An update on robotic thoracic surgery and anesthesia

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Purpose of review

Minimally invasive surgery involving the thoracic cavity continues to increase. With the introduction of robotic systems, particularly the da Vinci robot system more than 10 years ago, thoracic operations have been performed with some provocative results and limited, defined advantages. The present review provides an overview of common thoracic surgical procedures performed with the robotic system and discusses the anesthetic implications.

Recent findings

The literature on this topic currently includes case reports or series of clinically prospective or retrospective observational reports with the use of robotic systems, involving the thoracic cavity (mediastinal mass resections, lobectomies, and esophagectomies); unfortunately there are very limited reports related to anesthetic implications or complications related to the use of this technology. The majority of the surgical reports involve the use of lung isolation devices for thoracic surgery, specifically the use of a double-lumen endotracheal tube (DLT); a few centers use carbon dioxide (CO_2) insufflation as part of their management to achieve maximal surgical exposure while compressing the operative side of the lung away from the operative area.

Summary

Anesthesiologists must be familiar with lung isolation techniques and flexible fiberoptic bronchoscopy while participating in thoracic surgical cases that require robotic systems. In addition, prevention and recognition of potential complications, such as crushing injuries or nerve damage, must be sought. Because the potential for converting to an open thoracotomy exists, all measures must be taken to manage patients accordingly if the situation arises.

Keywords

brachial plexus injury, da Vinci robotic surgical system, fiberoptic bronchoscopy, lung separation techniques, thoracic anesthesia, thoracic robotic surgery

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Introduction

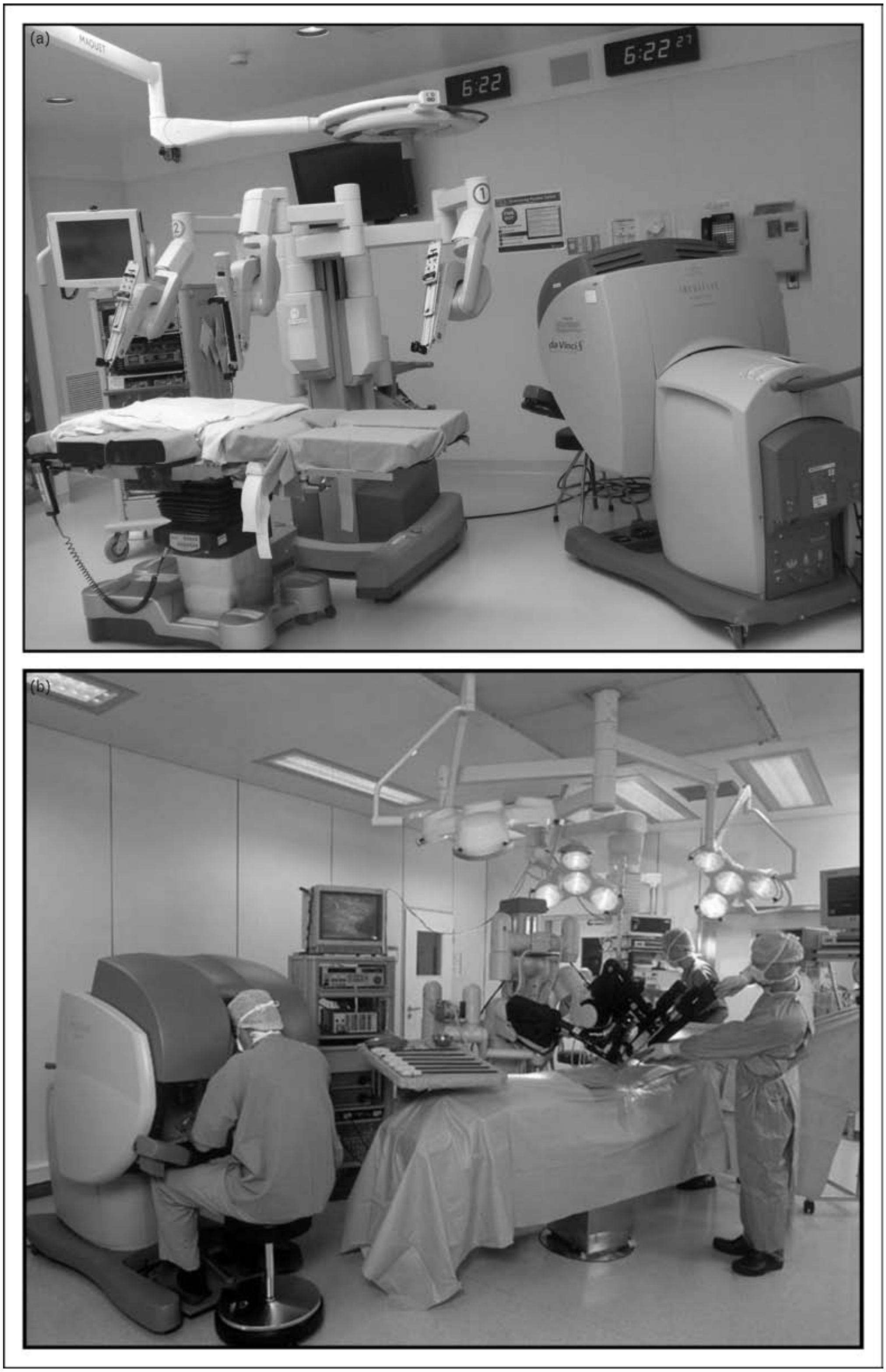
Minimally invasive surgery approaches have become increasingly popular in thoracic and esophageal surgery. Video-assisted thoracoscopic surgery continues to gain acceptance for diagnostic and therapeutic procedures involving the lung or adjacent organs [1,2]; despite reported favorable outcomes with these techniques, there are some limitations for their methodology such as impaired vision and restricted maneuverability of the tips of the instruments [3]. A robotic system, the da Vinci Robotic Surgical System (Surgical Intuitive, Inc, Mountain View, California, USA), has been used to overcome these difficulties at the same time as enhancing surgical management [4,5]. The present review provides an overview of the anesthetic implications and the use of the robotic system in patients undergoing robotic-assisted surgery through the thoracic cavity with particular emphasis on the mediastinum, lungs, and esophagus.

The da Vinci Robotic Surgical System

The da Vinci Robotic Surgical System provides three-dimensional (3D) video imaging plus a set of tele-manipulated flexible effector instruments [5]. The system consists of three major components, a console for the operating surgeon, a patient-side cart with four interactive robotic arms, and a vision cart including optical devices for the robotic camera. Figure 1a and b displays the da Vinci Robotic Surgical System.

The surgeon operates while seated at a console and views a 3D image of the surgical field through the vision system. The patient-side cart (the actual robot) consists of three or four robotic arms, two or three instrument arms, and

Figure 1 da Vinci Robotic Surgical System



(a) The console, the robotic system, and the monitors. (b) An actual operation being performed with the robotic system.

one endoscope arm, which houses the camera. A full range of EndoWrist (Surgical Intuitive) instruments are used to assist with the surgery.

In practice the first two arms, representing the surgeon's left and right hands, hold the EndoWrist instruments; a third arm positions the endoscope. The optional fourth arm, which represents the latest design in the da Vinci Robotic Surgical System, adds surgical capabilities by enabling the surgeon to add a third EndoWrist instrument. The surgical instruments are introduced via special ports and attached to the arms of the robot. The surgeon sitting at the console triggers highly sensitive motion sensors that transfer the surgeon's movement to the tip of the instruments. The EndoWrist technology provides seven degrees of motion, which exceeds the capacity of a surgeon's hand in open surgery, and two degrees of axial rotation to replicate human wrist-like movements. Robotic procedures are usually performed by two surgeons, the surgeon at the console and the table-side surgeon, who places the trocars and connects them with the robotic arms, changes the robotic instruments, and manipulates additional endoscopic instruments through the auxiliary ports if needed. The size of the robotic trocar is 10 mm for the binocular robotic camera and 8 mm for the instruments.

With the progress in minimally invasive surgery there has been an increased utilization of new technology; unfortunately in thoracic surgery only a few case series or isolated case reports have been published. One of the advantages of using the da Vinci Robotic Surgical System in esophageal or thoracic surgery is a shorter hospital stay, less pain, less blood loss and transfusion, minimal scarring, faster recovery, and probably a faster return to normal activities [6,7].

Surgical procedures performed in thoracic surgery with the da Vinci Robotic Surgical System are as follows:

(1) thymectomy,
(2) mediastinal mass extirpation,
(3) fundoplications,
(4) esophageal dissections,
(5) esophagectomy, and
(6) pulmonary lobectomy.

Robotic-assisted surgery and anesthesia for mediastinal masses

One of the thoracic surgical procedures performed to date using the da Vinci Robotic Surgical System is the thymectomy [7]. Of the patients scheduled for robotic-assisted thymectomy, some have the diagnosis of myasthenia gravis because the presence of a thymoma. Therefore, all precautions must be taken regarding the anesthetic management, including the proper use of muscle relaxants and also the effects of the size of the mediastinal mass in relation to the airway and its implications for obstruction.

Patients undergoing thymectomy with the robotic system require the use of lung isolation devices. The most common device used in this setting is the left-sided double-lumen endotracheal tube (DLT). Performing a thymectomy with the use of the robot system requires an optimal surgical position. In these cases, the patients are placed in an incomplete side-up position at a 30° angle right or a left lateral decubitus position with the use of a beanbag. The arm of the elevated side is positioned at the patient's side as far back as possible so the surgeon can gain enough space for the robotic arms. The surgical incisions are made through the chest with one incision in the fifth intercostal space on the midaxillary line and two incisions for thoracic ports through the third intercostal space in the midaxillary region and another incision in the fifth intercostal space on the midclavicular space. Specific points to consider while the robot is in use are to protect all pressure points and avoidance of unnecessary stretching of the elevated arm because it can produce damage to the brachial plexus. Also, before the arm of the robot is in the chest cavity, a complete lung collapse must be maintained throughout the procedure. Robotic surgery with the da Vinci Robotic Surgical System does not allow for changes in patient position on the operating room table once the robot has been docked. Special attention must be given to the elevated arm or head to prevent crushing injuries by the robotic arms. A recent case report [8•] described a brachial plexus injury in an 18-year-old male after robot-assisted thoracoscopic thymectomy. In this report the left upper limb was in slight hyperabduction. It is important to keep in mind that hyperabduction of the elevated arm to give optimal space to the operating arm of the robot can lead to a neurologic injury. Close communication between the surgeon and anesthesiologist in relation to the positioning and functioning of the robot is mandatory, and all proper measures must be taken, including the use of soft padding and measures to avoid hyperabduction of the arm. The elevated arm should be protected by using a sling resting device.

An early report by Bodner *et al.* [9] involving 13 patients with mediastinal masses resected with the da Vinci Robotic Surgical System showed no intraoperative complications or surgical mortality. In this series of patients, a complete thymectomy with en bloc removal of all mediastinal fat around the tumor was performed. In this report, cases were restricted to patients with a tumor size of less than 10 cm in diameter.

In a report by Savitt *et al.* [10] involving 14 patients undergoing robot-assisted thymectomy, all patients received a DLT for selective lung ventilation; in addition, patients were managed with arterial and central venous pressure catheters. Complete thymectomy was performed on all 14 patients. Right-lung deflation was accomplished with selective lung ventilation and carbon dioxide (CO_2) insufflation to a pressure of 10–15 mmHg to maintain the lung away from the operative area. It is important that the anesthesiologist recognize the effects of CO_2 insufflation in the thoracic cavity and its potential for hemodynamic instability, including obstruction to venous return and profound hypotension [11•]. Also, CO_2 insufflation in the chest cavity will lead to an increase in peak airway pressure, particularly during one-lung ventilation. The outcome of this report included no conversion to open thoracotomy, nor any intraoperative complications or deaths; the median hospital stay was 2 days with a range of 1–4 days.

In another report, Rückert *et al.* [12] had zero mortality and an overall postoperative morbidity rate of 2% in 106 consecutive robot-assisted thymectomies. Therefore, robotic thymectomy is a promising technique for minimally invasive surgery. Length of stay is shorter with robotic thymectomy than with the conventional approach via sternotomy.

Robotic-assisted pulmonary lobectomy and anesthetic implications

With the introduction of the da Vinci Robotic Surgical System more than 10 years ago, there has been widespread interest in its use in minimally invasive surgery involving the chest. Unfortunately, the use of the robotic system for pulmonary resections, particularly lobectomies, has been limited to a few cancer centers around the world.

A report by Park *et al.* [13] showed robot-assisted thoracic surgical lobectomy to be feasible and safe. In the report, the operation was accomplished with the robotic system in 30 out of the 34 scheduled patients. Four of these patients required conversion to open thoracotomy.

Positioning the patient for a robotic lobectomy includes placing the patient over a bean bag in a maximally flexed lateral decubitus position with the elevated arm slightly extended so that the thoracic cavity can be accessed and no damage to the arm occurs during manipulation of the robotic arms. Patients undergoing robotic lobectomy must have a lung isolation device to achieve one-lung ventilation. In the vast majority of these cases, a left-sided DLT is indicated and optimal position achieved with the flexible fiberoptic bronchoscope [14]. In a few cases in which the airway is deemed to be difficult, an independent bronchial blocker should be used, and optimal position achieved with the use of a fiberoptic bronchoscope [15]. Initial thoracic exploration is performed with conventional thoracoscopy to verify tumor location. In general, three incisions are made. One incision is for the camera and is placed on the 7th intercostal space at the posterior axillary line. The next incision is placed just above the diaphragm posterior to the tip of the scapula. These incisions in general are no more than 2 cm in length. A third incision is made, usually a minithoracotomy 4 cm in length; this is made at the 4th or 5th intercostal space in the anterior axillary line. This incision is used for retrieval of the specimen. During robot-assisted lobectomy, it is mandatory that lung collapse is achieved effectively to allow the surgeon the best field of vision and to avoid unnecessary damage to vessels or lung parenchyma.

All patients undergoing robot-assisted thoracic lobectomy must have an arterial line. The anesthesiologist must be ready for the potential of conversion to an open thoracotomy. In the Park report [13], three out of the four cases that needed to be converted had minor bleeding; in addition, in one case lung isolation was lost, requiring an open thoracotomy. It is mandatory that anesthesiologists involved in these cases have experience in placing a DLT [16] and can guarantee optimal position with the aid of a flexible fiberoptic bronchoscope.

A recent report by Gharagozloo *et al.* [17] involving 61 patients who underwent lobectomy and complete mediastinal nodal dissection for early stage lung cancer (stage I and II) with the robotic system reported nonemergent conversions to an open thoracotomy. In the report, postoperative analgesia was managed with the infusion of a local anesthetic (0.5% bupivacaine, 4 ml/h) through catheters placed in a subpleural tunnel encompassing intercostal spaces two to eight. All patients in this report were extubated in the operating room. Overall mortality within 30 days was 4.9%, and median length of stay was 4 days. Postoperative complications included atrial fibrillation in four cases, prolonged air leak in two cases, and pleural effusion requiring drainage in two cases – complications that do not differ from those occurring with video thoracoscopic surgery. Although lobectomy can be performed via robot-assisted surgery, the advantages at the present time are not well defined. In contrast, the increasing surgical times, the increased number of operating room personnel needed, and the cost and outcomes of robotic surgery need to be studied and compared with thoracoscopic lobectomy.

Robotic-assisted esophageal surgery and anesthetic implications

Transthoracic esophagectomy with extended lymph node dissection is associated with higher morbidity rates than transhiatal esophagectomy. Esophagectomy is a

Table 1 Complications of robotic-assisted thoracic surgery

Author	n = cases	Operation	Intraoperative complications	Postoperative complications
Rea *et al.* [7]	33	Thymectomy	0	Chylothorax $n=1$; hemothorax $n=1$
Pandey *et al.* [8•]	1	Thymectomy	–	Brachial plexus injury
Bodner *et al.* [9]	14	Mediastinal mass resection	0	Postoperative hoarseness due to lesion to left laryngeal recurrent nerve
Savitt *et al.* [10]	15	Mediastinal mass resection	0	Atrial fibrillation $n=1$
Rückert *et al.* [12]	106	Thymectomy	Bleeding $n=1$	Phrenic nerve injury $n=1$
Park *et al.* [13]	34	Lobectomy	Conversion to open thoracotomy $n=3$; lack lung isolation $n=1$	Supraventricular arrhythmia $n=6$; bleeding $n=1$; air leak $n=1$
Gharagozloo *et al.* [17]	100	Lobectomy	0	Atrial fibrillation $n=4$; air leak $n=2$; bleeding $n=1$; pleural effusion $n=2$
van Hillegersberg *et al.* [20]	21	Esophagectomy	Conversion to open procedure $n=3$	Pulmonary complication 60% first 10 cases; pulmonary complication 32%, 11 patients
Kernstine *et al.* [21]	14	Esophagectomy	Conversion to open procedure $n=1$	Thoracic duct leak $n=3$; vocal cord paralysis $n=3$; atrial fibrillation $n=5$

palliative and potentially curative treatment for esophageal cancer. Minimally invasive esophagectomy has been performed to lessen the biological impact of surgery and potentially reduce pain. The initial experience with the da Vinci robot system involved a patient who had a thoracic esophagectomy with wide celiac axis lymphadenectomy; the case was reported by Kernstine *et al.* [18] and had promising results. Thereafter, another report described using the da Vinci robot system in six patients undergoing esophagectomy without intraoperative complications [19]. The surgical approach in this report was performed from the right side of the chest. A left-sided DLT was used to selectively collapse the right lung while at the same time ventilation was maintained in the left lung.

In a report by van Hillegersberg *et al.* [20] involving 21 consecutive patients with esophageal cancer who underwent robot-assisted thoracoscopic esophagolymphadenectomy, 18 were completed thoracoscopically and three required open procedures (because of adhesions or intraoperative hemorrhage). In this case series, all patients received a left-sided DLT and a thoracic epidural catheter as part of their anesthetic management. Positioning of these patients was in a left lateral decubitus position, and the patient was tilted 45° toward the prone position. Once the robotic thoracoscopic phase was completed, the patient was then put in the supine position and a midline laparotomy was performed. A cervical esophagogastrostomy was performed in the neck for the completion of surgery.

Of interest in this series is the fact that pulmonary complications occurred in the first 10 cases (60%), caused primarily by left-sided pneumonia and associated acute respiratory distress syndrome in three patients (33%). These complications were probably related to barotrauma to the left lung (ventilated lung) attributed to high tidal volumes and high peak inspiratory pressures. In the 11 patients that followed, the same authors modified their ventilatory setting to administer continuous positive airway pressure ventilation 5 cmH_2O during single-lung ventilation and pressure-controlled ventilation was used; with this approach the respiratory complication rate was reduced to 32%.

Another study [21] involved 14 patients who underwent esophagectomy using the da Vinci robot system in different surgical stages. It showed that, for a complete robotic esophagectomy including laparoscopic gastric conduct, the operating room time was an average of 11 h with a console time by the surgeon of 5 h, and an estimated average blood loss of 400 ± 300 ml. In this report after the robotic thoracoscopic part of the surgery was accomplished with the patient in the lateral decubitus position, patients were then placed in the supine position and reintubated, and the DLT was replaced by a single-lumen endotracheal tube. The head of each patient was turned upward and to the patient's right, exposing the left neck for the cervical part of the operation. Among the pulmonary complications in the postoperative period, atrial fibrillation was present in five out of the 14 patients.

In Kernstine's report [21], among the recommendations to improve efficiency in these cases is the 'use of an experienced anesthesiologist who can efficiently intubate and manage single-lung ventilation and hemodynamically support the patient during the procedure.' This follows what Nifong and Chitwood [16] have reported in their editorial views regarding anesthesia and robotics: that a team approach with expertise in these procedures involving nurses, anesthesiologists, and surgeons with an interest in robotic procedures is required. Table 1 displays the complications of robotic-assisted thoracic surgery involving the mediastinum, lung and esophagus.

Conclusion

The use of the da Vinci robot system in thoracic and esophageal surgery continues to gain acceptance.

Although its use has reduced surgical scarring and decreased length of stay, specific indications for use in these areas needs to be determined. Because of the limited reports available, all reports indicate the use of lung isolation devices, particularly a left-sided DLT, as part of the intraoperative management of thoracic surgery patients as mandatory to facilitate surgical exposure. In addition, because the surgical approach varies depending on the thoracic procedure, optimal positioning is not standard, and varies according to the specific surgical procedure; vigilance is required with patients' elevated arms to avoid nerve injuries or crushing injuries with the robotic arms. The potential to convert to an open thoracotomy requires preparation by the surgical team and anesthesiologist. The use of the da Vinci Robotic Surgical System is expected to grow in the years to come [22]. Prospective studies are needed to define the specific advantages of this robotic system.

References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

Additional references related to this topic can also be found in the Current World Literature section in this issue (p. 116).

1 McKenna RJ Jr, Houck W, Fuller CB. Video-assisted thoracic surgery lobectomy: experience with 1100 cases. Ann Thorac Surg 2006; 81:421–425.

2 McKenna RJ Jr, Mahtabifard A, Pickens A, *et al.* Fast-tracking after video-assisted thoracoscopic surgery lobectomy, segmentectomy, and pneumonectomy. Ann Thorac Surg 2007; 84:1663–1668.

3 Dieter RA Jr, Kuzyçz GB. Complications and contraindications of thoracoscopy. Int Surg 1997; 82:232–239.

4 Melfi FM, Menconi GF, Mariani AM, Angeletti CA. Early experience with robotic technology for thoracoscopic surgery. Eur J Cardiothorac Surg 2002; 21:864–868.

5 Mack MJ. Minimally invasive and robotic surgery. JAMA 2001; 285:568–572.

6 Bodner J, Wykypiel H, Wetscher G, Schmid T. First experiences with the da Vinci operating robot in thoracic surgery. Eur J Cardiothorac Surg 2004; 25:844–851.

7 Rea F, Marulli G, Bortolotti L, *et al.* Experience with the 'da Vinci' robotic system for thymectomy in patients with myasthenia gravis. Ann Thorac Surg 2006; 8:455–459.

8 Pandey R, Elakkumanan LB, Garg R, *et al.* Brachial plexus injury after robotic-
• assisted thoracoscopic thymectomy. J Cardiothorac Vasc Anesth 2009; 23:584–586.

Interesting case report of a nerve injury.

9 Bodner J, Wykypiel H, Greiner A, *et al.* Early experience with robot-assisted surgery for mediastinal masses. Ann Thorac Surg 2004; 78:259–265.

10 Savitt MA, Gao G, Furnary AP, *et al.* Application of robotic-assisted techniques to the surgical evaluation and treatment of the anterior mediastinum. Ann Thorac Surg 2005; 79:450–455.

11 Sullivan MJ, Frost EA, Lew MW. Anesthetic care of the patient for robotic
• surgery. Middle East J Anesthesiol 2008; 19:967–982.

A complete review of anesthetic implications and robotic surgery.

12 Rückert JC, Ismail M, Swierzy M, *et al.* Thoracoscopic thymectomy with the da Vinci robotic system for myasthenia gravis. Ann N Y Acad Sci 2008; 1132:329–335.

13 Park BJ, Flores RM, Rusch VW. Robotic assistance for video-assisted thoracic surgical lobectomy: technique and initial results. J Thorac Cardiovasc Surg 2006; 131:54–59.

14 Campos JH. Update on tracheobronchial anatomy and flexible fiberoptic bronchoscopy in thoracic anesthesia. Curr Opin Anaesthesiol 2009; 22:4–10.

15 Campos JH. Progress in lung separation. Thorac Surg Clin 2005; 15:71–83.

16 Nifong LW, Chitwood WR Jr. Challenges for the anesthesiologist: robotics? Anesth Analg 2003; 96:1–2.

17 Gharagozloo F, Margolis M, Tempesta B, *et al.* Robot-assisted lobectomy for early-stage lung cancer: report of 100 consecutive cases. Ann Thorac Surg 2009; 88:380–384.

18 Kernstine KH, DeArmond DT, Karimi M, *et al.* The robotic, 2-stage, 3-field esophagolymphadenectomy. J Thorac Cardiovasc Surg 2004; 127:1847–1849.

19 Bodner JC, Zitt M, Ott H, *et al.* Robotic-assisted thoracoscopic surgery (RATS) for benign and malignant esophageal tumors. Ann Thorac Surg 2005; 80:1202–1206.

20 van Hillegersberg R, Boone J, Draaisma WA, *et al.* First experience with robot-assisted thoracoscopic esophagolymphadenectomy for esophageal cancer. Surg Endosc 2006; 20:1435–1439.

21 Kernstine KH, DeArmond DT, Shamoun DM, Campos JH. The first series of completely robotic esophagectomies with three-field lymphadenectomy: initial experience. Surg Endosc 2007; 21:2285–2292.

22 Czibik G, D'Ancona G, Donias HW, Karamanoukian HL. Robotic cardiac surgery: present and future applications. J Cardiothorac Vasc Anesth 2002; 16:495–501.