Application of the da Vinci in thoracic surgery

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Abstract: The da Vinci Surgical System is an advanced minimally invasive surgical technique that has been widely applied in many fields of surgery. It was adopted relatively late in China, and its use in thoracic surgery is still growing. In this paper, we summarized its present applications in thoracic surgery. We also objectively evaluated its advantages and disadvantages in comparison with traditional open chest surgery and video-assisted thoracoscopic surgery (VATS). We believe that this technology has the potential to markedly change general thoracic surgery.

Keywords: Robot-assisted surgical system; minimally invasive surgery (MIS); lung; esophagus; mediastinum

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Surgical techniques have changed considerably over time, from large-incision open surgery to small-incision open surgery, and now to minimally invasive surgery (MIS), which is widely used. MIS reduces tissue trauma and pain, shortens the recovery time, minimizes complications and improves cosmetic results (1).

Minimally invasive thoracic surgery has been the focus of research in recent years. Video-assisted thoracoscopic surgery (VATS) has been used for more than 20 years in China and has gained broad acceptance for various thoracic diseases. Although VATS is recommended as the standard operation for radical lung resection by the National Comprehensive Cancer Network (2), its limitations include the restriction of sensory information to a two-dimensional image and difficulty in maneuvering tips of instrument. The da Vinci robotic Surgical System was introduced to overcome these limitations.

As early as 500 years ago, Leonardo da Vinci, the greatest European artist and inventor of the 15th century, designed a humanoid robot on the drawings. In 1990s, Intuitive Inc. invented the da Vinci Surgical System, by applying the most advanced robotic arm used in the space program for clinical use. In 2000, the da Vinci Surgical System became the first automatic control system for endoscopic surgery approved by the U.S. Food and Drug Administration (3).

The da Vinci Surgical System consists of three major components (*Figure 1*): a console for the operating surgeon, the robotic arm cart, a vision cart including optical devices for the robotic camera. This system makes it possible for the surgeon sit at the console and trigger highly sensitive motion sensors that transfer the surgeon's movements to the tips of the instruments, rather than directly operating on the patient with surgical instruments. The da Vinci Surgical System is clearly the next step for MIS after VATS. Ruijin Hospital adopted the da Vinci Surgical System for thoracic tumors early and has accumulated practical experience.

Advantages of the da Vinci Surgical System

Compared with traditional MIS, the robotic arms of the da Vinci Surgical System effectively eliminate any hand tremor to improve the stability. The system also provides a clear and magnified three-dimensional operative field (4). The image and the instruments are kept in the same direction to optimize eye-hand coordination, which enables precise tissue dissection, hemostasis, and suturing. The flexible

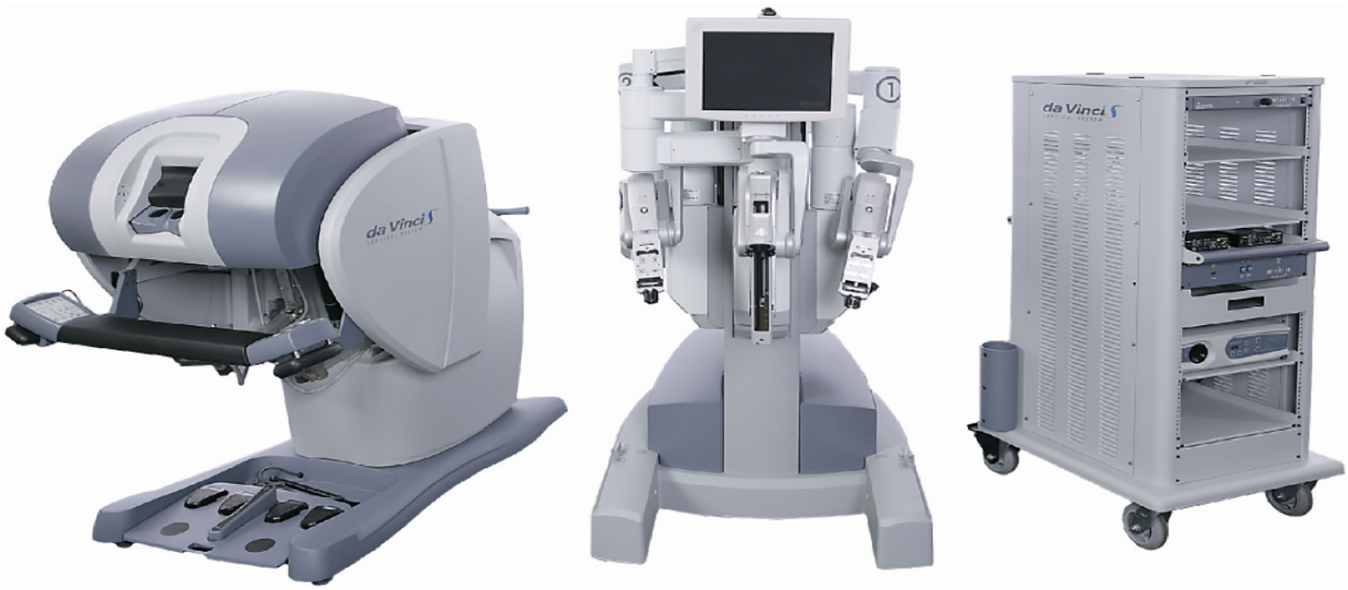

Figure 1 The components of da Vinci Surgical System.

multi-joint arms and so-called "Endo Wrist technology" offer seven degrees of freedom, exceeding the capacity of the surgeon's hand in open surgery. The surgeon can adjust the camera and manipulate the field of view simultaneously (5). The da Vinci Surgical System can reduce tissue trauma and shorten the recovery time, which is the advantage of precise MIS. In the future, telesurgery may become possible with this robotic system.

Application of the da Vinci Surgical System in thoracic surgery

The da Vinci Surgical System was approved for thoracic surgery in 2001 and was introduced in China in 2006 (3,5,6). This new technology has been used by many medical institutions for thoracic procedures, such as pulmonary lobectomy, esophagectomy, resection of mediastinal cystic and solid tumors, thymectomy, diaphragmatic hiatus repair, cardiomyotomy, and lymph node dissection, etc.

Conditions for use

(I) Strict indications: patients should undergo a full evaluation to determine the indication. Injuries caused by prolonged surgeries and anesthesia must be avoided.
(II) Experienced teams: a successful team includes skilled surgeons, anesthetists, and nurses to ensure efficiency, safety, and thoroughness.
(III) Flexibility: the surgical team should have the insight and decisiveness to rapidly respond to unexpected situations.

Lung surgery

Lobectomy with lymph node dissection is a major challenge in thoracic robotic surgery, and surgeons must also be familiar with open surgery and VATS (7). Surgeons usually choose small tumor to learn robotic surgery techniques and accumulate experience. When the tumor is large and adheres to blood vessels, open surgery is safe. Early in 2000, Okada *et al*. (8) used the Televox AESOP system and automatic traction control to perform right middle lobectomies and mediastinal lymph node dissections. Then AESOP was replaced by the da Vinci Surgical System. In 2002, Melfi *et al*. (9) used the da Vinci system for 12 lung surgeries: 5 lobectomies, 3 mass resections, and 4 pulmonary bullae resections. As the technology has developed, and surgeons have accumulated experience, especially with the second-generation da Vinci Surgical System, robotic lung surgery has become widely accepted by surgeons and patients (10,11). The system has a clear and magnified three-dimensional operative field, and its robotic arms effectively eliminate the hand tremor to improve stability, which enables precise segmental resection and sleeve resection (12,13). Robotic lung surgery was adopted late in China. In 2011, Yi *et al.* (14) completed 22 robotic surgeries on lung nodules. In 2013, Wang *et al.* (7) reported successful robotic lung surgeries and completed the first robotic surgery of the right lower lobe for central lung cancer, upper lobe dorsal segment resection, and lymph node dissection. The retrospective studies of Brooks (15) and Park (16) *et al.* showed that robotic-assisted lobectomies were feasible, safe and oncologically sound procedures for patients with stage IA or IB lung cancer, but noted that there is a steep learning curve. Mahieu *et al.* (17) reported that perioperative results for lung surgeries were comparable to results of robotic surgery and VATS. Numerous researchers consider robotic lung surgery to be comparable to VATS, or even superior to VATS regarding accuracy. However, multi-center and large randomized controlled studies are needed to compare the long-term outcomes of robotic-assisted lung surgery with those of conventional open surgery and VATS (18,19).

Esophagus surgery

Esophagus cancer operations are complex and multisite, which is a challenge in robotic surgery and they were attempted relatively late. The most important factors associated with long-term survival are local recurrence and lymph nodes recurrence. Therefore, lymph node dissection is important in esophagus cancer and the dissection range is from the apical chest to above the diaphragm. The da Vinci Surgical System offers convenience for lymph node dissection. In 2003, Horgan (20) reported the first robotic transhiatal esophageal resection and treated 15 patients with this procedure in the following 2 years. In 2004, Kernstine (21) reported the first robotic transthoracic esophageal resection. Other reports described primary experiences to demonstrate the feasibility of robotic esophageal resection. In 2011, Yi *et al.* (14) reported robotic esophageal resection in China. In recent years, some researchers tried using a semi-prone position rather than the traditional left lateral position to provide a clear operative field and convenient space for the surgeons (22). In 2013, Ishikawa *et al.* (23) reported the safety and feasibility of using semi-prone position for robotic surgery, and Dunn (24) reported similar results for a single-center clinical trial of 40 patients. Mori *et al.* (25,26) compared the robotic transthoracic esophageal resection with the traditional transthoracic approach and found that the robotic surgery was superior for lymph node dissection and resulted in a lower rate of postoperative infection. A study by Park (27) reported good safety and perioperative results of robotic esophageal resection with mediastinal lymph node dissection in 114 patients. However, prospective studies are still needed to compare the survival rates of traditional and robotic esophageal resection. As this new technology continues to develop, and surgeons accumulate experience, robotic esophageal resection will be more widely applied.

Mediastinal surgery

Midsternal incisions used for thymomas and other anterior mediastinal tumors fully expose tissues but can lead to serious complications. For that reason many medical institutions use VATS instead of open surgery. However, VATS is limited for superior mediastinal suprathoracic lesions. The magnified three-dimensional view and EndoWrist of the da Vinci system overcome the limitations of VATS. Thus, many European hospitals use the da Vinci Surgical System for thymectomies (28).

The da Vinci Surgical System has been used in mediastinal surgery for more than 10 years, especially for myasthenia gravis (29). In 2002, Yoshino *et al.* (30) reported the first robotic thymectomy. In 2009, Huang *et al.* (31) completed the first robotic thymectomy in China. After Bodner *et al.* (32,33) concluded that robotic thymectomy has obvious advantages, it became a routine surgery in many medical institutions. A study by Seong *et al.* (34) describing the treatment of anterior mediastinal tumors in 145 patients showed that robotic surgery is superior to open surgery and comparable to VATS. A retrospective study by Ding *et al.* (35) including 203 patients with mediastinal lesion showed that surgery time was comparable between robotic surgery and VATS. In addition, robotic surgery was superior to VATS regarding safety and recovery but costs more. Kajiwara *et al.* (36) also reported that the robotic surgery is comparable to traditional surgery but is safer and easier to perform than traditional surgery. Many medical institutions emphasize the importance of using a trocar, and the choice is dependent on the position of the tumor (31,34,35).

The flexible robotic arms can completely dissect the adipose tissue near the phrenic nerve completely. The superior vena cava and both innominate veins can be exposed safely and clearly, make it convenient and accurate to access the top of thymus, which has obvious advantages in the removal of superior mediastinal tumors and is comparable to open surgery (37). Thymic veins, which are the primary vessels that must be dealt with in thymectomies, can be easily clamped, ligatured, and sutured in robotic surgery. The structure of the anterior mediastinum can be demonstrated clearly (38-40). A case series involving more than 50 patients at Shenyang Military Hospital (37) showed that the robotic surgery considerably reduced postoperative pain and discomfort caused by the pleural drainage tube, minimizing trauma and accelerating recovery. Robotic thymectomy is also used in certain patient populations, such as children, obese patients, and the elderly.

Other surgery

There are limited reports about other surgeries, such as Hellers' myotomy, hiatal hernia repair, diaphragmatic hernia repair, and esophagobronchial fistula repair. Tolboom *et al*. (41) reported that robotic surgery has no obvious advantage for hiatal hernia repair and gastroesophageal reflux surgery but has an advantage over a second surgery or huge hiatal hernia repair. Most of the reports were published in the early stage of robotic surgery use, and the primary aim was to accumulate experience.

Limitations

The maker of da Vinci Surgical System has a monopoly in the minimally invasive robotic surgery market. There are still some technical defects to overcome. For example, the mechanical fingers lack the force feedback (42) which make it difficult to judge tissue texture, elasticity, and vessel pulsatility and limits the determination of the tissue intersection and dissociation of vessels. This system is complex and carries a high possibility of operating problem that requires a specialized technician (43). Because the learning curve of the robotic system is relatively steep and prolonged, few surgeons have experience using this system. Wang *et al*. (7) concluded the surgeons should be skilled in VATS before learning robotic surgery, but Lee *et al*. (43) reported that was no advantage for surgeons with VATS experience in learning robotic surgery. It is still controversial whether robotic surgery should be used in children. Cundy *et al*. (44,45) reported that in the future, robotic surgery systems matched to specific populations(e.g., children) will be developed. In addition, the high cost is another limitation of the da Vinci Surgical System.

Prospects

The da Vinci Surgical System, which represents precise MIS, reflects that trend in MIS development. In our analysis, the da Vinci Surgical System produces less tissue trauma, reduces postoperative complications, and shortens the recovery time compared with traditional VATS. This system has a broad application in MIS and is worth promotion. In the future, the da Vinci Surgical System will likely be miniaturized and have force-feedback technology. In addition, the Intuitive Surgical Inc. is developing a small highly integrated uniportal surgical robot, which could be a technological breakthrough. Along with the increase in yield and the realization of localization, the problem of high cost will be solved when robotic surgery is popularized in China in the near future.

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Footnote

Conflicts of Interest: Both authors have completed the ICMJE uniform disclosure form (available at http://dx.doi.org/10.21037/amj.2017.01.02). The authors have no conflicts of interest to declare.

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