

Robot Assisted Pulmonary Resection

Zane Hammoud* and Ko Un Park

Consultant for Intuitive Surgery, Henry Ford Hospital, Detroit, USA

Abstract

Since its inception in the 1980s, robotic surgery has rapidly progressed into a variety of surgical fields including general surgery, urology, gynecology, cardiac surgery as well as thoracic surgery. In this review, we highlight the robotic assisted thoracic surgery (RATS) in primary lung cancer, focusing on basic surgical technique, anesthetic considerations, outcome, complications, and cost. We discuss our experience as a tertiary urban referral center that routinely performs robotic lung resections. Finally, we discuss potential hurdles and the future directions in robotic surgery.

Keywords: Robotic systems; Pulmonary resection; Cardiac surgery; Thoracic surgery

Introduction

The term 'robot' originates from the Slavonic term 'robota' which means forced labor but was made famous by the 1921 Czech play Rossum's Universal Robots (RUR) written by Karel Capek [1]. Thus, the robotic systems used in surgery today are not true robots because they lack independent motions or preprogrammed actions but are more accurately described as computer-enhanced telemanipulator systems. The concept for the modern day system first began in the mid 1980s with Scott Fisher, PhD at the National Aeronautics and Space Administration (NASA) Ames Research Center (Palo Alto, CA, USA.), and Joseph Rosen, MD (Department of Plastic Surgery, Stanford University, Palo Alto) who conceived the notion of combining virtual reality with surgical robotics or telepresence surgery. The idea of telepresence surgery was implemented by the Department of Defense of the U.S. military when analysis of the casualties of the Vietnam War revealed a large percentage of soldiers dying of wounds that were deemed survivable by today's technology. Thus, an advanced biomedical technical program was implemented to develop a military vehicle (Medical Forward Advanced Surgical Treatment [MEDFAST]) with a surgical station that was controlled by a surgeon at the telesurgery unit in a nearby hospital. The idea was to perform damage control surgery "in the field" via the robot while transporting the soldier to the hospital for more definitive care. Although telesurgery in the battlefield never was implemented mainly due to the change in warfare from open areas to closed urban terrain which was ill fit for the MEDFAST, the system was revamped and commercialized as the da Vinci surgical system (Intuitive Surgery, Sunnyvale, CA, USA), the present day's robotic system. This system offers a high resolution 3 dimensional (3D) visual field and EndoWrist instruments, which provide 7° of freedom, 90° of articulation, and tremor reduction.

In this review, we highlight the robotic assisted thoracic surgery (RATS) in primary lung cancer, focusing on basic surgical technique, anesthetic considerations, outcome, complications, and cost. We also discuss our experience as one of the centers routinely performing robotic lung resections as well as discuss future directions in robotic surgery. While any discussion of minimally invasive surgery for lung resection is not complete without the inclusion of video assisted techniques (VATS), such a discussion is beyond the scope of this review. Thus, this review will focus only on RATS for lung resection.

Anesthetic considerations

Since the first robotic cholecystectomy was performed in late

1990s, the technology has been popularized in various surgical fields. The number of robot assisted procedures performed worldwide has nearly tripled since 2007, from 80,000 to 205,000 in 2010 [2]. These procedures include a variety of general surgical procedures such as cholecystectomy and gastric bypass, urological procedures such as prostatectomy, gynecologic procedures such as hysterectomy, cardiac surgical procedures, as well as thoracic surgical procedures such as lung resection. Given the steady increase in the volume of robotic cases, it is critical that the anesthesiologist becomes familiar with some key differences in the conduct of robotic lung surgery versus traditional open surgery, i.e. thoracotomy. Epidural catheters, which are almost always used for thoracotomy, are not used during robotic lung resection. While patient position is similar, i.e. lateral decubitus, it must be understood that once the robot is docked, the patient cannot be repositioned. Furthermore, the operating table is often turned to allow the robot to dock caudally, further limiting the anesthesiologist's access to the patient. Single-lung ventilation is achieved by selective lung ventilation and carbon dioxide (CO₂) insufflation to a pressure of 10-15 mm Hg [3]. The key issues of anesthesia for robotic thoracic surgery are physiologic disturbances associated with single-lung ventilation and CO₂ pneumothorax, which may increase pulmonary vascular resistance and peak airway pressure, reduce cardiac output, potentially resulting in hypoxemia and hemodynamic compromise. For all these reasons, the anesthesiologist must develop a thoughtful plan of anesthetic management of the patient, especially during the first several cases performed.

Robotic surgery for primary lung cancer: historical perspective

Over a decade ago, Melfi et al. from Italy described the first robotic application in thoracic surgery [4]. Using the da Vinci robotic system they reported on several robotic assisted thoracic procedures, including lobectomy. Their operative time varied between 2.5 to 5 hours. Since

*Corresponding author: Zane Hammoud, Henry Ford Hospital, Detroit, USA, Tel: 313-916-2698; E-mail: ZHAMMOU1@hfhs.org

Received September 02, 2015; Accepted September 22, 2015; Published September 28, 2015

Citation: Hammoud Z, Park KU (2015) Robot Assisted Pulmonary Resection. Adv Robot Autom 4: 135. doi: 10.4172/2168-9695.1000135

Copyright: © 2015 Hammoud Z, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

this initial report, the number of robotic lobectomies performed has steadily increased [5]. With the advent of the second generation da Vinci S robotic system with high resolution 3D vision, several reports have demonstrated that using the robot it is feasible and safe to perform anatomic pulmonary resection of any lobe of the lung [6]. There are reports of 3 – port or 4 – port techniques. Furthermore, in a small retrospective review of prospectively archived multicenter data, robotic segmentectomy for a single lesion was found to be feasible, safe, and reproducible [7]. Thus, RATS for lung resection has been shown to be a safe alternative to traditional open surgery.

Current surgical technique

The latest generation of the only FDA approved robotic platform is called daVinci Xi, which has been approved for use less than a year ago. The majority of our current experience highlighted below is with the previous generation called daVinci Si (Figure 1). The platform consists of the robot itself with 4 “arms” and a console by which the surgeon manipulates the arms. In some instances, there are 2 consoles, one of which is the primary surgeon console while the other serves as an observational or teaching console. For pulmonary resection, some surgeons will utilize 3 arms (camera plus 2 surgeon arms) but our preference is to utilize the 4 arm technique wherein the surgeon controls a camera along with 3 robotic arms. In addition to the robotic ports, an additional port is placed for a bedside assistant. This port is used to introduce stapling devices, suction, etc. and is frequently widened to facilitate removal of the specimen. With either technique, the goal is to perform a completely portal robotic lobectomy (CPRL). Our standard port placement is shown in Figure 2. It is important that the robotic arms be placed at least 9 cm apart in order to avoid external limitation of movement of the arms. The robot is brought in from the head of the patient at an approximately 15° angle (Figure 3). Once docked, surgical resection is accomplished in standard fashion. When performing CPRL, individual vessels are dissected and ligated and a thorough lymph node dissection is performed. The resected lobe is then placed in a plastic bag and removed through a 3-4 cm incision located low in the chest cavity (usually by widening the assistant port). A single chest tube is placed through one of the port sites after



Figure 2: Standard port placement for robotic pulmonary resection.



Figure 3: Robot is docked from head of patient at approximately 15° angle.



Figure 1: The daVinci Si robotic surgical system.



Figure 4: Typical incision after robotic lung resection.

the robot is undocked and moved away from the patient. Patients are extubated in the operating room and have an average length of stay of 2-4 days depending on resolution of any air leak. Figure 4 shows typical incisions after CPRL 2 weeks after discharge from the hospital.

Outcomes

In a recent study of a single surgeon performing VATS and RATS lobectomies, there were only a few differences between the two [8]. Notably, there was no difference in length of stay, stapler loads used, lymph node data, morbidity or mortality. However, in terms of operative time the robotic upper lobectomies were significantly longer than VATS. The operative time data is conflicting with other studies wherein there were no statistically significant difference in operative time between RATS and VATS [9,10].

A meta-analysis by Cao et al. identified nine updated retrospective observational studies, mostly from institutions in the United States and Italy involving patients with early-stage NSCLC who underwent RATS lobectomy procedures [9]. These studies reported comparable perioperative outcomes to the results of a recent systematic review on conventional VATS. In a recent study by Swanson et al. that evaluated the Premier hospital database, which contains billing and coding data from more than 600 health care facilities throughout the United States, approximately 4% of minimally invasive lung resection was performed with RATS between 2009 and 2011 [10]. Average length of stay between VATS and RATS was not statistically different for lobectomy and wedge resection.

Robust long-term oncologic outcomes such as 5-year survival and disease recurrence rates for patients with malignancies are relatively scarce, with only one small case-series reporting follow-up of more than three years [9]. In the largest, multicenter, international study that evaluated the long-term oncologic outcome of robotic lobectomy in 325 consecutive patients with a mean follow up of 27 months, the 5-year survival was 91% for stage 1A, 88% for stage 1B and 49% for stage II patients [11]. These results are consistent with the largest recent series of VATS lobectomies.

Complications

Regarding RATS in comparison to VATS, most recent study results are confirmatory for no statistical differences in major complications in both lobectomy and wedge resection between the two cohorts [10]. Cao et al. also report a trend towards fewer complications after RATS compared to open thoracotomy for selected patients with early-stage NSCLCs [9]. There is no complication identified to date that is characteristic to robotic surgery, and the mortality is 0-3% which is similar to that after conventional lung cancer surgery [6].

Quality of Life

Using the Short Form Health Survey (SF-12) with supplemental questions about analgesic control at 3 weeks and 4 months postoperatively, Cerfolio et al. report a significantly higher mental and physical quality of life score and lower pain score at 3 weeks for the robotic group compared to VATS [12]. However, the difference dissipated by 4 months.

Cost

Unfortunately regardless of the specialty, robotic surgery is more expensive if the purchase and maintenance of the robot system are included in the total costs [13]. Robotic surgical systems have high fixed costs, with prices ranging from \$1 million to \$2.5 million for each unit [14]. It is difficult to discern the exact difference in cost with RATS versus VATS and open thoracotomy. In a cost analysis by Park et al., RATS added on average \$3981 per operation compared with VATS [13]. When analyzing the daily costs, it was clear that the increased cost

of employing robotics was incurred almost fully in the first hospital day, mainly through additional procedures. For instance, much higher percentage of RATS patients underwent bronchoscopy and extensive lysis of adhesions. Furthermore, Park et al. estimated an additional \$730 direct cost due to the specialized instruments and certain disposables required to use the robot and the necessary drapes for a three-arm approach [13]. However, the average total costs of robotic cases were still substantially less than open thoracotomy by \$3988 even with the amortization. Furthermore, some argue that the difference in cost of robotic surgery is offset by reductions in postoperative hospital costs and by productivity gains if patients recover more rapidly and can return to work and other activities sooner [14].

Our Experience

Our institution is a level 1 trauma center, urban tertiary care academic center with 802 beds located in Detroit, Michigan. The da Vinci system was first introduced in our institution over 10 years ago for use in prostatectomies. Like other institutions, the number and scope of robotic assisted procedures has increased dramatically over time. Our thoracic surgical service has performed over 200 robotic procedures of which 35 have been CPRL with mediastinal lymph node dissection. We have also performed 25 sublobar resections. We have incurred no mortality and we have not had any conversions to thoracotomy.

Future Direction of Robotic Surgery

Currently, most of the robotic lung resections are performed in teaching hospitals with more than 200 beds [10]. According to the most recent review of the national database, centers performing robotic thoracic operations are urban hospitals, majority affiliated with a medical school and Graduate Medical Education-approved residency training programs [5]. Furthermore, compared to non-robotic surgeons, robotic surgeons who performed at least 1 robotic lobectomy a year had a higher annual lobectomy case volume overall. Given the increased number of specially trained operating team and minimum two surgeons (main surgeon at console and assistant at bedside) required for robotic lung resections, it is not surprising that it is mainly performed at high volume academic centers.

In terms of training in robotics, currently there are no standardized robotic fellowships or board certification process. However, a study from Mayo Clinic demonstrates that training in robotic thoracic surgery can be standardized [15]. Using a triphasic pathway for developing robotic competency, which included dry lab and robotic simulators, residents in training were able to perform RATS lobectomy. The outcome of resident physician performed RATS lung resections yielded hospital length of stay and chest tube duration comparable with published outcomes for traditional thoracoscopic approaches.

Conclusion

Some argue that in thoracic surgery the advances of robotic surgery are not helpful because the operative field is wide and the operation is primarily one of resection rather than reconstruction [16]. Furthermore, proponents against RATS argue that compared with a VATS approach, the robotic incisions are the same size, the stapling instruments are the same, and the removal of the specimen is the same. Certainly, development of robotic specific instruments (i.e. stapler, vessel sealing system, soft coagulation device) along with instruments with tactile sensor tips and wide-angle view 3D cameras to eliminate blind spots can be anticipated to differentiate the advantages of robotic surgery

[17]. As technology advances, the robotic system will become smaller, less expensive, and better equipped for advanced diagnostic systems such as ultrasonography, near-infrared, and confocal microscopy equipment directly mounted on the robotic systems for minimally invasive diagnosis [1].

As we move forward, one thing is clear in that further evidence-based medicine and comparative effectiveness research is needed to discern the optimal role of robotic surgery [18]. Future studies should discern if robotic surgery preserve oncologic principles and is beneficial to patients with respect to postsurgical pulmonary function, pain, activity parameters, and overall well-being, as current studies present surgical outcomes without standardized definitions or an intention-to-treat analysis (e.g. variable definition of 'conversion rates,' morbidity outcomes, and the exclusion of patients with extensive disease or those who required conversion from statistical analysis) [9].

References

1. Satava R (2002) Surgical Robotics: The Early Chronicles: A Personal Historical Perspective. *Surg Laparosc Endosc* 12: 6-16.
2. Barbash GI, Glied G (2010) New technology and health care costs-the case of robot assisted surgery. *N Engl J Med* 363: 701-704.
3. Campos JH (2010) An update on robotic thoracic surgery and anesthesia. *Curr Opin Anaesthesiol* 23:1-6.
4. Melfi FM, Menconi GF, Mariani AM, Angeletti CA (2002) Early experience with robotic technology for thoracoscopic surgery. *Eur J Cardiothorac Surg* 21: 864-868.
5. Kent M, Wang T, Whyte R, Curran T, Flores R, et al. (2013) Open, video-assisted thoracic surgery, and robotic lobectomy: review of a national database. *Ann Thorac Surg* 97: 236-242.
6. Nakamura H, Taniguchi Y (2013) Robot-assisted thoracoscopic surgery: current status and prospects. *Gen Thorac Cardiovasc Surg* 61: 127-32.
7. Pardolesi A, Park B, Petrella F, Borri A, Gasparri R (2012) Robotic anatomic segmentectomy of the lung: technical aspects and initial results. *Ann Thorac Surg* 94: 929-934.
8. Lee BE, Korst RJ, Kletsman E, Rutledge JR (2013) Transitioning from video-assisted thoracic surgical lobectomy to robotics for lung cancer: Are there outcomes advantages? *J Thorac Cardiovasc Surg* 1-6.
9. Cao C, Manganas C, Ang SC, Yan TD (2012) A systematic review and meta-analysis on pulmonary resections by robotic video-assisted thoracic surgery. *Ann Cardiothorac Surg* 1: 3-10.
10. Swanson SJ, Miller DL, McKenna RJ, Howington J, Marshall MB, et al. (2013) Comparing robot-assisted thoracic surgical lobectomy with conventional video-assisted thoracic surgical lobectomy and wedge resection: Results from a multihospital database (Premier). *J Thorac Cardiovasc Surg* 147: 929-937.
11. Park BJ, Melfi F, Mussi A, Maisonneuve P, Spaggiari L, et al. (2012) Robotic lobectomy for non-small cell lung cancer (NSCLC): long-term oncologic results. *J Thorac Cardiovasc Surg* 143:383-9.
12. Cerfolio RJ, Bryant AS, Skylizard L, Minnich DJ (2011) Initial consecutive experience of completely portal robotic pulmonary resection with 4 arms. *J Thorac Cardiovasc Surg* 142: 740-746.
13. Turchetti G, Palla I, Pierotti F, Cuschieri A (2012) Economic evaluation of da Vinci-assisted robotic surgery: a systematic review. *Surg Endosc* 26: 598-606.
14. Barbash GI, Glied G (2010) New technology and health care costs-the case of robot assisted surgery. *N Engl J Med* 363: 701-704.
15. Sedar CW, Cassivi SD, Wigle DA (2013) Navigating the Pathway to Robotic Competency in General Thoracic Surgery. *Innovations* 8: 184-189.
16. Swanson SJ (2010) Robotic pulmonary lobectomy-the future and probably should remain so. *J Thorac Cardiovasc Surg* 140: 954.
17. Kajiwarra N, Kakiwana M, Usuda J, Ohira T, Kawate N, et al. Robot Assisted Thoracic Surgery (RATS). *Current Concepts in General Thoracic Surgery* 6.
18. Weissman JS, Zinner M (2013) Comparative Effectiveness Research on Robotic Surgery. *JAMA* 309: 721-722.