Review Article

Video-assisted thoracoscopy for lung cancer: who is the future of thoracic surgery?

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Abstract: As the computer processing technique and display technology evolved dramatically, the surgical approach to early-stage non-small cell lung cancer (NSCLC) has made a rapid progress within the past few years. Currently, the gold standard for NSCLC is lobectomy. After the introduction of video-assisted thoracoscopic surgery (VATS), lung resection can now be conducted mini-invasively, enabling better prognosis for patients and better operation condition for surgeons. At the very beginning, the conventional two-dimensional (2D) system enabled operators to have a closer, magnified and illuminated view inside the body cavity than open thoracotomy. With the introduction of the glasses-assisted three-dimensional (3D) and glasses-free 3D display system, multiple viewing angles were further enhanced, thus a more stable, easier to master and less invasive video-assisted thoracoscopic surgery (VATS) appeared. However, given that the standard VATS is associated with limited maneuverability and stereoscopy, it restricts the availability in more advanced cases. Hopefully, most of the limitations of standard VATS can be overcome with the robotic-assisted thoracic surgery (RATS). The RATS system consists of a remote console and a robotic unit with 3 or 4 arms that can duplicate surgeons' movements. Also, it provides a magnified, 3D and high definition (HD) operation field to surgeons, allowing them to perform more complicated procedures. Apart from these, some new technologies are also invented in combination with the existing surgery system to solve difficult problems. It is hoped that the higher costs of innovative surgical technique can be offset by the better patient outcomes and improved benefits in cost-effectiveness.

Keywords: Video-assisted thoracic surgery (VATS); 2D; 3D; glass-free; robotic-assisted thoracic surgery (RATS)

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Lung cancer is one of the most commonly diagnosed cancer with an estimated 228,820 new cases in 2020, representing 12.67% of all new cancer cases (1). According to a systemic global cancer study, lung cancer is the main cause for cancer deaths, with 1.9 million deaths worldwide (2). Due to the high incidence and mortality, lung cancer has become a heavy burden on public health. However, with the extensive use of low-dose computed tomographic screening, more patients with operable lung cancer (stages IA–IIIA) can be diagnosed at an early stage. Additionally, with the revolution of surgical interventions and development of chemotherapy and radiotherapy, the 5-year survival for lung cancer cases is further improving.

For the treatment of lung cancer, video-assisted thoracic surgery (VATS) is of prime significance. In the 1990s, the introduction of VATS launched a new era in the diagnosis and treatment of thoracic diseases (3). During the past 30 years, continuous efforts on technical enhancement and surgical instruments advancement have been made to simplify the surgical procedure, lessen the resection area while maintaining the same therapeutic effect and improve the long-term survival as well as short-term complications from the surgery. In 2012, VATS was adopted in lung cancer diagnosis and treatment in accordance with the guidelines released by the US National Comprehensive Cancer Network (NCCN). Currently, traditional two-dimensional (2D) technology, 3D high-definition (HD) video technology, multi-view glasses-free 3D display system and robotic-assisted thoracic surgery (RATS) system are applied in thoracic surgery, enabling a less invasive, more advanced and more personalized treatments for thoracic disorders (4).

In consideration of the mentioned progress in thoracic surgery for lung cancer, we now pose the question: who is the future of thoracic surgery? In this paper, we will review the history of lung cancer surgery, discuss current surgical technologies and put forward potential future directions.

2D VATS system

Since the surgical procedures in VATS are fundamentally different from that in thoracotomy, a phenomenal interest regarding minimization of the invasiveness of thoracic surgery was generated. In VATS, surgeons make multiple small incisions to pass the rigid straight instruments and the endoscope camera without removing or stretching the ribs, so it avoids injuries to muscle related to respiration and minimizes the loss of lung function. Also, the view in VATS is from anterior hilum to posterior hilum, while the open thoracotomy view is looking down at the lung from above (4).

Compared to open thoracotomy, such procedures in VATS are found to be safe, feasible, reliable and cost effective (5). What's more, VATS lobectomy is associated with fewer pulmonary comorbidities, decreased intraoperative blood loss and postoperative pain, lower morbidity and shorter time of hospital stay while maintaining similar oncologic outcomes with open thoracotomy (6-8). In addition, for those patients who encounter limited lung functions or additional complications, it is also beneficial to utilize VATS in lung cancer treatment (9-11). Based on the superiority of VATS, it is widely considered to be the gold standard for early-stage non-small cell lung cancer (NSCLC) treatment (3).

To perform thoracic surgery in a safe and straightforward manner, standardized procedures and operative schemes must be followed. The process of obtaining experience and enhancing skills in surgery is called the "learning curve". However, owing to the poor mobility of the rigid and straight instruments, conventional 2D VATS is inferior when it comes to fine vascular or nodal dissection, large tumors resection, tying and suturing (4). Besides, it lacks a 3D sense of anatomical structures, resulting in the absence of depth perception and spatial orientation. Hence, it is difficult for surgeons to identify the accurate position and distance between surgical instruments and the target (12), and it poses a great challenge for proficient surgeons in adapting the 2D VATS system, not to mention inexperienced novice.

Although some surgeons criticized traditional 2D VATS as a technically limited approach for treatment, thanks to the wide dissemination of this technique, some operators are quite adept in it and even applied this system in more complicated cases.

Notably, conventional VATS is conducted through two to four incisions, including an observation port for the endoscope camera and the others for the operation devices (13). In uniportal VATS, major surgical procedures are performed via a single small incision of about 3–5 cm. In the last decade, it was remarkably developed and became increasingly popular worldwide a novel approach to operate early stage lung cancer (14-16). It was demonstrated in a number of studies that uniportal VATS represents less surgical trauma and postoperative pain than traditional VATS, suggesting a faster recovery for patients (17,18). Nonetheless, on account of the limited quantity and quality of relative researches, it remains premature to show superiority for uniportal VATS. We proposed that longer follow-up and more rigorous randomized controlled trials (RCTs) should be conducted to provide adequate evidence on this issue. Given that uniportal VATS is a challenging approach, a long-term training is essential for surgeons to get accustomed to the instruments and improve proficiency.

3D VATS system

As the video imaging and endoscopic technology continue to evolve, the first 3D endoscopic system has been proposed as an approach to enhance surgical performance. However, because of the heavy, bulky head-mounted devices and low quality of 3D imaging, it soon led to surgeons' headaches and ocular fatigue. Thus, the 3D VATS system could not be widely implemented at that time. As the 3D technology matured, novel 3D HD imaging systems enable significantly improved video quality and higher resolution via polarimetric glasses, which are lighter and more comfortable than the first-generation 3D endoscopic system was used. Nowadays, the 3D-HD VATS system has been adopted by a growing number of surgeons.

As an emerging thoracic surgical system and technique, 3D VATS system is correlated with a much stronger sense of depth perception, spatial location of the target and adjacent anatomic structures, resulting in higher precision of surgical performance (19). Likewise, more sophisticated tasks including suturing, ligation and bronchial or vessel sleeve resection can be performed more easily, effectively and precisely (20,21). Overall, compared with 2D VATS system, shorter operation times, less blood loss, lower incidence of surgical trauma and shorter postoperative hospital stay were observed while the perioperative morbidity, chest drainage volume, chest drainage duration and the number of retrieved lymph nodes were comparable between the two systems (22). In terms of the hospitalization costs of 2D and 3D VATS, no additional medical expenses are demanded, which is a superiority for Chinese patients with the national medical insurance.

For surgeons, especially for beginners with no need to adapt the conversion from 2D to 3D imaging, 3D views might be beneficial to shortening their learning curves. Consequently, attending a 3D system-simulated training course appears to improve proficiency, minimize the incidence of mistakes and accelerate acquisition of basic skills for thoracoscopic surgery (23). Such advanced training renders the surgeon and surgical team self-assurance when operating in confined intracavitary space.

As to the adverse effects of 3D VATS, it poses a great challenge to both surgeons and camera assistants. As we all know, the principle of the 3D display lies in the human eye parallax theory. When we watch a 3D image, different images enter our eyes through the polarizing filter glasses respectively. After the brain analyzes and synthesizes the image, a 3D vision is formed. During the operation, the eyes and the brain are working intensely, making some surgeons unable to work with 3D VATS system for a long time. In addition, the magnification of 3D VATS system is greatly larger than that of 2D system. Also, the polarizer could trigger a relatively dark operative field. In this situation, it is likely to increase the surgical difficulty due to a much smaller and darker visual field from the same distance.

Notably, unlike the conventional 2D VATS system, lens can only be rotated manually in 3D VATS system, causing a shifting vision in the screen. If the frames move too fast, surgeons may well have difficulty in adapting to a rotated view, leading to headache, eye fatigue, dizziness, nauseous and vomiting. Meanwhile, a clear and stainless lens is in greater demand in 3D system, otherwise it may cause vertigo and nausea for surgeons as well. Hence, it puts forward a higher demand on camera assistants when providing a steady vision for surgeons because the hand shanks of 3D VATS systems are heavier than that in 2D system (24). For those who are not accustomed to wearing glasses, it is also uncomfortable to wear 3D glasses during the operation, for reasons such as, blurred vision due to exhalation, or the discomfort on the nose and ears.

The 3D HD system, which combines the cost effectiveness of the 2D VATS system with the 3D imaging technology of the da Vinci Surgical System, may be an appropriate intermediate choice between the conventional 2D VATS and RATS at present, especially for patients in developing countries. In the near future, 3D VATS system has potential to be an incentive for improvement in minimally invasive thoracic surgery, enabling more complicated operations to be performed with better therapeutic efficacy.

Glasses-free 3D VATS

The glasses-free 3D VATS system is an update of conventional 3D VATS system. As an innovative technology, it gets rid of the shackles of 3D glasses and utilizes a head band worn by the surgeon and two sensors on the screen to acquire 3D images. Although the environment for thoracoscopic surgery is complicated, with the help of both face-tracking and eye-positioning techniques, glasses-free 3D system can trace the movements of surgeons in real-time and provide a smooth 3D HD visual fields at any angle (12).

However, it remains controversial when it comes to the clinical effectiveness of glasses-free 3D VATS system. A retrospective study compared the effects of glasses-free 3D VATS and conventional 2D thoracoscopic radical surgery on lung cancer. There were no significant differences in intraoperative indicators (mean number of lymph nodes dissected, incidence of massive bleeding, rate of conversion to thoracotomy and total amount of blood loss), postoperative indicators (volume of chest drainage, drainage days, and complications such as pneumonia and atelectasis) or postoperative systemic inflammation (decreased leukocytes and elevated body temperature) (12). Nonetheless, another clinical research indicated that glasses-free 3D system has potential benefits of less intraoperative bleeding, lower chest tube placement rate and shorter hospital stays (25). To further identify the clinical efficacy and the cost benefic of glasses-free 3D VATS, more in-depth researches including multi-center large-scale RCTs with more objective and rigorous clinical outcomes still deserve further investigation. Concerning the learning curve, visual field brightness in glasses-free 3D system is increased, thus beginners can more easily get accustomed to the surgical vision and enhance hand-eye coordination in a shorter amount of time, thereby shortening the learning process.

Nonetheless, the system only follows movements of the main operator, the other medical staff must wear the traditional polarized glasses to watch the 3D images on an additional. Similar to the traditional 3D VATS system, the viewing lens have a relatively fixed position. If there is an obstacle in front of the lens, the camera assistant has to rotate the camera body manually, causing dizziness, nauseous visual fatigue on surgeons as a result. Furthermore, even if the crosstalk rate has been reduced to 4%, image ghosting still needs to be eliminated in future development.

Generally, glasses-free 3D VATS is a brand-new resource for thoracic surgeons. Nevertheless, it remains in the early stages of development. Therefore, a wide-angle, high-resolution, multi-view glasses-free 3D system should be encouraged to be widely applied in minimally invasive thoracic surgery in the near future (26).

RATS system

By combining 3D images with increased degrees of freedom, the RATS system has been proposed as a "technological disruptor" to conventional surgery approaches (4). Since it was first introduced into clinical practice in 2002, it has become progressively popular and, with the rising numbers and styles of robotic platforms to choose from, may become the most essential armamentarium for thoracic surgeons in the foreseeable future.

The da Vinci Surgical System, the only robot available on the market for RATS, is the fruition of the minimally invasive surgery technique. It is composed of a robotic unit with 3 or 4 arms and a remote console. With RATS, surgeons perform an operation without necessarily at the bedside and not even sterile. Instead, the multi-angle image synthesizer in the camera arm creates a magnified and panoramic 3D HD vision while surgeons operate on the main console to dominate the other robotic arms. With the help of the highly sensitive motion trigger sensor, surgeons' movements can be transmitted to the tips of the instruments synchronously (27), then a variety of minimally invasive instruments are used to finish the operation.

For surgeons, the 3D HD imaging with depth perception guarantees the enhanced vision for fine dissection and binocular view of the whole thoracic cavity. Also, robotic instruments, with seven degrees of freedom, are able to duplicate the human-wrist movement inside the chest cavity while getting rid of surgeon tremors. As a result, it enables surgeons to perform an operation for a longer period of time with less fatigue (4). Because of its easier maneuverability, it may not require prior experience with laparoscopic or thoracoscopic surgery to get used to the system, demonstrating a better adaptability. However, the drawbacks of the da Vinci Surgical System include loss of haptic feedback and limited selection of instruments in comparison with that of thoracoscopic or open lobectomy. Consequently, as surgeons climb the learning curve in robot-assisted apparatus, they need to familiarize themselves with how to handle robotic surgical instruments and become accustomed to the absence of tactile feedback in a magnified but restricted operative field (28). As the accumulation of experience with robotic lobectomy grows, the drawbacks might become less obvious.

As an alternative to standard VATS, the da Vinci Surgical System has been increasingly applied to thoracic surgeries. Much work so far has focused on the safety and efficacy of open thoracotomy, VATS and RATS. Several studies proposed that the outcomes of the robotic technique contain smaller incisions, lower conversion rate to open surgery, decreased postoperative pain, shorter time of laying up, less incidence of complications, faster recovery, higher survival but longer operative time compared to conventional open thoracotomy (29,30). Nonetheless, given that most of the previous studies were based on retrospective observational studies and no large-scale RCTs have devoted to the comparison of various surgical approaches, the equivalence of long-term oncologic outcomes and cost effectiveness between RATS and VATS remains controversial (31,32). What's more, the high costs caused by implementation and maintenance have hindered robotic technology and surgery from becoming a widely used system. Hopefully, we can then anticipate that the competition and collaboration between the increasing manufacturing companies and academic institutions will contribute to decreasing the overall costs of RATS in the future.

The latest generation system, da Vinci Xi, was launched in 2014 with a concise docking, a more user-friendly design and laser guidance. In this system, a digital end-mounted camera with autofocus was installed on the thoracoscope for ameliorating the vision, enabling the ports to placed relatively close together but still avoid collision (28).

To date, the surgical robots are mostly assembled from rigid components and have relatively limited telescopic bending capabilities. The Flex Robotic System is the representative of the soft robotic platform, another interesting area of the future. It is featured by higher telescopic ability and easier access to difficult-to-reach regions of the body, thus making natural orifice endoscopic surgery possible (33). The softness and flexibility are both their merits and their weaknesses, so it calls for a balance between the rigidity of the instruments and the difficulty of manipulation (26). At present, some of these soft robots are in development, and the Flex Robotic System, is conducting human trials, particularly in the domain of transoral robotic surgery (34,35). As the robotic system evolves at a staggering pace, single-incision robotic chest surgery will be more and more widely applied in the years to come, resulting in safer, less painful, and superior efficacy operations for patients (36,37).

In conclusion, RATS is supposed to be a feasible and safe technology, with at least equivalent surgical efficacy with VATS. Besides, with the superiority in dexterity and stereoscopy, it is also an evolving field which allows more complex and precise procedures in narrow spaces in the thoracic cavity. Concerns of operative time and overall costs will be addressed by better proficiency of surgical team and the evolution of instruments, becoming more competitive with VATS. However, the related indication of RATS based on strong evidence are still vague. Therefore, it is still a challenge to set up the rigorous eligibility criteria and explicit definition of outcomes. Apart from these, the benefits between RATS and VATS is still a topic of debate and further studies are warranted to better define its potential the strengths and weaknesses.

Conclusions

Based on the mentioned progress in thoracic surgery for NSCLC, we propose that the glass-free 3D VATS system and RATS system have potential to be the mainstream approaches for future minimally-invasive thoracic surgery, with great economic and social benefits. Even though they are very promising, the authors consider they are still too early to be widely disseminated as routine surgical procedures currently. To further evaluate their feasibility, necessity and cost-effectiveness, more objective and clinically relevant outcomes by rigorous design clinical trials are indispensable before extensive usage.

It can be foreseen that the field of surgical technology will continue to make enormous strides. For instance, custom-designed light detection and ranging (LiDAR) scanner, electromagnetic navigational localization and 3D reconstruction can be implemented to further enhance the ability to localize and process the specific target. Besides, with the help of the coming 5G technology, if real-time 4k imaging technique was available, the quality of stereoscopic images will become even better. For RATS, surgeons have no direct contact with the tissues and only count on visual cues to evaluate consistency and tension, which is both the advantage and drawback. Correspondingly, another possible improvement may lie in the virtual haptic feedback for robotic surgeons.

In recent years, new inventions appear almost as fast as the demand for them. To this end, more surgeons, engineers and scientists will continue to collaborate in terms of evolution of more advanced technology.

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