions and more precision. Taken together, these factors contribute to improving the effectiveness of surgical treatment in patients with early-stage lung cancer and to better long-term oncological outcomes.

Results and Prospects for the Development of Minimally Invasive Cardiothoracic Surgery

A number of studies have been identified that assess the outcomes and future prospects of minimally invasive cardiothoracic surgery [38–43]. Most current publications note that the use of video-assisted and robot-assisted technologies is associated with a lower rate of postoperative complications compared with traditional open procedures. In particular, reduced surgical trauma and more accurate visualization of anatomical structures make it possible to decrease the risk of bleeding, postoperative infections, and cardiorespiratory complications. At the same time, a shorter hospital stay is reported, which is related to faster recovery after minimally invasive surgery.

Several clinical studies have shown that patients after VATS lobectomy or robotic procedures spend, on average, several days less in hospital than patients after traditional thoracotomy. A shorter hospital stay is accompanied by faster functional recovery, earlier patient mobilization, and quicker return to daily activity [44–54]. Accumulated clinical data show that in early-stage non-small cell lung cancer, minimally invasive procedures provide oncological outcomes comparable to open surgery, while being associated with less trauma and often faster recovery. This should be considered when choosing the treatment approach.

Similar conclusions are presented in the study by S. Takamori et al. [10, 14], which analyzed surgical outcomes in patients with centrally located clinical stage I non-small cell lung cancer. The findings indicate that anatomical lobectomy remains more often preferable than sublobar resections, as it provides more reliable oncological control. In addition, modern imaging methods and intraoperative navigation help determine the optimal extent of resection more accurately and reduce the risk of local recurrence, although clinical nuances remain important.

Additional data on factors influencing surgical outcomes are provided in the study by J. Zimmermann et al. [19], which examined how comorbidities affect overall mortality in patients after surgical treatment for non-small cell lung cancer. The results showed that comorbid pathology significantly reduces long-term survival. This highlights a simple but important conclusion: for such patients, less traumatic surgical approaches are not only desirable but often necessary.

In recent years, the development of minimally invasive cardiothoracic surgery has been discussed increasingly often [55, 56]. Promising directions include robotic surgical systems, expanded navigation capabilities, the use of artificial intelligence algorithms for medical image analysis, and the formation of personalized surgical strategies. The integration of these technologies is expected to improve the precision of interventions, reduce complication rates, and enhance long-term outcomes in patients with thoracic malignancies.

CONCLUSION

Video-assisted thoracoscopic surgery for peripheral lung tumors combines the clinical advantages of minimally invasive access with the possibility of full oncological treatment. In early-stage non-small cell lung cancer, VATS allows anatomical resections to be performed with less surgical trauma, reduced postoperative pain, shorter hospitalization, and faster patient recovery. The clinical effectiveness of the method largely depends on accurate localization of small and non-palpable nodules; therefore, CT-guided navigation, tumor marking, microcoils, and electromagnetic navigation bronchoscopy are becoming an important part of modern surgical strategy. The molecular aspect of the problem is associated with changing approaches to lung cancer treatment: neoadjuvant immunotherapy, assessment of pathological response, and the need for targeted removal of residual tumor require more precise surgical planning. Further development of VATS is associated with the introduction of 3D modeling, fluorescence navigation, robot-assisted systems, and personalized selection of the extent of resection. This approach makes it possible not only to improve the safety of the intervention but also to preserve a larger volume of functioning lung tissue while maintaining the principles of oncological radicality.

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