Early experience with robotic technology for thoracoscopic surgery

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Abstract

Objective: Recently, robots have been introduced into surgical procedures in an attempt to facilitate surgical performance. The purpose of this study was to develop a technique to perform thoracoscopic lung resection using a telemannipulation system. Methods: We have used a robotic system to perform thoracoscopic surgery in 12 cases: five lobectomies, three tumor enucleations, three excisions and one bulla stitching completed with fibrin glue for spontaneous pneumothorax. The operations were performed using the Intuitive Microsurgical system (Da Vinci System) through three ports and, a fourth space ‘service entrance’ incision, in the major lung resection. Results: Three procedures begun with the robotic technique were completed by a minimal thoracotomy. No technical operative mishaps were associated with the manoeuvres of robotic arms. In all manoeuvres (up, down, insertion, extraction, etc.), the robotic arms moved appropriately in the favorable operative fields. All patients tolerated the procedure well and the post-operative course was satisfactory, requiring few analgesics. Conclusions: Although further studies on robotically assisted procedures are needed to clarify the clinical feasibility of this procedure, the results in our cases are encouraging. We believe that thoracoscopic procedures using a robotic manipulation system may be technically feasible in selected cases and in the hands of experienced thoracic surgeons. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

The advent of endoscopic techniques has modified surgical practice in many regards. This technique has become widespread and is currently used in a wide range of surgical procedures, but many major difficulties remain. Sensory information is restricted to a two-dimensional image, and effector instruments have limited manoeuvrability due to the rigid shaft axis fixed to the thoracic or abdominal wall by the entry trocar. To overcome these problems, advanced engineering technology has been introduced in endoscopic surgery which includes three-dimensional (3-D) video-imaging, robotic camera-holders, telemanipulated flexible effector instruments and tactile feedback. Robotic surgery is the most recent and advanced stage of this process.

Currently two robotics systems are used in clinical practice (cardiac and general surgery), the differences of which have been described in the literature [2–4]. Although there is a real difference between thoracic and cardiac surgery and systems have been developed for cardiac bypass, an application in the field of thoracic surgery seems realistic.

The Da Vinci robotic system became available in our institution in February 2001. This system consists of two components: (1) a master console where the surgeon sits comfortably, using a 3-D vision and handling telemanipulators and optical controls; (2) a surgical arm cart which moves the instruments. The movements of the surgeon’s hands are transmitted without any delay to the tips of the two robotic arms. The main technical advantages of this system are scaling, indexing and tremor filtration [1]. Consequently, surgical precision and accuracy are the real benefits of this technique.

No information was available regarding the clinical applicability of this robotic device to the thoracoscopic procedures when we started our program. After a period of technical development and training using animal models, we made use of the robotic system to treat patients with various pulmonary diseases. We have focused our efforts on the development of this technique in the field of the thoracic surgery. Particularly, we assessed the advantages and limits of using the robotic surgery to perform thoracoscopic lung procedures.
2. Methods

Since February 2001, we have applied robotic systems to treat 12 patients with various thoracic diseases. There were eight men and four women aged 19–70 years (mean age 41 years). Selection criteria for this approach was: (a) lesions < 5 cm in maximal diameter; (b) clinical stage I status for primary lung carcinomas, (c) absence of chest wall involvement; (d) absence of pleural symphys; and (e) complete or near complete interlobar fissures.

Procedures included five lobectomies (three left and two right lower lobe lobectomy), three tumor enucleations (one tuberculoma and two chondroma), three tumor excisions (fibrotic pleural tumor, enteric cyst, leiomyoma) and one bulla stitching completed with fibrin glue for spontaneous pneumothorax (Table 1). After obtaining written informed consent from the patients, we performed the operations using the Da Vinci Robotic System (Intuitive Surgical Inc., CA, USA). All members of the surgical team (surgeons, scrub nurses and technicians) had to undertake specific training. After an initial theoretical phase, training at the console was the surgeon’s first impact with robotic surgery. In the subsequent training phase animal models were used. The learning curve was relatively short, since the surgeons had a solid background in thoracoscopic surgery.

2.1. Robotic system

The Da Vinci Robotic System is a telemanipulator system which consists of: a master remote console that connects to the surgical manipulator with two instrument arms and a central arm to guide the endoscope.

Two master handles at the surgeon’s console are manipulated by the user. The position of the surgeon’s hands on the handles trigger highly sensitive motion sensors which transfer the surgeon’s movements to the tip of the instrument at a remote location. The surgeon sits at the master console, located at a distance from the patient, with his eyes focused downwards toward the operative field which appears as in open surgical technique, and the robotic unit provides a telepresence within the chest for micro-instrument manipulation.

A high-resolution 3-D, 0° or 30° scope, with two 3-chip cameras (CCD) is used for better depth perception and optical resolution. The scope is held by the central four DOF (degree of freedom) manipulator of a remote centre surgical cart. Independently, acquired images are transmitted to a high-resolution binocular display of the operative field (the operative image magnification may be up to ten times the actual size).

Movements exerted on the handles are sensed by high-resolution motion sensors, which process them and transfer them to the two surgical manipulators. These surgical arms provide three degrees of freedom (pitch, yaw, insertion). Attached to the surgical arm is the surgical instrument, the tip of which is provided with a mechanical wrist (EndoWrist) which adds four more degrees of freedom (internal pitch, internal yaw, rotation and grip).

In order to increase precision, a motion filter built into the system eliminates unintended movements caused by human tremor.

2.2. Operative technique

All operations were performed by the same surgeon and an assistant surgeon was on hand if needed. The patients were placed in the lateral position with general anaesthesia and single-lung ventilation.

During the operations the main body of the machine was placed behind the operative site and the best position of robotic-arms was established in relation to the side of the lesion. The first thoracoprot (12 mm) was placed for the 0° 3-D scope and the other two thoracoports (10 mm) were used for the placement of the right and left instrument-arms (Fig. 1). Correct placement of the robotic cart and the trocars is mandatory in order to avoid collision between the mechanical arms and to optimize system performance:

Table 1
Clinical features of patients undergoing robotic thoracoscopic surgery

<table>
<thead>
<tr>
<th>Age (years)/sex</th>
<th>Pre-operative conditions</th>
<th>Procedure</th>
<th>Pathological findings</th>
<th>Post-operative course</th>
<th>Discharge (days post-op.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>52/M</td>
<td>Unremarkable</td>
<td>Excision</td>
<td>Fibrotic pleural tumor</td>
<td>Uneventful</td>
<td>4</td>
</tr>
<tr>
<td>64/F</td>
<td>Diabetes</td>
<td>Right lower lobectomy</td>
<td>Adenocarcinoma, T1N0</td>
<td>Uneventful</td>
<td>5</td>
</tr>
<tr>
<td>50/M</td>
<td>Unremarkable</td>
<td>Enucleation (conversion)</td>
<td>Chondroma</td>
<td>Uneventful</td>
<td>3</td>
</tr>
<tr>
<td>20/M</td>
<td>Unremarkable</td>
<td>Excision</td>
<td>Enteric cyst</td>
<td>Uneventful</td>
<td>3</td>
</tr>
<tr>
<td>41/M</td>
<td>Unremarkable</td>
<td>Left lower lobectomy</td>
<td>Typical carcinoid</td>
<td>Uneventful</td>
<td>4</td>
</tr>
<tr>
<td>66/M</td>
<td>Unremarkable</td>
<td>Left lower lobectomy (conversion)</td>
<td>Typical carcinoid</td>
<td>Sputum retention</td>
<td>6</td>
</tr>
<tr>
<td>70/M</td>
<td>Prostatism/hypertension</td>
<td>Left lower lobectomy</td>
<td>Squamous carcinoma T1N0</td>
<td>Uneventful</td>
<td>5</td>
</tr>
<tr>
<td>37/M</td>
<td>Unremarkable</td>
<td>Enucleation</td>
<td>Tuberculoma</td>
<td>Uneventful</td>
<td>3</td>
</tr>
<tr>
<td>33/F</td>
<td>Dyspnea (spontaneous pneumothorax)</td>
<td>Bulla stitching</td>
<td>–</td>
<td>Uneventful</td>
<td>4</td>
</tr>
<tr>
<td>71/M</td>
<td>Unremarkable</td>
<td>Enucleation</td>
<td>Chondroma</td>
<td>Uneventful</td>
<td>4</td>
</tr>
<tr>
<td>19/M</td>
<td>Unremarkable</td>
<td>Excision</td>
<td>Leiomyoma</td>
<td>Uneventful</td>
<td>3</td>
</tr>
<tr>
<td>60/M</td>
<td>Cough</td>
<td>Right lower lobectomy (conversion)</td>
<td>Squamous carcinoma T1N0</td>
<td>Sputum retention</td>
<td>6</td>
</tr>
</tbody>
</table>
in particular the trocars must be positioned at a greater distance from each other than they normally would be in standard thoracoscopic surgery.

For the lesions located in a lower left position, the first port (0° 3-D scope) was placed in the seventh intercostal space at the mid-axillary line and the other two ports in the fifth and sixth space at anterior and posterior axillary lines, respectively.

For the lesions located in a lower right position, the ports were placed in a similar position as that of the left-side operations.

In the enteric cyst and in the leiomyoma the arms were placed in a different position: the scope was inserted in the eighth left intercostal space (posterior line) and in the seventh right intercostal space (midaxillary line), respectively; the arms were placed in the fifth and sixth intercostal space (at posterior and anterior axillary line) and in the fifth and seventh space (at posterior axillary line), respectively.

2.3. Lobectomy procedure

For the lobectomy procedures (left and right lower lobectomies) a ‘service entrance’ (3 cm) was made in the fourth intercostal space. Two additional thoracoports were inserted in the seventh and sixth–seventh intercostal spaces at the mid- and post-axillary line, respectively.

The ‘service entrance’ served for the right robotic instrument, and was also useful as a site to insert standard endoscopic instruments, when the robotic instruments were not suitable. Dissection of structures was performed with a combination of electrocautery and DeBakey forceps mounted on the robotic arms. Blunt dissection was particularly useful when dissecting around the pulmonary vessels and for sweeping tissue along the lobar bronchus peripheral to the line of intended bronchial division so that all the lobar bronchial nodes could be included in the operative specimen. In the right lower lobectomy the apical lower segmental artery and the main trunk was divided by stapling (Endopath TSW 35 mm vascular/thin; Ethicon Inc.). The lower lobe was retracted anteriorly (with traditional endoscopic forceps through the ‘service entrance’) and the pulmonary ligament incised to expose the lower vein, which was cleared of surrounding tissue and divided by stapling. The lobe was then retracted inferiorly and the anterior portion of the oblique fissure (between the middle and lower lobes) divided using electorocautery.

Finally, the lower lobe bronchus was divided by stapling (Endopath ATB45 Ethicon Endo-Surgery Inc.), with care being taken to preserve the middle lobe origin.

In the left lower lobectomy the apical lower and main-stem lower vessels were taken separately. In this case, a suture ligation was used with Linen 2.5 (Fig. 2). The pulmonary ligament was incised, and the lower vein cleared and divided. We gently placed a clamp vascular, and using arm-instruments (DeBakey Forceps and Micro Forceps) we stitched (polypropylene monofilament 4/0) on the transected lower vein. The clamp was removed when the closure was seen to be secure. The resected lobes were removed in sterile plastic bags through the ‘service entrance’, without a rib spreader.

2.4. Other procedures (tumor enucleations and excisions and the bulla stitching)

These operations were totally performed with robotic instruments (electrocautery and the DeBakey forceps). The enucleations were completed with single stitching (polyglyconate monofilament 4/0; Sherwood Davis & Geck) and fibrin glue to repair the lung. The bulla located on the right upper lobe was treated in the same way.

At the end of the operations the robotic arms were removed from the chest and two drains were inserted through the ports sites, into the chest cavity.

3. Results

Excellent visualization was achieved with the 0° 3-D scope. No technical operative mishaps related to

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Fig. 1. Position of the Intuitive Microsurgical system (Da Vinci System) for thoracic procedures.

Fig. 2. Suture ligation of lower left pulmonary artery.
manoeuvres of the instrument-arms occurred. Operative times varied between 2.5 and 5 h. This time was considerably longer than that for standard open surgery or video-assisted thoracoscopic procedures, but it decreased with experience so that the most recent four cases averaged 2.5 h. None of the patients had problems related to post-operative bleeding. All patients tolerated the procedure well and the post-operative course was satisfactory, requiring fewer analgesics. Chests tubes were removed after a mean of 2 post-operative days and the patients were discharged after a mean of 4 post-operative days.

Three patients, with lung cancer (one), typical carcinoid (one) and chondroma (one), required a minimal thoracotomy. We began the operations with the robotic technique which allowed us to isolate and stitch on the transected lower vein in the first two patients. We had to complete the operations using the ‘service entrance’ (enlarged by about 2 cm) due to hilar calcified lymph nodes, since these rendered the dissecting of the interlobar pulmonary artery unsafe. With the third patient, a small radiolabelled pulmonary nodule (<1 cm) was not detected with a gamma-ray detector. We had to enlarge the ‘service entrance’ so as to detect the lesion tactically and then we completed the operation with the robotic system. All patients were discharged in good condition and returned to pre-operative levels of physical activity within 10 days of the operation.

4. Discussion

Many high-technology innovations have been introduced to clinical medicine [5–8]. Although the indications for thoracic surgery have not yet been established, this innovative technique heralds the use of virtual reality technology in thoracoscopic surgery [9,10]. The development by Intuitive Surgical Inc. of a robotic system incorporating not only robotic-assisted visualization but also robotic-assisted instrumentation, prompted us to employ this system for thoracic surgery. The main technical advantages are: scaling (changing the ratio of movements of master instruments), indexing (freezing the slave instruments while repositioning master instruments), and tremor filtration [11,12]. Consequently, surgical precision and accuracy are the real benefits of this technique. At present, the areas of surgery where robotic technique is used to best advantage are those in which the procedures involves a small, deep, fixed operating field and require extreme accuracy (such as vessel dissections). A robotic system with its joint movements allows the surgeon to use his traditional open surgery techniques at the console which are simultaneously reproduced using endosurgery movements by arm-instruments at the surgical site [8–12]. Additionally, the mechanical wrist allows for a full range of motion of the tip of the instruments, which facilitates dissections in remote areas in the chest cavity.

Although this technology holds great promise, there are still major technical hurdles that can affect the dexterity of the surgeon and add to the complexity of the procedure [7–11]. The current robot manipulator system requires larger and bulkier instruments to obtain the seven degrees of freedom within the body cavity and the system’s size limits access to the patient by the surgical assistant [11,13]. The physical orientation and the optimal working angles between instruments, the lesion’s plane and the angle of the vision are important issues that must be considered when planning a closed chest approach [11,12,14]. One of the most difficult aspects was the proper positioning of the trocars in the chest cavity. In order to perform the procedure more easily we studied the best positioning of this system. The arm cart was placed behind the operative site and the best position of the robotic arms was established in relation to the side of the lesion. This position allowed the surgeon to have an excellent, unobstructed view of the chest cavity without arm impingement and interference.

Lastly, other two problems became evident and should be addressed in the future:

- the instrumentation (which is not adequate for thoracic surgery);
- tactility (lack of tactile feedback impairs one’s ability to judge the amount of tension applied during the manoeuvres of suture/ligation tensioning).

To the best of our knowledge, this is the first report on robotic surgery for thoracic diseases, using a robotic manipulator system. Although further studies on many robotic procedures are necessary to clarify the clinical feasibility and utility of our procedures, the results in this preliminary experience are encouraging. We believe that robotic procedures may be technically feasible in selected cases and in the hands of an experienced thoracic surgeon. Nevertheless, due to its technical features, it is currently indicated for reconstructive surgery. As robotic systems and their arm instruments are improved and adapted to thoracic surgery, their application will be extended to a wider range of operations and operating times will be significantly reduced.

References


Appendix A. Conference discussion

Dr F. Casselman (Aalst, Belgium): We have quite a bit of experience in coronary artery surgery with the robotic system and we are looking to expand our indications, and you said that time was a major issue for lobectomies, but you didn’t specify. Can you tell us a little bit more about that?

Dr Melfi: Initially, the lobectomy was very long, 5 h. You should consider that the first 2 h were reserved for the setting up of the machine, because at the beginning it took a long time to choose the positions, because it is very different from cardiac surgery. We didn’t really know the proper position. So we tested it, we studied this position, and at the moment the times have become much shorter, about 2.5 h.

Dr Casselman: Another issue also is that it is sometimes difficult to estimate the force that you are exerting on the arms to tie knots or whatever, and, I don’t know, but maybe in pulmonary artery surgery where you sometimes have some fragile structures, did you have any problems with that, have you torn up an artery or whatever by making the knots on the pulmonary artery branches?

Dr Melfi: This was one of the most difficult issues because you don’t really feel the tension, but we found it is possible, with experience, to improve this perception facility.

Professor A. Yim (Shatin, Hong Kong): One concern I have is the safety of this approach: if you get into major bleeding, how are you going to control it using the robotic system? Also, the main advantage of robotic technology is to allow port access to perform complex procedures. However, if you require a mini-thoracotomy anyway to retrieve the specimen, it seems that you are already defeating the purpose of robotics, and all you are doing is to make the operation more complicated.

Dr Melfi: Yes, I agree, the advantage at the moment is for the surgeon, of course. In comparison to video surgery, the surgeon is sitting and he doesn’t have any problem with orientation. When you use the instruments by video surgery, of course you use these instruments, but you are also looking at the display. And I agree with your comment about the small incision, but we don’t have all the instruments at the moment. We have very few robotic instruments, and we must use standard endoscopic instruments through a small incision. We just tested the feasibility of this procedure.

Dr P. Warnig (Vienna, Austria): Had you any training for your surgeons before starting this project?

Dr Melfi: Yes, we did.