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The evolution of operative access in lung surgery

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Abstract

In modern surgical practice, considerable attention is paid to reducing surgical trauma and reducing the incidence of postoperative complications, which has a direct impact on the duration of hospitalization and patient recovery. In chest surgery, this problem is most significant, since to perform small interventions on the lungs and pleura, a wide thoracotomy was required with the transection of the chest muscles and the separation of the ribs. The article describes modern minimally invasive approaches used in lung surgery. Particular attention is paid to the role of video-assisted surgical interventions in the surgical treatment of non-small cell lung cancer. The results of traditional multiport thoracoscopic lung resections were compared with standard open thoracotomy. The advantages and possible disadvantages of various options for video-assisted surgical interventions on the lungs are described.

Key words: thoracoscopy, lobectomy, video-assisted thoracic surgery.

Introduction

Surgery of the chest organs did not develop at such a rapid pace in comparison with general surgery, which was due to objective reasons. Traditional thoracotomy or sternotomy is a traumatic approach and cannot provide access and visualization of the necessary structures of the chest cavity and mediastinum. Despite the more than 100-year history of thoracoscopy, it remained diagnostic for a long time or was used in carrying out "minor" surgical interventions for spontaneous pneumothorax, talc pleurodesis and sympathectomy. In several decades, the rapid progress of minimally invasive thoracic surgery has been seen. This is primarily due to the development and improvement of video systems for endosurgery, which allow video-assisted thoracic surgery (VATS) to be performed. In 1992, Roviaro *et al.* in Milan performed the first VATS lobectomy in an elderly man with adenocarcinoma of the lower lobe of the right lung [1]. From that moment on, the active introduction of various techniques of VATS lung resections in thoracic oncology began. In 1993, Kirby published the first experience of 35 lobectomies in patients with stage 1 non-small cell lung cancer (NSCLC) [2]. The operations were performed through 2 additional thoracoscopic and additional mini-thoracotomies 6–8 cm long without early insertion of a speculum [2]. In the literature, "traditional" VATS means performing an operation with the installation of 3–4 small ones without the use of retractors (multiport VATS (mVATS)) [3]. Despite the need to purchase initially expensive equipment for performing VATS operations, the use of the method turned out to be economically more profitable due to the reduction in the time of the inpatient and the cost of his treatment in general. Jawitz *et al.* conducted a retrospective cohort analysis of the American database of lung cancer patients undergoing inpatient treatment in the period from 2008 to 2011 [4]. It was found that in the group of comorbid patients who underwent open lobectomy, there was higher mortality and frequency of various respiratory, gastrointestinal and cardiac complications [4]. Decaluwe *et al.* in 2015 published the results of a multicenter study, which analyzed the "large" intraoperative complications of 3076 videothoracoscopic anatomical lung resections in NSCLC and revealed that the conversion to thoracotomy due to non-oncological reasons significantly decreases as the surgeon gains experience in thoracoscopic operations [5]. After correcting the results obtained taking into account the learning curve, the conversion rate dropped to 2.4% [5]. The proven advantages of thoracoscopic access for anatomical lung resections are: a decrease in the time spent in the hospital, a decrease in the incidence of perioperative pulmonary complications and mortality, and a better cosmetic result [6]. In most cases, the national clinical practice guidelines for VATS are considered to be the modern history of stages of NSCLC. However, long-term results of mVATS intervention revealed chronic pain syndrome in the chest with a post-thoracotomy rate of up to 32% [2, 3, 7]. In addition, up to 53% of patients experience chest paresthesia for more than 1.5 years [3, 8]. This is probably caused by the pressure of rigid thoracoports on the intercostal nerve.

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Uniportal video-assisted thoracoscopic surgery (uVATS)

The desire to reduce the number of ports for the introduction of instruments into the chest cavity has led to the emergence of surgical interventions performed through a single access. Migliore *et al.* in 2000–2002 first published the results of a prospective study of the use of uVATS in the diagnosis and treatment of pleural cavity diseases [9]. One of the first thoracic surgeons to perform lung resection using the uVATS was Rocco [10]. However, in the period up to 2010 uVATS was used to carry out "small" surgical interventions: marginal resection of the lungs with nodular formations, spontaneous pneumothorax, biopsy of mediastinal lymph nodes, etc. [11]. Further popularization of the method was facilitated by the development and improvement of double-hinged surgical instruments of increased length adapted for uVATS and special ring-shaped wound protectors (Alexis type). There are at least 3 options for uVATS access – anterior, posterior and axillary. With an anterior approach, an incision of about 3–4 cm in length is usually performed in the fifth intercostal space between the anterior and middle axillary line; the patient is in the lateral position. Due to the absence of trauma to the intercostal nerves, the pain syndrome after uVATS is less pronounced, the need for opioid analgesics is lower, and the quality of life of patients in the long-term postoperative period is better [11, 12]. In traditional mVATS, working instruments and optics are located at different angles, which complicates the spatial orientation and coordination of movements during the operation and requires highly coordinated work of the operating surgeon and assistant. In uVATS, instruments and optics are located in a single plane, providing direct access to the treated structures of the lung or mediastinum, and movement of instruments similar to their manipulations in open surgery.

One of the pioneers in the development of video-assisted single-port anatomical lung resections is the Spanish surgeon Diego González-Rivas, who in 2010 adapted and performed uVATS lobectomy for the first time. In 2013 he published the results of 222 uVATS lobectomies and thoroughly described the technique for performing various anatomical lung resections and lymphadenectomy from a single-port approach in NSCLC [13]. The indications and contraindications for uVATS are similar to those for standard mVATS [14]. As surgeons accumulate experience with single-port operations in the literature of recent years, there are more and more papers describing the successful results of using uVATS in patients with advanced stages of NSCLC after chemoradiation therapy, with tumor invasion into the chest wall, pronounced adhesions in the pleural cavity, tumors of the apex of the lung (Pancoast tumor), and angiobronchoplastic interventions [15–17]. According to González-Rivas, more than 95% of large lung resections can be performed using uVATS [14]. Systematic literature reviews and meta-analyses of data clearly demonstrate the advantages of uVATS over mVATS for lobectomies and segmentectomies in the early stages of NSCLC. Harris *et al.* conducted a systematic review using seven major electronic databases (Ovid Medline, Embase, PubMed, the Cochrane Central Register of Controlled Trials (CCTR), Cochrane Database of Systematic Reviews (CDSR), ACP Journal Club and Database of Abstracts of Reviews of Effects (DARE)). Eight relevant observational studies with a high level of evidence were included in the meta-analysis. These results demonstrated a statistically significant reduction in the overall incidence of complications, period of hospital stay, and duration of postoperative drainage in patients undergoing uVATS lobectomy versus mVATS [18]. There were no significant differences between the two groups in terms of mortality, duration of surgery, intraoperative blood loss, or the rate of conversion to thoracotomy [18]. Since with uVATS the surgical access is small and limited by the soft tissues of the chest wall and ribs, the possible disadvantages include the conflict of instruments and rather poor ergonomics, high requirements for the assistant for fixing the thoracoscope, and the presence of postoperative pain, although less pronounced in comparison with thoracotomy and mVATS.

Subxiphoid uniportal video-assisted thoracoscopic surgery (sVATS)

The subxiphoidal approach has been used in thoracic surgery for a long time. It was originally used to reach the pericardium and perform pericardiocentesis or drain the pericardial cavity when exudate accumulates. In 1999 Mineo *et al.* proposed an original method of video-assisted transxiphoidal bilateral metastasectomy [19]. A semi-lunar skin incision in the transverse direction, about 8 cm long, was carried out in the projection of the xiphoid process of the sternum and the lower edges of the ribs. This access allowed a hand to be inserted into the pleural cavity, palpating the lung, detecting metastases and performing their resection. If necessary, surgical intervention on the opposite side could be performed from the same access with the opening of the corresponding pleural cavity in the same way [19]. Such surgical interventions came to be called hand-assisted thoracoscopic surgery (HATS). The disadvantage of the operation is the possibility of the development of arrhythmogenic cardiac complications, including atrial fibrillation, caused by the pressure of the hand on the heart. Research to reduce trauma to the intercostal nerves during transthoracic VATS procedures has led to the development of a new single-port subxiphoidal approach (sVATS) technique. In 2005, a group of Japanese scientists proposed an improved HATS technique. A 109 mm long port was introduced into the pleural cavity through a vertical incision below the xiphoid process, only 2.5 cm long [20]. In December 2014 Liu *et al.* first reported sVATS for radical left upper lobectomy with lymphadenectomy in a 49-year-old female patient with NSCLC staged as T2aN1M0 after surgery [21]. Since then, there has been active introduction of sVATS in various medical centers around the world. The advantages of the method in comparison with traditional thoracoscopic and single-port operations include greater freedom in manipulating instruments, since there is no limiting effect of inactive ribs.

The use of various scales for assessing pain in the postoperative period clearly showed that patients who underwent surgery with the subxiphoidal approach had a better quality of life, and there was no chronic pain in the long-term period. Immediately after sVATS, pain was localized only in the epigastric region; in most patients, opioid analgesics were not required [22]. Currently, using this approach, lob- and segmentectomies, complex anatomical resections of the lungs, interventions for thymomas and other neoplasms of the mediastinum are performed. It is a promising method in the treatment of bullous emphysema of the lungs and spontaneous pneumothorax, since it allows one-stage intervention on both lungs and the induction of pleurodesis to be achieved through one access; drainages are removed in the lateral corners of the surgical wound, which significantly reduces pain in the postoperative period [23]. However, significant difficulties in access to the posterior lower parts of the lungs during sVATS, difficulties in controlling intraoperative bleeding, the possibility of arrhythmogenic complications and hemodynamic instability during left-side operations were noted [21–23]. A rare specific complication of sVATS is the formation of a hernia of the anterior abdominal wall. Zieliński *et al.* when performing 611 sVATS observed thymectomies in three patients with the formation of incisional hernias [24]. sVATS has a fairly long learning curve (significantly reduced with experience with uVATS) and takes longer than mVATS.

Transcervical video-assisted thoracoscopic surgery (tVATS)

For a long time, this access had limited application and was used for thymectomy, aberrant goiter operations, and mediastinoscopy for staging NSCLC. Zieliński *et al.* improved the technique of transcervical lobectomy, expanded the operational indications for performing uniportal tVATS not only for upper but also for lower lobectomies [25]. In 2018 16 single-port tVATS lobectomies were reported. Access was made through a collar incision on the neck 5–8 cm long. The first stage was transcervical extended mediastinal lymphadenectomy (TEMLA) with intraoperative examination of the removed lymph nodes. In the absence of metastases in them, a single-port VATS lobectomy was performed at the next stage through the cervical approach [25]. The advantage of tVATS is the possibility of simultaneous access to both pleural cavities and bilateral lung resection during one intervention. The unique advantages of the transcervical approach are TEMLA before lung resection and intraoperative staging of NSCLC, the ability to perform simultaneous resection of the thyroid gland in its pathology, and low postoperative pain. Technical complexity and duration are disadvantages of tVATS lobectomy. Unlike uVATS and sVATS, tVATS lung resections cannot be performed in patients who are not intubated or who have previously undergone sternotomy. Pneumonectomy, tracheal bifurcation resections and angiobronchoplastic operations are impossible using the tVATS technique; removal of the lower group lymph nodes is significantly difficult. Manipulation in a small space bounded by large vessels is associated with the risk of uncontrolled bleeding. Thus, the method can be used in relatively simple cases in the initial stages of NSCLC with the localization of the pathological process in the upper lobes of the lungs [26, 27].

Robot-assisted thoracoscopic surgery (rVATS)

Initially, rVATS found wide application in mediastinal tumor surgery (thymectomy) due to its excellent 3D imaging and wide range of maneuverability. Since 2001, when the first robotic lobectomy was reported, there has been significant progress in the use of robotic surgery in the treatment of NSCLC [28]. With the accumulation of surgical experience and the improvement of robotic systems, the time of surgical intervention has significantly decreased. The problem of the lack of tactile feedback was partially solved in 2009 by upgrading the DaVinci platform, called "FireFly" (Novadaq Technologies Inc.), which implemented the possibility of fluorescence monitoring in the near infrared region of the spectrum using indocyanine green (ICG). This enables the surgeon to clearly identify the vessels and intersegmental line during segmentectomy, and localize the thoracic duct or tumor [29].

The key to the success of surgical treatment of lung cancer, regardless of the choice of access, is the mandatory systematic lymph node dissection. In the literature, there is still a discussion about the adequacy of performing lymph node dissection when using various minimally invasive interventions in lung cancer surgery. Currently, there is evidence from studies confirming that lymphadenectomy during minimally invasive interventions (mVATS, uVATS, sVATS) is qualitatively not inferior to lymphadenectomy during open operations. When analyzing the radicalism of rVATS lobectomies performed for NSCLC, some authors demonstrate better long-term results in comparison with open surgery and other types of VATS operations [30]. According to the observations of Zirafa *et al.*, overall survival of patients undergoing radical rVATS operations for NSCLC at 60 months was 98.5%, 93.7%, 73.1% and 0% for stages I, II, III, and IV, respectively [31]. Robotic lobectomy potentially reduces the risk of postoperative pulmonary complications, especially in patients with limited lung function [32]. Lymphadenectomy with rVATS lobectomies can be more radical due to better instrument maneuverability and 3D imaging, as well as a higher rate of nodule removal compared to VATS [33]. However, in another study, Yang *et al.* analyzing the results of treatment of 153 patients with NSCLC (rVATS n = 76, uVATS n = 77) did not find a statistically significant difference in the number of removed lymph nodes in the rVATS and uVATS groups [34]. Despite the advantages of robotic operations, rVATS still requires the installation of multiple ports and a long time for pairing the instruments and the operation itself.

Prospects for reducing surgical trauma

The development and implementation into practice of endoscopic operations using NOTES technology (Natural Orifice Translumenal Endoscopic Surgery) attracts the attention

of thoracic surgeons. Several publications are devoted to the study of animal models of transesophageal, transgastric and transesophageal access to the mediastinum and lungs [35–37]. In 2007 Sumiyama *et al.* first reported the possibility of access to the pleural cavity transesophageally, by forming a working space in the submucosal layer of the esophagus and myotomy [35]. In 2010 De Palma *et al.* in an experiment with a transgastric transdiaphragmatic approach, successfully performed a lung biopsy in 4 pigs. The forming defect of the stomach wall was clipped [36]. In 2007 Lima *et al.* published the results of performing a transvesicular transdiaphragmatic biopsy of the left lung in six pigs using a ureteroscope [37]. Attempts at laparoscopic transdiaphragmatic lung operations have also been made in humans [38]. Zhu *et al.* in 2013 reported on the successful experience of performing transumbilical transdiaphragmatic bilateral sympathectomy for palmar hyperhidrosis. All patients underwent surgery through a 5 mm umbilical incision in combination with a 5 mm diaphragm incision using an ultrathin flexible endoscope [39]. The advantages of the method include low postoperative pain and an excellent cosmetic effect. However, there is a high likelihood of development of an adhesive process in the abdominal cavity, its infection or seeding with tumors of the lungs and mediastinum [38]. In 2010 Liu *et al.* demonstrated the possibility of transtracheal access to the pleural cavity. Subsequently, the technique was improved and in experimental work on animal models (dogs), a comparison was made between transoral and traditional thoracoscopy for lung biopsy and examination of the pericardial cavity. There was no significant difference in the duration of surgery between groups [40]. The lack of clinical studies of a high degree of evidence does not allow us to speak about the prospects for the development of the NOTES methods described above.

Conclusions

The advantage of various minimally invasive interventions in comparison with those discovered in the treatment of early stages of NSCLC and a number of other diseases has been proven by numerous studies. However, each of the VATS options has both advantages and disadvantages. The use of one method or another largely depends on the technical equipment of the clinic and the preferences of the surgeon. Further progress in thoracic surgery is inextricably linked with the improvement of medical instrumentation and operating imaging systems and accurate methods of preoperative diagnostics, which will make it possible to safely perform complex operations with minimal trauma to the patient.

Disclosure

The authors report no conflict of interest.

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