Minimally invasive thoracic surgery: robot-assisted versus video-assisted thoracoscopic surgery

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Abstract

Minimally invasive techniques have been widely applied in general thoracic surgery. Compared with video-assisted thoracoscopic surgery (VATS), due to its theoretic superiority, robotic surgery is challenging the traditional position of VATS. With its unique advantages, including 3D vision and a high-freedom endowrist, it leads to easier lymph node dissection, more convenient blood vessel dissection, a shorter learning curve and competence for the completion of complex surgery. However, as a new surgical technology, the safety and efficacy of robotic-assisted thoracoscopic surgery (RATS) still need to be further verified. Thus, in this article, we review and summarize the application of RATS versus VATS in general thoracic surgery.

Key words: *video-assisted thoracoscopic surgery, robotic-assisted thoracoscopic surgery, minimally invasive, thoracic surgery.*

Introduction

Continuous minimization of surgical trauma is the driving force for the surgeon. In the past 30 years, with the development of new technologies and innovation of surgical techniques, minimally invasive surgery has gradually evolved and flourished. Compared with the conventional open approach, minimally invasive thoracoscopic techniques have achieved tremendous success in thoracic surgery. Nonetheless, with the continuous deepening of the application, the inherent defects of video-assisted thoracoscopic surgery (VATS) are gradually exposed, such as bidimensional impaired view, non-ergonomic stiff instruments and insufficient processing capacity in a narrow space. To overcome the limitations, the robotic surgical operating system has emerged and further promoted the development of minimally invasive surgical techniques.

The Da Vinci robot surgical system, as a typical representative, possesses 3D visualization, high-resolution magnification of the surgical field, tremor filtration, and improved maneuverability of the instruments with 7 degrees of freedom. Since the approval for clinical application by the FDA in 2000, the Da Vinci robot surgical system has been widely used in many fields of surgery, including general thoracic surgery. Moreover, due to its theoretic advantages over VATS, robotic-assisted thoracoscopic surgery (RATS) is constantly challenging the traditional position of VATS.

Aim

Recently, several studies were conducted to compare the feasibility and safety of RATS over the VATS approach in certain aspects of general thoracic surgery. Thus, in this article, we review and summarize

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the application of RATS in general thoracic surgery and compare it with VATS.

Material and methods

A brief literature search in the PubMed database was conducted for studies and reports focusing on the application of RATS and VATS in general thoracic surgery. We used a combination of MeSH terms, subject headings and keywords as search strategies to obtain relevant articles.

Results

The application of RATS vs VATS in general thoracic surgery was reviewed and compared, as shown in Table I.

Lung surgery (RATS vs. VATS)

In 2002, the Da Vinci System was first introduced to perform thoracoscopic lung resection [1]. Gradually, with the growth of this novel technique throughout the world, the indications for RATS are increasingly closer to the conventional VATS, and mainly for early-stage lung cancer. Supported by the positive results and increasing experience, consequently, the thoracic surgeons confidently expanded the indications to increasingly complicated procedures. Nowadays, RATS has been successfully applied in locally advanced lung cancer and other challenging cases, including bronchial/arterial sleeve resection [2–4], pneumonectomy [5], and lobectomy following induction therapy [6].

Standard procedure and short-term results

There is nearly no doubt about the feasibility and safety of RATS. Numerous studies have found that RATS was equivalent to conventional VATS. A systematic review and meta-analysis was performed to compare the effect of RATS and VATS in lung resection (pneumonectomy, lobectomy, and segmentectomy). Operation time, mortality, drainage duration and length of hospitalization of patients were analyzed, and the result showed that RATS was as time-efficient as VATS and showed a trend to reduced hospital stay and drainage duration, with lower mortality [7]. A meta-analysis including 12 retrospective studies was conducted to evaluate the feasibility and safety of RATS versus VATS for lobectomy in patients with non-small cell lung cancer (NSCLC). The short-term surgical effect of RATS was equivalent to VATS, but its cost effectiveness was a problem worth considering [8]. A recent meta-analysis of 14 studies including a total of 7438 patients was conducted, comparing the safety/efficacy of the RATS and VATS approach to lobectomy/segmentectomy for radical lung cancer resection. The results showed that the robotic approach is a feasible and safe alternative to VATS, with significantly lower 30-day mortality (0.7% vs. 1.1%; odds ratio (OR) 0.53, p = 0.045) and conversion rate to open surgery (10.3% vs. 11.9%; OR = 0.57, p < 0.001) [9]. Recently, a multi-institutional propensity score-matched (257 paired patients) analysis was conducted to compare the early outcomes of robotic versus thoracoscopic segmentectomy for early-stage lung cancer. The ro-

Table I. Application of RATS vs VATS in general thoracic surgery

Surgery	Field	RATS vs. VATS	
		Advantage	Disadvantage
Lung surgery	Standard lung surgery	Equivalent to VATS	Higher cost
	Lymph node evaluation	Potential superiority with regards to the number of dissected lymph nodes, lymph node stations and the rate of nodal upstaging	
	Bronchial/arterial reconstruction	Technique simplification with 3D visualization, tremor filtration, etc.	
Esophageal surgery	Esophagogastrectomy	Potential superiority in lymph node dissection and protection of recurrent laryngeal nerve	Higher cost
	Other esophageal procedures	Controversial	
Mediastinal surgery	Mediastinal surgery	Potential superiority in cases of greater size, locally invasive, located extremely	Inferiority in posterior mediastinal tumors, with a higher cost

botic technique was equivalent to VATS in operative time, blood loss, rates of overall complications, and length of stay, with a higher cost [10, 11].

In summary, for a standard procedure, mainly for early-stage lung cancer, RATS seem to be equivalent to VATS in terms of short-term results, with a higher cost. And it could be considered the standard technique in anatomic lung resection.

Complex procedures

Lymph node evaluation

The number of dissected lymph nodes, lymph node stations and the rate of nodal upstaging represented completeness of nodal evaluation and quality of surgery.

Mungo *et al.* investigated the result of robotic versus thoracoscopic resection for lung cancer, and robotic surgery appeared to be associated with more lymph nodes retrieved (9 vs. 7, $p = 0.049$) [12]. Several studies have found that the robotic approach harvested a higher number of median stations of lymph nodes than VATS [10, 11, 13]. Zhang *et al.* retrospectively analyzed 774 patients (298 via robotic, 476 via VATS) under segmentectomy for early-stage NSCLC, and the robotic approach harvested a greater number of N1 lymph nodes and N1 stations, indicating a better N1 lymph node dissection [10]. Among RATS, VATS and open lobectomy in stage I NSCLC, the highest number of median stations of lymph nodes (5 for robotic vs. 3 for VATS vs. 4 for open; $p < 0.001$) was harvested in the RATS group. Another study reported that the robotic approach harvested a higher number of median stations of lymph nodes (5 for robotic vs. 3 for VATS vs. 4 for open; $p < 0.001$), resulting in greater lymph node assessment [13].

Kneuertz *et al.* [14] retrospectively analyzed 1053 patients with clinical stage N0/N1 NSCLC, and the pathologic nodal upstaging by robotic, video-assisted thoracoscopic, and open lobectomy was compared to assess the effectiveness of intraoperative lymph node (LN) staging. The overall rate of LN upstaging was similar for open (21.8%) and robotic (16.2%), lower for VATS (12.3%) lobectomy ($p = 0.03$). In Wilson' study robotic resection appeared to be superior to VATS and similar to thoracotomy in the rate of nodal upstaging for clinical stage I NSCLC [15].

In summary, based on the limited evidence, RATS was at least not inferior to VATS and even superior with regards to lymph node assessment. RATS shows potential superiority with regards to the number of dissected lymph nodes, lymph node stations and the rate of nodal upstaging.

Bronchial/arterial reconstruction

Robotic surgery used in the treatment of centrally located lung cancer and complex lung cancer was limited, including bronchial or pulmonary arterial sleeve resection, and there are very few related randomized controlled studies. In 2011, Schmid *et al.* reported the first case of bronchial anastomosis by RATS technique in the right upper lobe bronchial sleeve resection [16]. Subsequently, several small case series were reported and preliminarily proved that the robotic sleeve resection for centrally located lung cancer was feasible and safe [17, 18], even for double-sleeve resection [4].

In 2019, Jiao *et al.* [2] published the largest single-center retrospective study so far; a total of 67 consecutive patients who underwent robotic bronchial sleeve lobectomy were enrolled. A half-continuous suture technique with two Prolene sutures for bronchial anastomosis was applied. All the patients successfully completed the surgery with no conversion to thoracotomy. The total bronchial anastomosis time was 20.8 min (range: 10–44) and the postoperative morbidity rate was 20.9%.

In summary, RATS bronchial/arterial reconstruction is safe and feasible for the treatment of centrally located lung cancer in selected patients by highly experienced operators.

Long-term results

There are few studies exploring the long-term benefits of RATS and VATS. The existing studies are mainly retrospective, non-randomized studies.

Yang *et al.* [19] evaluated the outcomes of VATS versus robotic lobectomy for clinical T1-2, N0 non-small cell lung cancer from 2010 to 2012 in the National Cancer Data Base using propensity score matching. Between the two groups (robotic, $n = 1938$; VATS, $n = 1938$), there was no statistically significant difference in 2-year survival. Another study also reported that VATS and robotic lobectomy for clinical N0 lung cancer were similar in 2-year overall survival (88% vs. 95%, respectively; $p = 0.40$), or 2-year disease-free survival (83% vs. 93%, respectively; $p = 0.48$) [20]. Park *et al.* [21] evaluated the long-term oncologic results of robotic lobectomy for non-small cell lung cancer (NSCLC). From November 2002 to May 2010, at 3 institutions, a total of 325 consecutive patients were enrolled. Long-term stage-specific survival is acceptable and consistent with prior results for VATS and thoracotomy [21]. With a median follow-up of 27 months, 5-year survival was 91% for stage IA, 88% for stage IB, 49% for stage II disease, and 3-year survival was 43% for stage IIIA disease. Yang *et al.* [13] compared the long-term (from 2002 to 2012) outcomes among 172 RATS, 141 VATS and 157 open lobectomies for stage I non-small cell lung cancer (NSCLC). The study indicated that minimally invasive approaches, including RATS and VATS, presented with similar 5-year long-term survival and shorter length of stay [13]. The latest study compared robotic-assisted, VATS and open lobectomy for patients with stage I–IIIa NSCLC (from 2012 to 2017), with 514 patients in total and 245 robotic-assisted, 118 VATS and 151 open lobectomy subgroups [22]. The 5-year overall survival for robotic-assisted, VATS, and open lobectomy was 63%, 55%, and 65%, respectively (p = 0.56). Equivalence was also found in stage-specific survival for stage I, II, and IIIa.

In summary, based on the existing evidence, RATS presented with a similar long-term oncological effect to VATS for lung cancer. Prospective randomized trials comparing open, VATS and RATS approaches are necessary.

Esophageal surgery (RATS vs. VATS)

In 2002, Melvin described their initial robotic experience in foregut surgery, including the first case of robotic esophagectomy with intrathoracic anastomosis [23]. Robotic-assisted transhiatal and transthoracic techniques were then developed in 2003, 2004, respectively [24, 25]. Gradually, robotic-assisted minimally invasive esophagectomy (RAMIE) was expanded to the major medical centers around the world. Additionally, robotic fundoplication and robotic Heller myotomy were also widely adopted. The application in robotic esophageal surgery has gained increasing interest and acceptance.

Esophagogastrectomy

Esophageal cancer was the most common indication of esophageal surgery. Due to the particularity of esophageal cancer surgery, the optimal approach is still under debate, with diverse tubular stomach methods, esophagastro anastomotic technique, range of lymph node dissection, and so on. Robot-assisted McKeown and Ivor-Lewis esophagectomy with two/three-field lymph node dissection are the two most typical methods, each of which has advantages and disadvantages.

McKeown surgery is widely used, and most reported RAMIE are performed with the McKeown procedure, since the first case in 2004. Cervical anastomosis can ensure a sufficient proximal margin of tumor, and the incidence and mortality of cardiopulmonary complications followed by anastomotic fistula are low. Compared with the Ivor-Lewis esophagectomy, the incidence of anastomotic fistula for McKeown surgery is relatively high. For Ivor-Lewis esophagectomy, it was mostly applied in lower thoracic part esophageal carcinoma, emerging as a mainstream approach. Intrathoracic anastomosis leads to lower anastomotic tension and anastomotic fistula rate, which is suitable for tumors located in the lower esophagus or the gastroesophageal junction. However, the intrathoracic gastroesophageal anastomosis is relatively difficult and the safety of the anastomosis raised concern, which limits the extensive application of the technique. In addition, transhiatal esophagectomy is mainly applied in esophagogastric junction (EGJ) tumor, and robotic-assisted transhiatal esophagectomy was reported in 2003 [25]. Compared with McKeown and Ivor-Lewis surgery, it avoids an intrathoracic procedure, reducing the complications of the cardiopulmonary system. However, the incompleteness of lymph node dissection was a concern for most thoracic surgeons, so its promotion was very limited. In recent years, inflatable mediastinoscopic and simultaneous laparoscopic transhiatal esophagectomy has been promoted in some centers [26, 27]. The approach is in its infancy, and has yet to be assessed.

Together with laparoscopic/thoracoscopic minimally invasive esophagectomy, robotic esophagectomy was also considered as minimally invasive esophagectomy (MIE). A series of studies has proved the effect and safety of robot radical resection of esophageal cancer. Zhang *et al.* recently published the results of robot-assisted versus thoracoscopic-assisted Ivor Lewis esophagectomy for esophageal cancer [28]. Propensity score-matched analysis was performed and 66 matched pairs were analyzed. Except for a longer operative time for robotic-assisted MIE (RAMIE), there was no significant difference in the short-term outcomes, including blood loss, rates of overall complications, length of stay, the number of total dissected lymph nodes, and so on. Chen *et al.* compared the robot-assisted and thoracoscopic-assisted McKeown esophagectomy for resectable thoracic esophageal squamous cell carcinoma [29]. A 1 : 1 propensity score match analysis (54 pairs) was performed, and the RAMIE presented better recurrent laryngeal nerve protection and higher total and daily expenses. The other characteristics were comparable between the two groups, including operative time, intraoperative blood loss, number of resected lymph nodes, and R0 resection rates. Another study identified 9,217 patients who underwent RAMIE (581; 6.3%), MIE (2,379; 25.8%), or open esophagectomy (OE, 6,257; 67.9%) using the National Cancer Data Base, from 2010 to 2013. After the propensity-matched analysis (569 pairs), the number of lymph nodes harvested and survival were similar among the three groups [30]. A meta-analysis involving 1862 patients (931 under RAMIE and 931 under MIE) assessed the safety and feasibility of RAMIE versus MIE in patients with esophageal cancer, conducted by Jin *et al.* The analysis indicated that RAMIE and MIE display similar feasibility and safety [31], with a similar R0 resection rate, conversion to open surgery, 30-day mortality rate, 90-day mortality rate, in-hospital mortality rate, postoperative complications, number of harvested lymph nodes, operation time, and length of stay in hospital.

Furthermore, some studies suggested that RAMIE may be superior in R0 resection of locally invasive tumors, lymph node dissection, and exposure of mediastinal fine structures (such as recurrent laryngeal nerve and thoracic duct). Several studies found that RAMIE could harvest a significantly greater number of total dissected lymph nodes [32, 33], including recurrent laryngeal nerve lymph node [32–34]. Also, compared with conventional MIE, RAMIE did not increase the rates of recurrent laryngeal nerve palsy [33, 34], or even presented better nerve protection [29, 31]. Better quality lymphadenectomy could be achieved in RAMIE; however, prospective randomized studies are necessary. Lately, a multicenter, open-label, randomized controlled trial (Robotic-assisted Esophagectomy vs Video-Assisted Thoracoscopic Esophagectomy) was conducted [35]. The primary outcome measure is the rate of unsuccessful lymph node dissection along the left recurrent laryngeal nerve. The perioperative and oncological outcomes were also analyzed. The final results are expected.

There are few studies focused on the long-term prognosis benefit of the two techniques for esophageal cancer. A large-scale study evaluated outcomes of minimally invasive approaches to esophagectomy using the National Cancer Data Base, and open (n = 2,958), standard minimally invasive esophagectomy without robotic assistance (n = 1,077) and robot-assisted esophagectomy (n = 231) for cT1-3N0-3M0 cancer of the middle or distal esophagus were enrolled and analyzed [36]. The subgroup analysis was performed to compare the robotic technique with the conventional MIE. The result indicated that perioperative outcomes and 3-year survival were similar between the two approaches. Other studies have shown that in long-term follow-up, the oncological effect of RAMIE is comparable to MIE [30, 36].

Other esophageal procedures

In addition, RATS has also been widely applied in other esophageal procedures, and several comparative studies have been conducted between RATS and conventional minimally invasive procedures, such as Heller myotomies for the treatment of achalasia [37–39], Nissen fundoplications for gastroesophageal reflux disease (GERD) [40, 41], hiatal hernia repair [42], resection of benign esophageal tumors, and excision of symptomatic epiphrenic diverticula. These limited studies revealed that RATS is feasible and safe for these benign esophageal disorders. When compared with the conventional minimally invasive procedures, the results were controversial. Some studies stated that RATS is associated with longer operative time and higher total costs, with no additional benefit, while others suggested that the robotic surgical system might simplify the operation and reduce the complications. However, most studies were very preliminary, with a low level of evidence, restricting the interpretation of these results.

In summary, based on the previous data, RAMIE would be similar to the conventional MIE in the short-term perioperative results and curative effect, and might be superior in lymph node dissection and protection of the recurrent laryngeal nerve. Comments regarding the other robotic applications of esophageal disorders are premature at present.

Mediastinal surgery (RATS vs. VATS)

In 2001, Yoshino *et al.* [43] pioneered the first case of mediastinal tumor resection with the da

Vinci computer-enhanced surgical system. Nowadays, in the treatment of mediastina disease, including thymic thymoma, thymic carcinoma, teratoma, neurogenic tumor, benign cyst and so on, RATS could achieve good short-term clinical efficacy and safety.

The selection of the patient's position and the port incision is crucial to the success of robotic surgery. Based on the mainstream mature mode, the technique could be adjusted appropriately according to the surgeon's preference and patients' condition. At present, the intercostal and trans-subxiphoid approach are the two main choices. Through the intercostal approach, the robotic port selection was generally similar to VATS and could vary slightly according to the location of the tumor, tumor size, and so on. The advantages of the intercostal approach lie in its visual field and short operation distance, but it also has disadvantages, such as intercostal nerve injury and difficulty in total or extended thymectomy and large solid specimen retrieval. For routine posterior mediastinal tumors and benign anterior mediastinal tumors, the intercostal approach is relatively simple and preferred. The trans-subxiphoid approach possesses unique advantages, such as no intercostal nerve injury, better vision of both phrenic nerves and the neck, simultaneous access to bilateral pleural cavities, and so on. For mediastinal tumors, especially for anterior mediastinal tumors, with the assist of artificial pneumothorax or sternum elevating retraction, the technique could achieve satisfactory effect as the median sternotomy approach. Recently, trans-subxiphoid RATS in thymectomy/extended thymectomy for thymoma/myasthenia gravis has attracted growing attention [44, 45]. The long-term prospect of this approach will need further confirmation. In addition, with the upgrading of the robotic system and the cooperation of more intelligent and exquisite operating instruments, there would be fewer limitations of patient' position and more choices of approaches in the future.

For anterior mediastinal lesions, thymoma with/without myasthenia gravis (MG) in particular, the treatment was of great concern. A series of studies has been conducted to compare the outcome of RATS/VATS in the surgical treatment of thymoma. Compared with the treatment of thymoma under VATS, whether robotic surgery was superior was still unclear. The previous published case-control studies are controversial, and a series of meta-analyses was conducted to systematically evaluate the value of RATS for thymoma. It was widely accepted that RATS is at least not inferior to VATS. A meta-analysis including 5 of the 478 studies describing robotic versus thoracoscopic thymectomy was conducted [46], and surgical outcomes, operation time, length of hospitalization, intra-operative blood loss, conversion to sternotomy and post-operative complications was analyzed. Buentzel *et al.* [46] found that there were no significant differences between the two groups. A systematic review conducted by Fok *et al.* [47] enrolled 350 patients receiving minimally invasive thymectomy, for which 182 and 168 patients underwent RATS and VATS thymectomy, respectively. The results showed that there was no significant difference in the conversion to thoracotomy, length of hospital stay and postoperative pneumonia between the two groups, while the robotic group had a longer operation time. Another systematic review was conducted comparing robotic to both open and VATS thymectomy for myasthenia gravis, and the results suggested that robotic thymectomy was comparable with the VATS approach and superior to open surgery [48]. Besides the mentioned short-term promising outcomes, however, due to the inertness and occult nature of the thymoma, future randomized controlled studies evaluating long-term (> 10 years) oncological outcomes are imperative to make definitive conclusions.

For posterior mediastinal tumors, generally, VATS is superior to RATS, due to its feasibility, safety and cost-effectiveness. In certain situations, such as those mediastinal lesions located adjacent to the superior/inferior sulcus of the thoracic cavity or aorta, which are very difficult for VATS to reach, the resection under the RATS approach could be performed safely and precisely [49, 50].

Furthermore, due to the unique characteristics, RATS showed potential advantages in surgical treatment of mediastinal tumors involving the pericardium and greater vessels [51], including difficult dissections, complex sutures or excision of very large tumors (> 8 cm) [52]. In addition, our previous study showed that RATS presented a significantly lower unplanned conversion rate than the VATS group in the resection of mediastinal lesions [53].

In summary, the application of RATS for mediastinal tumor resection is similar to the conventional VATS. While dealing with tumors which are of greater size, locally invasive, located extremely, RATS seemed feasible and safe.

Other thoracic surgery

RATS has also been applied in other thoracic diseases, such as acute diaphragmatic rupture repair and thoracic duct ligation. However, due to the few cases reported in the literature, a relevant discussion was not included.

Others

Cost analysis of RATS

Several studies have argued a higher cost of RATS over VATS or open surgery [54–58], which limited the wide acceptance and application of RATS, to a certain extent. The cost comparison was mainly conducted in lung surgery. Park *et al.* [55] assessed the financial impact of RATS, VATS and open lobectomy, and the average cost of RATS was found to be higher than VATS, but less than thoracotomy. Paul *et al.* enrolled 2,498 RATS and 37,595 VATS lobectomies performed between 2008 and 2011 in the United States, and they concluded that RATS lobectomy in the early experience was more expensive than VATS ($ 22,582 vs. $ 17,874, $p < 0.05$) [56]. The hospital costs of VATS lobectomies and wedge resections versus RATS were compared in another study, of 15,502 cases analyzed, and the average hospital cost of lobectomies that underwent RATS was $25,040.70 vs. $20,476.60 for VATS ($p = 0.0001$) and $19,592.40 vs. $16,600.10 ($p = 0.0001$) for wedge resections, respectively [57]. Deen *et al.* [58] reported that robotic lobectomy and segmentectomy cost $3,182 more than VATS ($p < 0.001$) owing to the cost of robotic-specific supplies and depreciation. A recently published study revealed that robotic segmentectomy was more costly ($12,019.30 ±1678.30 vs. $7834.80 ±1291.20; $p < 0.001$) because of the amortization and consumables of the robotic system [10]. Robotic thymectomy was estimated to cost V1701 ($2279) more than VATS thymectomy [59]. With regards to esophagectomy, RAMIE was more costly (25.3 ±9.0 vs. 20.8 ±9.0 thousand US dollars, $p = 0.009$) [31].

Importantly, the cost and maintenance of the da Vinci robotic surgical system should also be taken into account. Generally, the costs of a da Vinci robotic surgical system ranged from $1 to $2.5 million [60], and the annual maintenance was approximately $100,000 to $170,000 [55, 61]. It is clear that the more cases are performed by each machine, the lower is the indirect cost and the better the cost-efficiency. Furthermore, in hospitals whose annual volume was > 25 lobectomies, robotic-assisted lobectomy was cost-comparable to VATS and open lobectomy ($p = 0.11$) [62]. And if more manufacturers enter into the competition, and a new economical generation of robotic systems is developed, RATS would be more cost-effective.

Conclusions

At present, the Da Vinci robot surgical system is widely applied in general thoracic surgery, coexisting with conventional VATS. With its unique advantages, including 3D vision and a high-freedom endowrist, it leads to easier lymph node dissection, more convenient blood vessel dissection, a shorter learning curve and competence for the completion of complex surgery for RATS. In the future, large randomized trials will be necessary to elucidate the potential benefit. But RATS still has several shortcomings to overcome: the robotic surgical system is expensive to purchase and the medical cost (the instruments need to be replaced regularly) and maintenance cost are high; force feedback is lacking; the preoperative preparation and replacement of instruments are relatively time-consuming; it needs a more skilled assistant in case of conversion to thoracotomy and so on. In addition, the monopoly position of Intuitive Inc. in the field and patent protection further restrict its development. However, it is believed that with the appearance and competition of the emerging robotic system, the evolution of the technique, the improvement of patient income level and medical insurance policy in the coming future, minimally invasive robotic surgery could be routinely performed and benefit more and more patients.

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Conflict of interest

The authors declare no conflict of interest.

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