Advanced thoracoscopic procedures are facilitated by computer-aided robotic technology

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Abstract

Objective: Computer (robotic) enhancement has been used to facilitate simple thoracoscopic procedures such as internal mammary artery (IMA) mobilization. This report describes the use of robotic technology in advanced thoracoscopic procedures. Methods: Ten patients underwent advanced thoracoscopic procedures utilizing the Da Vinci robotic surgical system (Intuitive Surgical, Mountain View, CA) at our institution. Results: Patients 1–6 underwent endoscopic phrenic nerve mobilization with insertion of phrenic nerve pacemakers. The indications were quadriplegia (n = 2), central hypoventilation syndrome (n = 2), and intractable hiccups (n = 2). Three 1-cm incisions were made to access each hemithorax. Patients 7 and 8 underwent robotically assisted resection of posterior mediastinal masses. Patient 9 underwent robotically assisted thoracoscopic left lower lobectomy for a lung mass. Patient 10 underwent robotically assisted left ventricular lead placement for biventricular pacing for heart failure. Conclusions: Robotic technology can be used to perform advanced intrathoracic maneuvers thoracoscopically. The increased visualization and instrument dexterity afforded by this technology may facilitate the development of minimally invasive thoracic approaches that were previously not feasible.

Keywords: Advanced thoracoscopic procedure; Robotic system

1. Introduction

Robotic technology has been employed to perform various cardiac surgical procedures. Among them include internal mammary artery (IMA) mobilization [1], atrial septal defect (ASD) repair [2], mitral valve repair (MVr) [3–7], and coronary artery bypass grafting (CABG) [8–12]. This report describes the use of robotic technology in advanced thoracoscopic procedures.

2. Materials and methods

Informed consent was obtained from all patients and the study was approved by the institutional review board.

2.1. Da Vinci robotic system

The Da Vinci robotic system (Intuitive Surgical, Mountain View, CA) is used in our institution. The system consists of two primary components: the surgeon’s viewing and control console along with the surgical arm unit that positions and maneuvers detachable surgical instruments. From the console, the surgeon peers through an eyepiece, which provides a binocular, three-dimensional, magnified, stereoscopic view of the operative field. Beneath the console are two ‘master’ handles, which the surgeon telemanipulates. The robotic system provides the surgeon with seven degrees of freedom. The surgeon’s motions translate into movement by the robot.

A patient-side surgeon assists with the exchange of robotic instruments through the trocar unit. Instruments of 8 mm along with a three-dimensional endoscopic camera are placed in the chest through port-sized incisions. The camera view may be straight (0°) or angled (30° upward or downward). Endoscopic instruments include various
forceps (DeBakey, long-tip, round-tooth, and micro), scissors, clip applier, electrocautery, and ultrasonic shears. The robot’s wrists take the place of the surgeon’s hands within the chest bending back and forth, side to side, and rotating in a full circle. This expanded movement provides greater range of motion than humanly possible. The system provides the instruments with seven degrees of freedom [13,14].

2.2. Insertion of phrenic pacemaker with robotic assistance

Over 1 year, six patients underwent implantation of phrenic nerve pacemakers (Avery Laboratories, Dobelle Institute, Commack, New York, NY) via an endoscopic approach with robotic assistance. Mean age was 40.2 ± 24.2 years (range 16–81) with three males and three females. The indications were quadriplegia (n = 2), central hypoventilation syndrome (n = 2), intractable hiccups (n = 2). In five patients, a single-staged bilateral procedure was performed, whereas in one patient, unilateral procedures were performed in two stages. One patient had a history of previous coronary artery bypass with left IMA–left anterior descending artery (LIMA–LAD) anastomosis, and required extensive lysis of adhesions.

Patients were positioned in the supine position. After general anesthesia, a double-lumen endotracheal tube was placed. The first 1-cm incision was made in the fourth intercostal space, 2 cm anterior to the anterior axillary line. The robotic endoscopic camera, which was attached to a fiberoptic cable, was inserted, and entry into the pleural space was confirmed. Two additional 1-cm incisions were made in the second and sixth intercostal spaces, through which the right and left arms of the robotic system were inserted sequentially, under direct videoscopic guidance (Fig. 1).

Using robotic instruments, the surgeon dissected a small segment of the left phrenic nerve free from the pericardium. The pacing lead was positioned around the nerve and affixed to the pericardium using a 4-0 braided polyester suture (Fig. 2). On the left, implantation site was at the level of the left pulmonary artery, whereas on the right, it was at the confluence of the superior vena cava-right atrium. The lead was passed through the robotic arm trocar site and attached to the receiver, which was implanted in a small subcutaneous pocket. The pacer was then tested for proper function. For the bilateral procedures, the robot was moved from one side of the patient to the other between pacemaker implants.

2.3. Resection of mediastinal and chest wall masses with robotic assistance

The first patient was a 50-year-old woman with a significant smoking history who presented with an asymptomatic, suspicious mass found on chest X-ray (CXR). On confirmatory computed tomography (CT) scan, the mass measured 3 × 4 cm, and there were no signs of metastases. The left superior posterior mediastinal mass abutted but did not invade the left subclavian artery. This patient underwent a robotically assisted left posterior mediastinal mass resection (Fig. 3).

The second patient was a 62-year-old man also with a significant smoking history, who presented with a 2.7 × 1.9-cm left chest wall mass, located in the left upper hemithorax, discovered on CXR during work-up for tuberculosis. The patient underwent CT-guided biopsy of the mass, which was nondiagnostic. He subsequently underwent a robotically assisted left posterior chest wall mass resection. Both procedures were performed via a left chest approach.

Patients were positioned supine for the procedure. Resection of the masses was performed using three 1-cm incisions, with ports placed in the fifth intercostal space, 2 cm anterior to the anterior axillary line, as well as the third and sixth intercostal spaces, slightly anterior to the camera port site.
2.4. **Left lower lobe lobectomy with robotic assistance**

This patient was a 70-year-old man with a significant history of smoking, emphysema, coronary artery disease, carotid disease, s/p right carotid artery endarterectomy, abdominal aortic aneurysm s/p repair, with an ejection fraction of 52%. He presented with a 2 x 1.6-cm left lower lobe (LLL) lesion visualized on CT, which could not be biopsied secondary to its central location. The mass had increased in size from 1.1 cm in the 6 months preceding presentation. Bone scan revealed no evidence of metastatic disease. He underwent bronchoscopy, mediastinoscopy, and robotically assisted left lower lobectomy.

The patient was intubated using a double lumen endotracheal tube and positioned in the right lateral decubitus position. With three 1-cm port incisions, along with a 4-cm minithoracotomy in the left chest, visualization of the pertinent anatomy was obtained. The inferior pulmonary vein was divided with an endo-GIA V stapler (Fig. 4). The fissure was dissected using Endo-30 and Endo-45 staplers (Fig. 5). The bronchus was stapled using an Endo-33.5 stapler, and the pulmonary artery with an Endo-30 V stapler. Standard lymph node dissection was performed. The specimen was removed through the 4-cm minithoracotomy incision.

2.5. **Left ventricular (LV) lead placement with robotic assistance**

This patient was a 51-year-old woman with chronic heart failure s/p biventricular pacing lead insertion and recent loss of LV pacing due to coronary sinus lead displacement, with decreased exercise tolerance. She had undergone a failed attempt at replacement/revision of her pacemaker system. She subsequently underwent robotically assisted LV lead placement.

With the patient in the supine position, three left thoracoscopic port-sized incisions were made. The robotic system was used to perform a pericardiotomy and the LV myocardium in the region of the OM1–OM2 territory was identified. An epicardial, unipolar, steroid-eluting lead was positioned on the epicardium in this area and sewn on using 4-0 Tevdek suture. Next, a screw-in epicardial lead was passed into the chest and also affixed to the epicardium a few centimeters away from the first lead. The pericardium was closed over the leads with S105-2 (26 mm) U-clips (Coalescent Surgical Inc., Sunnyvale, CA) using long-tip forceps. The U-clips were passed into the chest through one of the robotic trocar arms and ‘parked’ in the pericardium until ready for use.

Both leads demonstrated excellent function, with high R-wave amplitudes and pacing thresholds less than 0.6 mA. The leads were passed out of the highest port site, and tunneled a short distance to the pacemaker pocket, which was opened. The generator was disconnected and replaced with a new biventricular pacemaker generator. This generator was fitted with the previously placed atrial and RV lead connectors, as well as with the newly placed sew-on steroid-eluting LV lead. The screw-in LV lead connector was capped and placed in the pocket with the generator.

3. **Results**

Phrenic pacemakers were successfully implanted via a
totally endoscopic approach with robotic assistance in all six patients. There were no intraoperative complications or conversions to open. Total operative time ranged from 80 to 120 min. In five patients, effective pacing was confirmed intraoperatively. In one patient, testing after 3 weeks confirmed effective pacing. There were no postoperative complications or mortalities. Mean length of stay in the hospital was 1.7 ± 1.0 days, without the need for intensive care unit (ICU) monitoring.

Mean follow-up was 258.3 ± 176.3 days for phrenic pacemaker patients. All patients were noted to have effective pacing at most recent follow-up. There were no device malfunctions or mechanical difficulties. One quadriplegic patient has been rendered ventilator-free during the day. The other quadriplegic patient is ventilator-free for 4–5 h each day. The first patient with central hypoventilation syndrome is ventilator-free approximately 50% of nights. The other patient with central hypoventilation syndrome has not yet begun pacing. One of the singultus patients has experienced significant improvement in symptoms.

Both mediastinal masses were successfully excised, leaving the tumor capsules intact. There were no conversions to thoracotomy or sternotomy. There were no postoperative complications. The pathology in the first patient was benign, hyalinized apical neurofibroma. The pathology in the second patient was a left chest wall benign Schwannoma. Both patients were discharged on postoperative day 2.

For patient #9, who underwent a pulmonary lobectomy, the pathology revealed a mucinous adenocarcinoma. The margins of the specimen were negative and there was no vascular or bronchial invasion. Level 9 and 11 lymph nodes were negative for tumor. The patient did well postoperatively, without any complications, and was discharged home on postoperative day 5.

Patient #10 underwent successful robotically assisted LV lead placement, and cardiac resynchronization was reestablished.

4. Discussion

There has been an effort over the last decade in cardiothoracic surgery to create a less invasive operative approach. This has involved techniques that either avoid a conventional sternotomy or thoracotomy, gaining access to the chest cavity via a partial sternotomy or minithoracotomy. The next logical step in this progression of minimization has been the establishment of port access surgery. With this approach, incisions are reduced to less than 1 cm in size, through which endoscopic instruments are placed.

Phrenic nerve pacing can improve quality of life in quadriplegics and patients with primary alveolar hypoventilation by eliminating the dependence on a ventilator. In patients with persistent or intractable hiccups, phrenic pacing can impact significantly on general health through improvements in eating, sleeping, and drinking [15]. Insertion of a phrenic pacemaker via a conventional approach is performed by making multiple neck incisions, or bilateral 5–7 cm anterior thoracotomy incisions with bilateral partial rib resections, or a sternotomy [16–19]. Because of incomplete coalescence of phrenic nerve fibers in the cervical region, it is thought that intrathoracic lead placement results in superior pacing capture. Using an endoscopic approach, the thoracic phrenic nerve may be utilized without the requirement for thoracotomy incisions.

Similarly, resection of a mediastinal mass with robotic assistance can be performed with three 1-cm incisions, sparing the patient a thoracotomy or sternotomy. Port placement is guided by localization of the lesion using preoperative CT scanning. Robotic technology provides excellent visualization of the thorax and mediastinal anatomy. Mediastinal masses can be dissected without penetration into the capsule and removed in a sterile specimen bag.

While more technically challenging than the other procedures, pulmonary lobectomy can be performed successfully using robotic technology [20]. As in resection of mediastinal masses, preoperative CT scanning aids in proper port placement. The visualization and manual dexterity provided by robotic technology are superior to video assisted thoracoscopic surgery.

Cardiac resynchronization through biventricular pacing, and possibly, through left ventricular pacing alone, has recently been introduced to treat patients with heart failure and intraventricular conduction delay [21,22]. Pacing may improve both systolic and diastolic function and has been shown to acutely improve dyspnea, fatigue, fluid retention, as well as long-term reduction of NYHA class [23,24]. Although sewn-in leads present a greater technical challenge to the surgeon than screw-in leads, steroid-eluting sewn-in leads are associated with improved longevity.

Although a standard thoracoscopic approach may be utilized to perform the described procedures, a specialized skill set is required. The use of robotic technology allows relatively challenging thoracoscopic procedures to be performed easily by surgeons with little thoracoscopic experience. Additionally, it provides superior optics and allows for enhanced dexterity. Furthermore, by reducing incision size and overall operative trauma to the patient, robotic technology may serve to improve postoperative quality of life. The hope is that patients will have less pain and a hastened recovery, as measured by ICU stay, hospital stay, ability to resume preoperative activities, and number of days to return to work after surgery. Unfortunately, little data exists comparing open, minithoracotomy, and robotic approaches. Certainly, the additional cost of this technology needs to be factored into an analysis of the overall benefit derived from this approach. We are currently undertaking such studies, specifically investigating postoperative quality of life and cost, in order to further address these issues.
References


Appendix A. Conference discussion

Dr A. Ritchie (Cambridge, UK): Very exciting and beautiful. The other thing that these operations potentially do, of course, is add time to the patient lying on an operating table. Do you have any data or information about the outcomes of atelecasis in this group of patients?

Dr Argenziano: That’s a great question. There is no question that all of these robotic procedures certainly add some time, specifically within the early portion of the surgeon’s learning curve. So, for instance, when we started doing robotic cardiac surgery, we were booking the cases later because it took the nurses 2 hours to dequip the robot. Of course, today that’s not the case and, in fact, in our cardiac and thoracic experience we run the cases at the same pace now as we did previously in terms of setup. There is no question that there is a 2–3 hour increase in the time of surgery in the operating room related to a number of things. Now, the reason I think that’s interesting is because in cardiac surgery there’s no question that robotic technology adds a certain number of obligatory delays. For instance, we don’t usually use double-lumen endotracheal tubes for cardiac surgery, but when we do it robotically we need a double-lumen tube. We don’t usually femorally cannulate patients for cardiac surgery but we do for robotic cardiac surgery. This adds a lot of time. Regardless, what we’re talking about here is adding robotics as a finer instrument to an already refined technique, which is VATS, and when we add robotics to VATS, we find that it does not in fact impact on the time, because you’re already using double-lumen tubes; you’re already positioning the patients in a similar way. The only difference is the time that it takes to put the robot in and to work the instrument, which, as you know, of all the learning curves, the surgeon’s learning curve is always the fastest to resolve. It’s always the other institutional issues about nursing and anesthesia, and other issues that tend to introduce delays. So, in fact, for VATS, because VATS is already pretty fast unachieved, we find that the delays are quite minimal.

Dr W. Weder (Zurich, Switzerland): I think the great advantage of this system is the three-dimensional movement of the instruments or of the arms inside the thorax and this may offer us a lot of additional possibilities when the technique is further applied. Actually what you showed us was probably not so convincing since many really experienced VATS surgeons are in the room, and dissecting an inferior pulmonary ligament or freeing a lymph node can be done quite easily with standard instruments. Unfortunately, ligation of the inferior pulmonary vein, which would be possible with this tool, you didn’t show. I think it would be possible that vascular structures by this three-dimensional movement can be sutured, they can be anastomosed, and I think when you come along and show us with this robot surgery that this can be done, then I think it might add something to the surgical procedures we are doing.

Dr Argenziano: I agree with you one hundred percent, but the point I would like to highlight is that although I am a cardiac surgeon, robotic technology allows me to perform general thoracic procedures thoracoscopically. There is no question that experienced thoracoscopic surgeons often look at this and say, ‘I don’t need a million-dollar robot. I can do that with standard thoracoscopic instruments and that same thing goes for abdominal surgeons who are very accomplished in laparoscopy. That doesn’t mean that this technology cannot make complicated operations more accessible to surgeons, but the real question is not to stop there, but to take surgeons like yourself with experience and say, ‘Well, if a surgeon with few thoracoscopic skills can do this with the robot, then what can you do with it?’ I agree with you that things like dealing with arteries in more complex ways, arterial sleeve resections, bronchial sleeve resections, things that would be considered beyond the scope of standard VATS, may become a possibility.