Technological innovation in video-assisted thoracic surgery

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Abstract: The popularity of video-assisted thoracic surgery (VATS) which increased worldwide due to the recent innovations in thoracic surgical technics, equipment, electronic devices that carry light and vision and high definition monitors. Uniportal VATS (UVATS) is disseminated widely, creating a drive to develop new techniques and instruments, including new graspers and special staplers with more angulation capacities. During the history of VATS, the classical 10 mm 0° or 30° rigid rod lens system, has been replaced by new thoracoscopes providing a variable angle technology and allowing 0° and 120° range of vision. Besides, the tip of these novel thoracoscopes can be positioned away from the operating side minimize fencing with other thoracoscopic instruments. The curved-tip stapler technology, and better designed endostaplers helped better dissection, precision of control, more secure staple lines. UVATS also contributed to the development of embryonic natural orifice transluminal endoscopic surgery. Three-dimensional VATS systems facilitated faster and more accurate grasping, suturing, and dissection of the tissues by restoring natural 3D vision and the perception of depth. Another innovation in VATS is the energy-based coagulative and tissue fusion technology which may be an alternative to endostaplers.

Keywords: Video-assisted thoracic surgery (VATS); innovation; thoracoscope; three-dimensional; endostaplers; energy-based coagulative and tissue fusion technology

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Introduction

Due to the recent innovations in thoracic surgical technics, equipments, electronic devices that carry light and vision and high definition monitors, thoracic surgeons have the chance to perform less invasive treatments compared to their mentors. This brought the popularity to the video-assisted thoracic surgery (VATS) which increased worldwide attention to less invasive but major thoracic operations. The current paper will focus on certain innovations in VATS equipments.

The era of need for more dedicated equipments

Before uniportal VATS (UVATS) is disseminated widely, with a history spanning over more than 15 years, VATS operations have been performed mostly with conventional equipments. Only a few dedicated clamps, scissors, graspers and needle holders were available. UVATS approach was introduced firstly in thoracoscopic sympathectomy for palmar and axillary hyperhidrosis (1). Rocco *et al.* (2) reported first UVATS simple lung wedge resection in 2004, then this approach advanced to major anatomical lung resections (3). Better cosmesis and patient's demand allowed UVATS to spread quickly across the world.

In a very recent large-scaled propensity-matched study, Shen *et al.* (4) demonstrated that UVATS was at least not inferior to conventional VATS in terms of intraoperative and postoperative outcomes. Another recent study showed that UVATS was equally safe and effective compared to conventional VATS, and also reduced postoperative wound discomfort and analgesics requirement (5). It was also shown that, compared to conventional VATS, the total number of lymph nodes dissected with UVATS can be even higher, and thus this suggests that the technique does not compromise lymph node dissection (6).

Common problems to overcome during UVATS are the fencing of the instruments, the limited range and angle of vision of the thoracoscopes, and the difficulties in achieving stapling angles. Thus, to overcome these restrictions, there has been a drive to develop new techniques and instruments what were available for conventional VATS (7). Most of the graspers changed owing to the UVATS approach. UVATS also necessitated special staplers with more angulation capacities compared to conventional VATS. Also wide use of angled tip staplers became popular for easier and safe division of major vessels.

Development of thoracoscopes

In VATS, the quality of vision depends on the thoracoscope. One of the most important technological advancement that allowed the development of VATS was the rod lens thoracoscopes. A 10 mm 0° or 30° rigid rod lens system has been regularly used in conventional VATS. But as the size of incision decreased, then there has been a need to reduce the instrument fencing. Thus 5 mm scopes have been introduced, and despite their more limited width of vision they became popular in the specialized departments (8). Many surgeons preferred a 30° lens due to improved viewing angles. To overcome the problems of vision with a 30 degree camera, a new generation of wide-angled rigid thoracoscope (Endocameleon, Karl Storz, Germany) has been developed. This new thoracoscope provided a variable angle technology and allowed 0° and 120° range of vision. This wide viewing angle gives an exceptional vision to the whole thoracic cavity (9). Besides, the tip of this thoracoscope can be positioned away from the operating side, and this feature can minimize fencing with other thoracoscopic instruments and free up more instrument operating space (7). Wide viewing angles can also be achieved by making the scope more ‘flexible’ with the introduction of a 5.4 mm diameter deflectable tip thoracoscope (Endo-Eye™, Olympus, Tokyo, Japan). This type of flexible videoscope allows excellent visualization of the whole thoracic cavity, and prevents fencing of the instruments during UVATS (10). The Cardioscope developed by Li *et al*. (11) can also reduce fencing. This device has an adjustable length of its flexible distal tip section, which is designed to further reduce the collision of the instruments and to improve visualization. But compared to the Endo-Eye, the image quality of the Cardioscope is inferior, and further development is required to bring the Cardioscope to the operating room.

Remote wireless steerable endoscope is a possible future development. This scope is inserted into the thoracic cavity through the incision, and magnetically anchored to the chest wall. It then, transmits the video images of the surgical site to the monitör, and the field of view is controlled by steering the scope magnetically. The main advantage of this new scope is that it omits the cables associated with endoscopes, and does not interfere with other instruments. This type of thoracoscope is still under development, and so far demonstrated good performance in sliding, rotating and providing multiple viewing directions and angles (12).

Development of endostaplers

Endostaplers are used for the division of hilar or segmental vascular and bronchial structures in VATS major lung resections. They also divide the fissures and resects the lung. Endostaplers are primarily designed for general surgical laparoscopic procedures, but later they are quickly adopted by thoracic surgeons for VATS. In conventional VATS, the endostapler is inserted through the different ports to obtain better stapling angles. But in UVATS, the endostapler has a limited stapling angle and this may cause fencing of the instruments. To overcome these restrictions, the surgeon should better use an endostapler with a reduced shaft to minimize the space occupied at the incision which would decrease fencing, and with an increased angle of flexion of the tip which would widen the stapling angles (13).

The use of the curved-tip stapler technology (Covidien, Mansfield, MA, USA) facilitated the passage around the artery and superior pulmonary vein (13). Ng *et al*. (14) demonstrated that a new stapler design (ECHELON FLEX™ powered vascular stapler, Ethicon, Somerville, NJ, USA) was superior to conventional endostaplers in terms of ease of access, need for hilar structure dissection, precision of control, and reducing surgeons’ stress. In addition, this new four-row endocutter with a narrower anvil can achieve hemostasis similar to that of a standard six-row stapler. This new design makes the endostapler better suited for vascular applications at the pulmonary hilum located deep in the pleural space. Another endostapler (iDrive Tri-staple, Covidien, Mansfield, MA, USA), similar to the above-mentioned one, has an improved stapling stability, hence, produces a more secure staple line (15). MicroCutter XCHANGE 30 (Cardica, Inc., Redwood City, CA, USA) is a future endostapler. It has a narrower shaft, is lighter than other endostaplers, and designed to function with more angulation which allows surgery through a smaller incision with larger degrees of freedom. The stapler has a 80° angulated 5 mm curved-tip, which is an excellent option for the uniportal approach and especially useful for the management of the upper veins (13).

Alternate accesses

UVATS has contributed to the growing interest in development of other forms of single access instrument platforms, named as embryonic natural orifice transluminal endoscopic surgery (e-NOTES), which may have a significant role in the future of thoracic surgery (15). In 2013, Zhu *et al*. (16) reported their initial experience of thoracic sympathectomy in patients suffering from palmar hyperhidrosis, using the umbilicus as the natural orifice. The authors used a modified 5 mm ultrathin flexible gastroscope, and showed that this technique was safe, efficacious, and had excellent cosmesis with patient satisfaction. Owing to the success of e-NOTES sympathectomy, Wu *et al*. (17) also reported successful e-NOTES pericardial window and wedge lung resections.

There are also some reports of e-NOTES on animal models, such as transumbilical anatomic lobectomy of the lung in a canine model (18), and e-NOTES via the trans-tracheal route in the animal swine model (19). Turner and colleagues (20) used a flexible endoscope to conduct transesophageal thoracic sympathectomy in animal models; however, this method was technically demanding, which prevented its widespread application to patients.

Such approaches may be adequate for performing simple thoracic procedures. However e-NOTES necessitates more sophisticated endoscopic platforms for future development of more complex thoracic procedures. Equipment used for e-NOTES are categorized into two: flexible equipments, and miniaturized devices (21). Some of these devices are merely prototypes. The better known examples are EndoSamurai (Olympos, Tokyo, Japan), Anubiscope (Karl Storz, Tuttlingen, Germany), TransPort (USGI Medical, San Celemente, CA, USA), Cobra (USGI Medical, San Celemente, CA, USA), and Direct Drive Endoscopic System (Boston Scientific, Marlborough, Massachusetts, USA). These platforms have a steerable endoscopic component, and some of which have an endoscope conformation fixation feature. Three channels (two articulating, one nonarticulating) with specialized instruments are used in these platforms. A needle cautery helps to create a pathway through the natural orifice, and cautery, graspers, and clips, are directed within the instrument arms. The maneuverable instrument arms provide a good manual dexterity, ergonomics, and control of the surgeon, allowing more complex procedure to be performed. Compared to the standard endoscope, the surgeon can even exert traction and countertraction through a single endoscopic port. The use of these advanced platforms for more complex thoracic procedures requires further refinement and future development (13,15).

Three-dimensional VATS (3D-VATS)

A recent development in VATS is the 3D imaging of intrathoracic structures using a double lens binocular system. In the beginning, there were some problems including excessively heavy 3D glasses and camera heads, dimmer images compared with 2D systems, sterilization compatibility, and high cost. But as the technology matured, these restrictions are no longer issues. However, the independent scope rotation associated with changes in visual horizon can still distort the 3D images, causing the loss of definition. 3D-VATS can restore natural 3D vision and the perception of depth, so it has the potential of improving visualization. This advantageous point facilitates faster and more accurate grasping, suturing, and dissection of the tissues (22). Besides, 3D systems can help with the training as they represent the depth better than traditional 2D screens, thus may help to accelerate the learning curve for surgical tasks (22,23).

Yang *et al*. (24) compared the patients undergoing 2D and 3D-VATS resection for benign pulmonary diseases, and reported that the only significant difference was the reduction in the operation time in 3D-VATS. Similar results have been reported studies concerning of patients undergoing thoracoscopic lobectomy due to lung cancer (25-27). Contrary to these results, a recent study reported that there was no statistical difference with respect to duration of surgery, volume of intraoperative bleeding, drainage volume after surgery, duration of drainage tube insertion, hospitalization time after surgery, hospitalization costs, complications between 2D and 3D-VATS lobectomy. In addition, both techniques yielded similar numbers and groups of all lymph nodes or N_2 lymph nodes (28).

Based on the abovementioned studies, one can conclude that the only demonstrated advantageous point of 3D-VATS compared with traditional 2D-VATS is the reduction of the operating time.

Energy devices in VATS

Energy-based coagulative and tissue fusion technology has been used and heavily evaluated in almost all fields of surgery during the last decade. The use of energy to execute vascular fusion and division is now emerging as an alternative to endostaplers. In VATS lobectomy, the technical difficulty is mainly related to pulmonary artery branch manipulation with an actual danger in injuring the pulmonary artery while using an endostapler. This is due to the size, rigidity, and footprint of the endostaplers. Energy devices used in VATS, have the potential to avoid this limitation, thus make the procedure safer and less stressful for the surgeon, because they have smaller footprint and are easier to manipulate around short and small branches of the pulmonary artery (29).

In electrocautery, high-frequency electric current is used to cut the tissue and coagulate the vessels. Ultrasonic shears use both compression and friction to deliver mechanical energy to target tissue. Several energy-based fusion devices are currently available. Some of them are the harmonic scalpel (Ethicon Endo-Surgery, Cincinnati, Ohio, USA), ultrasonic shears (Covidien, Mansfield, Mass, USA), Gyrus PK Tissue Management System (Gyrus Medical, Minneapolis, Minn, USA), BiClamp VIO300D Electrosurgical System (ERBE Elektromedizin GmbH, Tuebingen, Germany), Enseal PTS Tissue Sealing and Homeostasis System (SurgRx, Redwood City, Calif, USA), and the LigaSure Device (Valleylab, Boulder, Colo, USA) (30).

There exist several reports in the literature concerning with the usage of bipolar electrocautery and ultrasonic devices in VATS. Tsunezuka and colleagues (31), and Watanabe and colleagues (32) demonstrated the safe usage of LigaSure sealing of segmental and subsegmental pulmonary artery branches. Bipolar tissue fusion systems can be used safely during the division of both pulmonary arteries and veins (≤7 mm) during anatomic lung resection. It can be considered a valid alternative to stapling technology in this setting (30).

Liberman *et al*. (33) evaluated four different energy sealing devices in pulmonary arterial branch sealing in an *ex vivo* model. This study suggested that ultrasound sealing technology seems to be superior to advanced bipolar technology in sealing pulmonary artery branches. In the last few years, adaptive tissue technology provided greater precision through improved energy delivery in ultrasonic devices. A novel device, the Harmonic ACE+7 (Ethicon) demonstrated its safety in sealing all pulmonary artery branches in a canine model (29). Liberman *et al*. (34) used the Harmonic ACE+ Shears (ACE, Ethicon, Cincinnati, OH, USA) sealing device in an *ex vivo* model. The authors concluded that pulmonary artery branches sealed using the Harmonic ACE+ Shears in a simulated *ex vivo* model were capable of maintaining high intraluminal pressures before reaching their bursting point, comparing than those of the vascular endostaplers in all pulmonary artery diameter subgroups.

Transcollation® technique is a new approach in resection of blebs and bullae in the surgical treatment of primary spontaneous pneumothorax. A 5 mm endoscopic instrument called EndoFB 3.0 Floating Ball (Salient Surgical Technologies Corporate, Portsmouth, NH, USA) is used in this approach. This device has been widely used for liver resections. This is a saline-cooled radiofrequency powered device connected to a standard operating theatre electrosurgical generator. The device conducts radiofrequency energy from the generator to the electrode tip, in which continuous low-volume saline irrigation cools the contact interface with the lung tissue, and keeps the surface temperature at 100 ℃. This avoids the eschar and char formation that occurs with standard electrocautery devices. The thermal energy denaturates the protein in the wall of blebs and bullae causes shrinking of these blebs and bullae at their bases, and welding their walls to the underlying lung parenchyma. This phenomenon is called transcollation. Moreover, vessels and bronchioli close nearby the bulla may be sealed (35,36).

Many energy devices have entered in VATS during the last decade. Some of them have proven and recognized applications and some others require further trials. Currently used devices continue in the improvement and new applications for current devices will be evaluated.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

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