Review Article

Anesthesia for robotic thoracic surgery

ABSTRACT

The management of the robotic thoracic surgical patient requires the knowledge of minimally invasive surgery techniques involving the chest. Over the past decade, robotic-assisted thoracic surgery has grown, and, in the future, it will take an important place in the treatment of complex thoracic pathologies. The enhanced dexterity and three-dimensional visualization make it possible to do this in the small space of the thoracic cavity. Familiarity with the robotic surgical system by the anesthesiologists is mandatory. Management of a long period of one-lung ventilation with a left-sided double-lumen endotracheal tube or an independent bronchial blocker is required, along with flexible fiberoptic bronchoscopy techniques (best continuous monitoring). Correct patient positioning and prevention of complications such as eye or nerve or crashing injuries while the robotic system is used is mandatory. Recognition of the hemodynamic effects of carbon dioxide during insufflation in the chest is required. Cost is higher and outcome is not yet demonstrated to be better as compared to video-assisted thoracic surgery. The possibility for conversion to open thoracotomy should also be kept in mind. Teamwork is mandatory, as well as good communication between all the actors of the operating theatre.

Key words: Anesthesia; robotic; thoracic

Introduction

A robot is a machine capable of carrying out a complex series of actions automatically. Robots have been increasingly integrated into clinical medicine. Surgical robotics is an evolving field aiming to take advantage of the features of robotics which made them so valuable in other industries.

In 1985, the first surgical application of robotic technology in medicine was described performing a stereotactic brain biopsy.[1] In 1992, thousands of patients underwent hip surgery in Europe, but this device was not FDA approved because of the complication rates.[2-4]

In 1997, Intuitive Surgical's da Vinci® surgical system was used to perform a laparoscopic cholecystectomy.[5] In 1999, Computer Motion Inc. introduced the Zeus surgical system, with differences in the configuration of the surgeon's workstation. After several legal issues, in 2003, Computer Motion and Intuitive Surgical merged into a single company.

The da Vinci Surgical System® is a robotic surgical system made by the American company Intuitive Surgical and approved by the FDA in 2000. It is controlled by a surgeon seated at a console which gives him a three-dimensional (3D) image of the surgical field. The actual robot—the patient-side cart—consists of three or four robotic arms, housing different

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instruments and the endoscope embedded camera. The third component of the system is a video monitor, including optical devices for the robot.

A full range of Endo Wrists (Surgical Intuitive) instruments are at the disposal of the surgeon for the operation. They provide seven degrees of motion, which exceeds the capacity of a normal hand during open surgery and two degrees of axial wrist-like rotations.[6] The instruments are introduced via special ports and the surgeon's movements at the console are transmitted in a highly sensitive manner to the instruments attached to the arms of the robot.

Usually, a first surgeon operates the console, while the second surgeon, at the operating table, introduces and changes the trocars and the different instruments necessary for the operation.

Robotic-assisted thoracic surgery (RATS) started in a few centers in the mid-late 90s. The first report was made at the beginning of the year 2000.[7]

Yet, we may not recognize any major advantage in the outcome when compared to video-assisted thoracic surgery (VATS), but certainly, the capabilities of the robotic surgery could be beneficial. More experience in RATS may provide superior results in oncological, physiological, and life quality measurements.[8]

Advantages and Disadvantages of RATS

Advantages of VATS as compared to open thoracic surgery are less trauma,[9] shorter chest drainage duration, decreased hospital stay,[10-12] preservation of short-term pulmonary function,[13] reduced pain, and fewer complications. RATS was mainly compared with the VATS and because it is also a minimally invasive technique, it will be difficult to show major differences in performance.

RATS is a surgical technique that is getting more and more integrated in the spectrum of thoracic surgery. The spread of initial minimally invasive techniques was slow considering limitations (limited maneuverability and unstable camera platform)[7] and poor ergonomics. Often, one specific technique, either VATS or RATS, is chosen by one particular surgeon. A minority of thoracic surgeons are trained in both minimally invasive techniques and therefore it will be difficult to obtain large comparative studies with those equipoise experts. Also, worldwide the experience is widely differing, in some areas robotic platform has integrated very well, while in others RATS, programmes are just starting up.

The costs for the use of a robotic system are an important factor. Since VATS does not have such an expensive price tag, its penetration is more widespread. There is no real standardization of the VATS, which seems to be more the case with RATS. Furthermore, the learning curve for RATS is greater than for VATS (50 cases vs. 25 cases to be performed by the surgeon to be certified).[14,15] Obviously, the traditional way of surgical training must be taken into account. Previously, everyone was trained for open surgery through the thoracotomy or sternotomy, later on, the VATS was started up. In the group of people who have not switched to VATS, there are a number of surgeons that immediately switched to RATS bypassing VATS. Those surgeons who switched from VATS to RATS already had a minimal invasive thoracic surgery learning curve.

Advantages of RATS are the 3D vision, the use of the robot-controlled and hinged instruments, and the ergonomic aspect for the surgeon. Movements are more precise, filtered, and scaled, with improved surgical precision and accuracy.

The robotic system is not perfect: loss of tactile feedback, increased operation time, distance between the surgeon and the patient. The significant disadvantage remains the high cost price of the system and the parts that are needs for an operation. Instruments can only be used for a limited time, which leads to considerable costs. Some data suggest that shorter hospital stay will offset partially the higher cost.

Specific robotic training is required. This can be done on a dual console system. The "student"–surgeon and the experienced surgeon (proctor) have the same picture and switching the instruments between the two consoles is easy. In addition, the da Vinci® robot surgical system has introduced the da Vinci skills simulator, where surgeon and surgical team can participate in the development of specific skills in a simulator center.

In case of bleeding, there is often a better control possibly because the robots' arms remain firm in the same position and are not dependent on a human factor such as movements or distraction. An emergency thoracotomy can always be performed while the bleeding remains stable and control can be achieved better than with a VATS procedure.

Ergonomics for the surgeon at the robotic console are also better. Even physically, sitting down on a comfortable chair at the console is completely different from standing with two surgeons sideways from a patient and looking at a screen.

In the meantime, the technique has been considered safe, reproducible, and there is an association with a reduced duration of stay, low morbidity, and mortality.[11] Recent publications confirmed that RATS achieve equally good oncological results. Larger series show that the visualization and dissection of lymph nodes in the mediastinum can be performed more smoothly so that more nodal levels can be reached during dissection. This provides better staging of the disease and consequently a more adapted therapy.[10] This has also ensured that the RATS has developed well in recent years and the number of procedures continues to increase.

Surgical Possibilities with RATS

Lobectomy

The lobectomy is the most commonly performed oncologic procedure in which a precise anatomical dissection of the lung is performed. Long-term oncologic results are consistent with other large series using VATS or thoracotomy.[15] The morbidity is also the same and there are no specific complications because of the robotic system described in the literature (in case of thoracic surgery). A retrospective study by Bao *et al*. compared RATS *versus* VATS for lung resection and found no improvement in any clinical outcomes, but RATS procedures took longer and cost significantly more.[16] Blood loss is not significantly different in comparative ranges between VATS and RATS.[17]

Segmentectomy

Due to the wider range of well control movement of the robotic arms and improved operative visualization techniques of vascular structures with indocyanine green and creation of anatomic 3D models for preoperative planning, segmentectomy (sublobar anatomical resection in a lobe) has become an intervention that can also be performed by more surgeons using a mini-invasive approach. The meticulous dissection of hilar, bronchial, and vascular lymph nodes which are important for the correct staging of early lung cancer was made more accessible by RATS operation.

Thymectomy

Minimal invasive thymectomy is indicated for a majority of patients with myasthenia gravis and early-stage thymoma.[18] The robotic approach offers a better mediastinal dissection, may improve cosmetic results, and reduce postoperative pain with accelerated recovery.[19] Size is generally accepted as a factor for the choice of operative approach, although there are no guidelines. Masses smaller than 4 cm on imaging techniques resected by RATS give better results for quality of life (QoL) postoperatively. Balduyck *et al*. evaluated the QoL after RATS or open anterior mediastinal tumor resection. Open resection was characterized by a significant decrease in general functioning 1 month after surgery. Patients also complained of increased thoracic pain in the first 3 months after surgery. After RATS thymectomy, QoL scores approximated baseline preoperative values 1 month after surgery.[20]

Oesophagectomy

Robotic-assisted oesophagectomies are performed similarly to minimally invasive oesophagectomies, by using a transhiatal route or combined transthoracic and transabdominal approach.[6,21] The experiences with robotic oesophagectomies are very limited, therefore only case reports or case series were yet reported. No data demonstrated improved outcomes in terms of operative morbidity, pain, length of stay, operative time, or total costs, as compared to minimal invasive techniques.[6] Reported complications[22,23] after oesophageal cancer surgery were conversion to open procedure because of adhesions or hemorrhage, anastomotic leakage, dysrhythmia, acute lung injury, vocal cord paralysis—this latest seems to be less frequent than in case of classical surgery.[19] Kernstine *et al.*,[23] and Nifong and Chitwood[24] have reported the necessity of a team approach in case of robotic oesophagectomy, with trained nurses, surgeons, and anesthesiologists in robotic surgical procedures.

A study compared pressure versus Volume-controlled one-lung ventilation during oesophagectomy in prone position, without significant differences between the two ventilatory modes.[25]

Special Issues Concerning the Anesthetic Management

Given the relative recent introduction of RATS technique for thoracic surgery, there are few studies describing the anesthetic and analgaesic technique to be used during RATS. Nevertheless, there is evidence for some differences when compared to classical VATS, some specific points, while others are common for all types of robotic surgery that should be taken into consideration.

Understanding the surgical technique, equipment, and patient selection

The bulkiness and particularity of the robot operating technology could be a disturbing factor in an operating room (Figures 1). An increased number of operating room personnel is needed, as compared to open surgery. The thoracic robot is different from other robot-assisted surgery, because of the routine use of carbon dioxide insufflation, artificial pneumothorax, prolonged one-lung ventilation (OLV), and other factors that may influence significantly the respiratory and circulatory functions. A full understanding of not only the surgical technique, but also of the related equipment, their impacts on the patient and

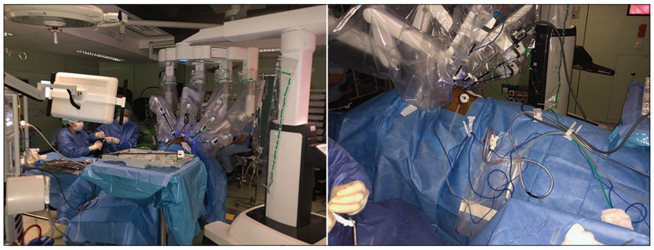

Figure 1: Images depicting the da Vinci operating robot and the space occupied during thoracic surgery

the corresponding pathophysiological changes is necessary to ensure both success of the surgery and the safety of the patient.

The patient's selection, including a height above 130 cm and a weight more than 30 kg, is necessary for RATS procedures. All patients scheduled for RATS should meet the general requirements for conventional thoracotomy or thoracoscopic surgery.

The duration of surgery is longer than a classical VATS, which consequently prolongs the period of OLV, thus may have a negative effect on the outcome. There are no clear numbers of necessary cases for surgeons to reduce the duration, nevertheless, as stated before, with learning curves the duration exceeds minimally that of a VATS procedure.

Access to the patient is another major problem in addition to a longer OLV; there is no or very small place to access to the head of the patient to control the position of the lung separating device by fiberoptic bronchoscopy, and the difficulty of fiberoptic bronchoscopy to the operated side.

Positioning of the patient

Given the long duration of surgery and the lateral decubitus (or prone in some cases of oesophageal surgery) of the patient, care should be taken for the correct positioning. With the taping of the head, instead of using protecting foam devices, cases of ear injury or facial numbness were already described.

Protecting the eyes with improvised devices, with two eye pads and tape is not efficient for protecting against pressure. Several companies are commercializing disposable eye protectors made from foam and having a transparent shell and allowing watching the eyes.

With the positioning of the patient, care should be taken with the bending of the arms—there should be enough place to allow the arms of the robot, without touching the patient.

There are robot-assisted oesophagectomies performed with the patient in prone position, but no major anesthetic complications were reported in these cases, despite a rise in central venous pressure and mean pulmonary artery pressure, no hemodynamic instabilities were mentioned.[26]

Intraoperative monitoring, CO_2 insufflation, fluids

As compared to standard thoracic surgical techniques, no extra intraoperative monitoring is needed. However, it should be mentioned that given the difficulty of access to the patient and the difficulty of visualization of the "real" surgical field, intraoperative diagnosis could be altered.

An acute decrease in the arterial blood pressure can be caused by a trocar insertion. However, other possible causes of intraoperative hypotension, as for example, the position of the patient with the dependent leg bent and hanging should be evaluated also.

Insufflation of carbon dioxide (CO_2) increases intrathoracic pressure, and secondary decreases preload, or even may cause pneumothorax and subcutaneous emphysema. Peak airway pressure increases and dynamic compliance of the lung decreases, without differences in tidal-volume or minute ventilation during volume-controlled ventilation.[27] The anesthesiologist must be vigilant to the possibility of lung separation device becoming mispositioned because of movement of the tracheobronchial tree and frequent variation in the delivered tidal volume. Mean central venous pressure, pulmonary artery pressure, and pulmonary capillary pressures are increased, and this increase is higher when the insufflation occurs on the right side.[27,28] The insufflation pressure of CO_2 should be starting at not more than 5 cmH_2O, limited to maximum 10 cmH_2O or even less if possible in compromised patients, under low flow (less than 2 l/minute) which is relatively safe.[29] The potential remedies for enhancing preload should be considered, like diminishing the insufflation pressure, inotropics, volume load, and/or repositioning the patient.

Concerning the fluids administration, we have evidence that they are not the trigger of post-pneumectomy pulmonary edema, but they contribute to its worsening. Restrictive versus goal-oriented fluid approach is still subject to debate. Thorough monitoring of fluid losses are difficult during RATS, given the "closed" hidden character of the operating field and some time it is difficult to evaluate the blood losses. With the long duration of surgery, the urinary output and temperature should be monitored mandatorily.

During the procedure, as compared to open or even to VATS procedures, rapid diagnosis of occurring intraoperative surgical problems and complications like bleeding or pushing with the retractor on the left atrium are difficult, despite the on-screen visualization of one or two of the operating robotic arms, but not all of them.

Communication

The space occupied by the robot, its arms, the console of the surgeon and the different screens not only limits the access of anesthesiologists to the patient but makes visual and verbal communication difficult. The surgeon, sitting at his console and speaking through a microphone while the others have to shout back, sometimes increases reaction times and misunderstanding frequency. The control console can be in the direct opposite corner of the room with numerous obstacles to cross (hanging cables, portable monitors, scrub tables, etc.).

An arrangement of the operating room with the surgeon sitting at his console next to the anesthesiologist could be helpful for this.[30] Clear commands, synergistic actions, and a good team working are necessary for the positive outcome.

Lung separation techniques

The difficult access to the head of the patients should be mentioned here. The patient is installed in a lateral decubitus position under the drapes, while the robot's arms are working above the patient, the possibility of the displacement of the lung separation device is a present risk. The best lung separation method is the method that the anesthesiologist best familiar and comfortable with. Double-lumen tubes (DLTs) may be used, but as an alternative, which can diminish the incidence of sore throats after anesthesia, is the use of single-lumen tubes with independent bronchial blockers (BBs). There is always best for every anesthesiologist to have an alternative for double-lumen tubes in his or her "tool box."[31] A helpful method for continuous monitoring of lung separation device position might be either the recently introduced left-sided DLT with embedded cameras in the tracheal limb (Viva-Sight DL, Ambu), connected to a screen, which permits a continuous visualization of the position of the DLT or a single lumen tube with embedded (VivaSight SL, Ambu) camera and using a BB.[32,33]

Pain management

Studies on postoperative pain after RATS are lacking, nevertheless despite the increase in number of surgical ports for the robot arms, it seems that RATS is associated with less postoperative pain. However, patients notice other pain sources like pain from bladder catheters, sorer throat, pain from chest tubes, and pain because of positioning, sometimes from cervico-facial numbness to shoulder pain. In order to reduce these painful regions, a BB with a single-lumen tube instead of a DLT could be used, the need for very restrictive positioning and for postoperative bladder catheter evaluated, infiltration of the chest tube insertion places with local anesthetics done. Surely depending upon institutional standards, thoracic epidural analgesia frequently remains the gold standard while other anesthesiologists might prefer as a valid alternative a paravertebral block, serratus anterior block, or intercostal infiltration. It has to be mentioned that there are no studies demonstrating neither the superiority, nor the non-inferiority of neither of these techniques.

Responsibility and Ethical Considerations

The human factors play an essential role in the safe delivery of patient care. The robots used in medicine and surgery, as well as for thoracic surgery are teleoperated robots, which raises the question of responsibility in case of injury from their use.

RATS may open new perspectives in the practice of thoracic surgery. Special training and experience along with high quality assessment are required in order to provide state-of-the-art treatment. While the legal basis for professional liability remains exactly the same, litigation with the use of robotic surgery may be more complex. In case of an undesirable outcome, in addition to physician and hospital, the manufacturer of the robotic system may be sued as well. In respect to ethical issues in robotic surgery, equipment safety and reliability, provision of adequate information to the patients, and maintenance of confidentiality are all of paramount importance. The cost of robotic surgery and the lack of financial support for such systems in most of the public hospitals may restrict the majority of the benefits offered by the new technology. Some even raised the question if RATS was not just a simple marketing strategy without any beneficial effect as compared to standard VATS which is beyond the scope of this manuscript.

While surgical robotics will have a significant impact on surgical practice, it presents challenges so much in the realm of law and ethics as of medicine and health care.

No serious device malfunctions were yet reported in RATS. More studies are needed to provide information about the safety and effectiveness of RATS compared with standard techniques and to delineate the nuances of RATS relative to VATS.

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Conflicts of interest

There are no conflicts of interest.

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