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Robot-assisted lung resection: outcomes and technical details

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Abstract

Robotic surgery has gained acceptance for surgical use but few data exist regarding its value in thoracic procedures. The aim of this study is to report our experience with totally robotic thoracic resections. From June 2001 to June 2009, 38 consecutive totally robotic lung resections were performed in two different hospitals by a single surgeon. All data was prospectively collected in a dedicated database, and reviewed retrospectively. A total of 32 lobectomies, three bilobectomies, and three pneumonectomies were performed. The indication was a malignant tumor in 28 cases. There were nine cases with benign pathology. Mean operating time was 209 min (range: 105–380 min). Six conversions were required (15.8%) and there was one postoperative death (2.6%). Four postoperative complications occurred (10.5%). Median hospital stay was 10 days (range: 3–24 days). After a median follow-up of 42 months, 80% of patients with stage I disease are alive without recurrence. Advanced thoracic procedures can be performed safely using the robotic system. In this heterogeneous series of lung resections, we report low mortality and morbidity. The robotic approach can achieve a good dissection in difficult to reach areas, making it particularly useful for oncologic resections.

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Keywords: Robot-assisted; Thoracoscopy; Lobectomy; Pneumonectomy; Lung cancer

1. Introduction

Since the early 1990s, thoracoscopic surgery has gained acceptance as both a diagnostic and therapeutic procedure [1], with good general and oncological outcomes for treatment of early stage non-small cell lung cancer [2].

Conversely, arguments against the use of thoracoscopic surgery include limited two-dimensional vision, an unsteady camera platform, and limited maneuverability of the instruments [3].

Thus, during thoracoscopic lobectomy, the vascular and mediastinal dissection can be difficult to accomplish using conventional videonendoscopic instruments. The use of the surgical robot (da Vinci®, Intuitive Surgical, Sunnyvale, CA, USA) can facilitate the dissection phase [3, 4], by providing a high-resolution binocular view, ‘wrist-like’ action of the instruments, and ease of fine dissection in a confined space.

Today, several authors [1, 3–8] have performed robot-assisted lung resections with encouraging results. We report our experience with totally robotic lobectomy and pneumonectomy.

2. Materials and methods

From June 2001 to June 2009, patients with intra-thoracic pathology, including clinical early stage lung tumors (stage I–II), were eligible to participate to this study. The preoperative staging consisted in whole-body computed tomography (CT), bronchoscopy and pulmonary function. Exclusion criteria were a lesion >5 cm, a chest wall invasion, endobronchial tumors visible at bronchoscopy, a central tumor, and forced expiratory volume in 1 s <65% of predicted. Minor lung resections were also excluded from the study.

A total of 38 consecutive totally robotic lung resections were performed in two different hospitals by the same surgeon (Pier C. Giulianotti). The first 29 cases (76.3%) were performed at the Department of Surgery, Misericordia Hospital in Grosseto, Italy and the final nine (23.7%) were performed at the Division of Minimally Invasive and Robotic Surgery, Department of Surgery, University of Illinois at Chicago, USA.

Informed consent for all robot-assisted procedures were obtained from patients. Data on patient characteristics, operative details, and postoperative recovery was collected in a prospective database and analyzed retrospectively.

2.1. Surgical technique

2.1.1. Patient positioning

Once single lung ventilation by a double-lumen endotracheal tube is complete, the patient is rotated onto the
flank opposite to the lesion, with a slight splaying of the ribs, with the arm up.

2.1.2. Equipment and personnel positioning
The robotic cart is draped and docked coming from the patient’s head. The surgeon sits at the robotic console while the assistant surgeon stands at the patient’s side in order to facilitate the change of instruments and to assist with suction, lavage, retraction, and the introduction of different devices as needed.

2.1.3. Trocar positioning
The trocar placement is summarized in Fig. 1 and can vary slightly depending on the patient’s anatomy and size. The minithoracotomy (without rib spreading) is also used by the assistant as an accessory port, and as the site for extraction of the specimen.

2.2. Surgical procedure
The robotic lobectomy was performed in eight steps as follows:

Step 1: Routine thoracoscopic exploration
A 30° videoscope is used to perform a full exploration of the pleural cavity. This is done to evaluate the feasibility of a minimally invasive procedure.

Step 2: Robotic pulmonary vein preparation
Once the feasibility of the procedure is assessed and confirmed, the robotic cart is brought into the operating field over the patient’s head.

Step 3: Fissura dissection
At the beginning of this phase, the mediastinal pleura is usually sectioned and the main superior or inferior pulmonary vein is isolated (Fig. 1a) and encircled with a vessel loop.

Step 4: Hilum dissection
The interlobar fissure is dissected after detaching the pulmonary parenchyma from the azygos vein and mediastinal pleura (Fig. 1b). The segmental arteries are then isolated (Fig. 1c) and selectively transfixed with polypropylene 4/0 (Video 1).

Step 5: Pulmonary vein transection
The dissected venous trunk is transected using the endostapler with a white load (inserted through the minithoracotomy or through the 12-mm assistant).

Step 6: Parenchymal transection
In this step, the posterior parenchymal bridge between the lobes is stapled (white load) and divided (Fig. 1e).

Step 7: Division of the bronchus
Once the vascular steps have been completed, the lobar bronchus is isolated and all peribronchial nodes are removed. The lobar bronchus is then divided with a green load endostapler (Fig. 1f) or using the robotic scissors.

Fig. 1. Port placement for robot-assisted thoracoscopic upper lobectomy. The first is a 12-mm trocar placed in the seventh intercostal space on the middle axillary line. A second incision for an 8-mm trocar is made on the fourth intercostal space on the posterior axillary line. The second robotic 8-mm trocar is placed through a 4–5-cm minithoracotomy along the fourth or fifth intercostal space, at the level of the anterior sub-mammary line. An additional assistant port may also be placed between the camera port and the left robotic arm. (a) Preparation of the right superior vein. (b) Dissection of the azygos vein. (c) Isolation of the segmental artery. (d) Dissection of the interlobar lymph node (LN). (e) Section of the parenchymal bridge with endostapler. (f) Section of the right superior bronchus.
suture line is secured with 3/0 polydioxanone interrupted stitches.

**Step 8: Completion of lymphadenectomy**

The lymphadenectomy is completed by sampling the interlobar nodes, the subcarinal, hilar, paraesophageal, lower paratracheal, and the upper paratracheal nodes. The specimen is then retrieved in an endobag through the minithoracotomy. A chest tube 28 F is inserted through a 12-mm port.

The technique for the pneumonectomy requires the same cart positioning and port placement. Here, the steps remain the same except that the hilum is approached first. Typically, we transect the different structures of the hilum using endostaplers.

**2.3. Statistical analysis**

The results of parametric and non-parametric data were expressed as mean ± standard deviation (S.D.) and median (range), respectively. GraphPad Software (La Jolla, CA, USA) was used for all statistical analysis. A P-value of ≤0.05 was considered statistically significant. Comparisons between groups were carried out using Student’s t-test.

**3. Results**

During the study period, 38 patients underwent surgery. This included 32 lobectomies (eight upper right, seven upper left, 12 lower right, and five lower left), three bilobectomies (two upper right and middle and one lower right and middle), and three pneumonectomies (two right and one left). All the cases of bilobectomies were performed because of lack of scissure. Among the three pneumonectomies, two were performed after conversion to achieve an adequate oncological resection. The third pneumonectomy was performed for a tumor close to the carina (pT3N0).

The patients’ characteristics are summarized in Table 1.

### 3.1. Histology

Of the 38 patients, 28 had a malignant disease (73.7%) and nine had a benign disease (23.7%). Data was missing for one case.

The malignant group included 24 primary tumors and four metastases. Primary tumors included 14 adenocarcinomas (50%), four squamous cell carcinomas (14.3%), three large cell carcinomas (10.7%), two non-small cell lung cancers (7.1%), and one carcinoid tumor (3.6%). The different pathological stages are reported in Table 1.

Metastasis included two from colon cancer, one from stomach cancer, and one from small bowel cancer. The benign group included two hamartomas (one large and one misdiagnosed as a metastasis), two inflammatory nodules (misdiagnosed preoperatively as primary tumors), two bronchiectases, two sequestrums, and one mycotic lung abscess.

### 3.2. Intraoperative results

The intraoperative results are summarized in Table 2. Of note, in the tumor group, the mean operative time was 200 ± 60 min (range: 93–300 min).

Six conversions were necessary (15.8%), but only one was an emergency situation which involved a hemorrhage from the pulmonary artery. Two other cases were converted due to locally advanced tumors (not evident at preoperative CT). One case was converted due to difficulty of pulmonary exclusion. The final two cases were converted due to pleural adhesions. For these last three cases, the conversion was decided after the exploratory thoracoscopy, and before the robot was docked.

<table>
<thead>
<tr>
<th>Gender</th>
<th>Patients’ characteristics (n=38) and tumor histology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>19 (50%)</td>
</tr>
<tr>
<td>Male</td>
<td>19 (50%)</td>
</tr>
<tr>
<td>Mean age (years)</td>
<td>66 (16–78)</td>
</tr>
<tr>
<td>Pathology</td>
<td>Malignant (28 (73.7%))</td>
</tr>
<tr>
<td>Benign</td>
<td>9 (23.7%)</td>
</tr>
<tr>
<td>Undetermined</td>
<td>1 (2.6%)</td>
</tr>
<tr>
<td>Tumor histology (n=28)</td>
<td>Adenocarcinoma (14 (50%))</td>
</tr>
<tr>
<td>Squamous cell carcinoma</td>
<td>4 (14.3%)</td>
</tr>
<tr>
<td>Large cell carcinoma</td>
<td>3 (10.7%)</td>
</tr>
<tr>
<td>Non-small cells cancer</td>
<td>2 (7.1%)</td>
</tr>
<tr>
<td>Carcinoid tumor</td>
<td>1 (3.6%)</td>
</tr>
<tr>
<td>Metastasis</td>
<td>4 (14.3%)</td>
</tr>
<tr>
<td>Stage TNM (n=24)</td>
<td>Stage IA (T1N0) (10 (41.7%))</td>
</tr>
<tr>
<td>Stage IB (T2N0)</td>
<td>7 (29.2%)</td>
</tr>
<tr>
<td>Stage IIA (T1N1)</td>
<td>1 (4.2%)</td>
</tr>
<tr>
<td>Stage IIB (T2N1 and T3N0)</td>
<td>2 (8.3%)</td>
</tr>
<tr>
<td>Stage IIIA (T2N2)</td>
<td>1 (4.2%)</td>
</tr>
<tr>
<td>Stage IIIB (T4N2)</td>
<td>1 (4.2%)</td>
</tr>
</tbody>
</table>
3.3. Postoperative outcomes

Postoperative results are summarized in Table 2 as well. There was one postoperative death (2.6%). This involved a 77-year-old patient who suffered from an adenocarcinoma T2N2, and underwent a right pneumonectomy. He developed a pulmonary artery hemorrhage which necessitated an emergent conversion. The patient died on postoperative day 17 due to respiratory insufficiency.

The complication rate in our series was 10.5% (n = 4). Two patients presented with a minimal air leak which was treated conservatively using chest tubes until postoperative days 12 and 14, respectively, with spontaneous resolution. Another patient presented on postoperative day 2 with respiratory distress, requiring mechanical ventilation for two more days. The final complication was a duodenal ulcer perforation which was treated surgically.

The median length of stay was 10 days (range: 3–24 days). The mean hospital stay for Italian patients was statistically longer than for Americans (13.1 vs. 7.4 days; P = 0.003).

Regarding the follow-up of primary tumors after a median of 60 months, 66.7% of patients are alive without recurrence, 28.6% died and 4.7% are alive with recurrence (bone recurrence in the hip with 11 months of disease free). Three patients were lost to the follow-up. In addition, when considering only patients with a stage I disease, the survival rate was 80% after a median of 42 months.

4. Discussion

Thoracoscopic lobectomy has been reported as feasible for more than 20 years, and as a safe and oncologically acceptable procedure for the treatment of early stage non-small cell lung cancer [2, 9]. Despite these encouraging reports, there is still no real standardization of the technique.

In order to overcome the limitations of thoracoscopy, new devices like the robotic system were developed. The advantages provided by such a system include notably: 1) a steady camera with a three-dimensional vision; 2) wristed instruments; 3) ergonomics for the surgeon.

Still, few studies assessing robotic thoracoscopic lobectomies are available (Table 3). In the early 2000s, several groups reported their initial experience with encouraging results [1, 7, 10].

Since that time, four major studies using the robot to perform dissection during lobectomies for lung cancer were published [3, 4, 6, 8]. They reported a mortality rate between 0% and 4.9%, and a morbidity rate between 20% and 26%. Our results compare favorably with this data.

Regarding the complications, an air leak is common following open lobectomy [12, 13] (between 9 and 19%) and has also been reported in the major robotic lobectomy series [3, 4, 6, 8], at a rate of 2.9–4%. Our results are within the range reported. In addition, one of the more frequent complications following robotic lobectomy remains atrial fibrillation, with a reported rate of between 6% and 17% [3, 4, 6, 8].

Finally, our conversion rate remained relatively low (15.7%) when compared to reports in the literature: 12–60% for robotic lobectomy [3, 11] and up to 20.8% for thoracoscopic lobectomy [12].

The present results, like those from other robotic studies [3, 4, 6, 8], are consistent with the thoracoscopic lobectomy experiences most recently reported [12–14]. In terms of operative time, our mean time of 200 min for the tumor group was well within the range of previously reported robotic [3, 4] (range: 216–218 min) and thoracoscopic [12, 14] (range: 164–200) series.

In terms of length of stay, we report a statistical difference between the Italian and American patients, reflecting mostly the difference in the health system between Europe and North America.

As far as oncologic safety is concerned, all oncologic patients underwent a R0 resection, with eight being the median number of lymph nodes (LNs) harvested. This compares favorably with other groups [3, 4, 12]. Regarding the survival rate for early-stage non-small cell lung cancer, a recent systematic review reported a four-year survival between 71 (open approach) and 88% (thoracoscopy) [15], that is similar to our 80% after 42 months.

Table 3. Results of robot-assisted thoracoscopic lobectomies in current literature

<table>
<thead>
<tr>
<th>Authors</th>
<th>Years</th>
<th>Number of patients</th>
<th>Length of stay (days)</th>
<th>Morbidity (%)</th>
<th>Mortality (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melfi et al. [7]</td>
<td>2002</td>
<td>5</td>
<td>5</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>Giulianotti et al. [10]</td>
<td>2003</td>
<td>5</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Park et al. [3]</td>
<td>2006</td>
<td>34</td>
<td>4.5</td>
<td>26</td>
<td>0</td>
</tr>
<tr>
<td>Gharagozloo et al. [6]</td>
<td>2008</td>
<td>61</td>
<td>4</td>
<td>22</td>
<td>4.9</td>
</tr>
<tr>
<td>Braumann et al. [11]</td>
<td>2008</td>
<td>5</td>
<td>18.5</td>
<td>NA</td>
<td>0</td>
</tr>
<tr>
<td>Gharagozloo et al. [4]</td>
<td>2009</td>
<td>100</td>
<td>4</td>
<td>21</td>
<td>3</td>
</tr>
<tr>
<td>Veronesi et al. [8]</td>
<td>2009</td>
<td>54</td>
<td>4.5</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Present study</td>
<td>2009</td>
<td>38</td>
<td>10*</td>
<td>10.5</td>
<td>2.6</td>
</tr>
</tbody>
</table>

*Median of six days for the American patients. NA, not available.
From a technical point-of-view, we performed all procedures using a totally robotic approach. In other series [3, 4, 6], the robot was used mainly for the mediastinal and the vascular dissection, and the lobectomy was performed using a classical thorascopic approach.

The use of a minithoracotomy at the beginning of the procedure is also worth noting. By doing this, it allows for the robotic arm and the assistant port to be placed through a unique 4–5 cm incision. It also enables control of the hilum in the case of a massive hemorrhage, as was the case for one patient in our series. Additionally, the specimen can be retrieved through a small incision, with no rib spreading.

5. Conclusion

The results presented here demonstrate that advanced thoracic procedures can be performed safely using a robotic system, allowing for precise dissection in difficult to reach areas. As a result, the robotic approach is of particular interest for oncologic resections because it enables a good mediastinal and vascular dissection to be achieved. Still, further comparative studies are needed in order to properly assess oncological results.

References

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