A Comparative Study of Robot-assisted Thoracoscopic Surgery and Video-assisted Thoracoscopic Surgery in Treatment of Pulmonary Sequestration in Children

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Abstract

Purpose

This study was performed to compare the application of robot-assisted thoracoscopic surgery with video-assisted thoracoscopic surgery in the treatment of pulmonary sequestration (PS) in children.

Methods

Clinical data of 128 consecutive pediatric patients undergoing robot-assisted thoracoscopic surgery or video-assisted thoracoscopic surgery for PS from May 2019 to July 2022 at our institution were reviewed. 62 patients underwent robotic-assisted thoracoscopic surgery (RATS group) while 66 patients underwent video-assisted thoracoscopic surgery (VATS group). There were no significant differences in age, weight, gender, type of PS, preoperative infection and surgical method between the two groups. Aberrant artery was ligated with silk suture or vascular clips and lobectomy, partial lobectomy or sequestrectomy was performed depending on the type of lesion in the two groups. Perioperative outcomes were compared between the two groups to evaluate the efficacy of the RATS.

Results

Neither group had surgical mortality. One case in each group required conversion to thoracotomy (1/62 vs 1/66, P>0.999). The median operation time of the RATS group was 77.5(60.0,111.3) minutes, while the VATS group was 60.0(40.0,75.0) minutes which had a significant difference (P<0.001) between the two groups. However, RATS was associated with less intraoperative bleeding [2.0(1.0, 2.0) ml vs 5.0(2.0, 5.0) ml, P <0.001], shorter postoperative duration [5.0(4.0, 6.0) days vs 6.0(5.0, 7.0) days, P<0.001] and shorter drainage days [1.0(0.8, 1.3) days vs 2.0(1.0, 3.0) days, P<0.001] compared with VATS. No significant difference was found for postoperative complications (hydrothorax and pneumothorax) incidence between two groups.

Conclusion

Although there was limitation of application of RATS in low-age, low-weight infants, RATS was a feasible and safe approach for pediatric patients with PS over 6 months and more than 7kg in weight. Furthermore, due to the enhanced vision and hand-wrist control, RATS had some advantages over VATS with less intraoperative blood loss and shorter postoperative drainage time and hospital duration.

Introduction

Pulmonary sequestration (PS) is a congenital malformation first reported by Pryce in 1946[1], where nonfunctional lung parenchyma with anomalous arterial supply is formed and isolated from the normal bronchial tree. Based on the visceral pleura at the border of normal lung tissue, PS can be divided into intralobar PS (ILS) and extralobar PS (ELS). In rare case, ELS can be found at the inner part of the diaphragm, abdomen, neck and mediastinum[2]. It may result in recurrent infections or, less likely,
hemoptysis in late childhood or early adulthood if untreated. Complete surgical resection is the treatment of choice for any type of PS. The traditional approach by thoracotomy has been successfully replaced by VATS[3]. The main surgical concern is managing aberrant vessels which caused disastrous bleeding if not handled properly. With the application of Da Vinci robot system which offered seven degrees of freedom combined with 3D high-definition imaging and steady operating arm, it have enabled surgeons to perform a safer, more precise dissection of the aberrant vessel and the sequestered tissue. RATS were successfully performed encouraging results in management of various thoracic pathologies, especially in adult surgery. Al-Mufarrej[4] reported the first robot-assisted thoracoscopic resection of ILS for a 26 years old female in 2009 and then several groups have attempted robot-assisted excisions of the sequestrations. Although robot technology was widely used in the adult surgery, it started relatively late in the field of pediatrics, and the number of operations carried out is far less than that of in adults. In the current study, we retrospectively analyzed the clinical data regarding either RATS or VATS procedures and outcomes of 128 pediatric patients with PS who were treated in our medical center from May 2019 to July 2022 with the aim of exploring the feasibility and clinical advantage of robot-assisted surgery over conventional endoscopic surgery in pediatric patients.

Patients And Methods

General data

Clinical data of 128 consecutive pediatric patients with PS who were treated in our medical center from May 2019 to July 2022 were retrospectively analyzed. The medical ethics committee of our hospital approved this retrospective study. The indication for surgery for each case was recommended after a detailed workup was completed. Benefits, risks, and expectations about RATS or VATS were explained in detail to the parents. All surgical cases were approved by the parents. 62 patients underwent RATS, while 66 patients underwent VATS. There were no significant differences in baseline of the two groups such as age, weight, gender, type of PS and preoperative infection ratio (Table 1). All the patients were diagnosed based on radiological appearance of enhanced computer tomography (CT) before surgery. Pathology also confirmed the resected specimen as PS. This study was approved by the Medical Ethics Committee of our hospital (2022-IRB-272)
Table 1
Patient Demographics and Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>RATS (n = 62)</th>
<th>VATS (n = 66)</th>
<th>$\chi^2$/z value</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (month), median ($P_{25}$, $P_{75}$)</td>
<td>9.5(7.0, 24.0)</td>
<td>9.5(7.0, 17.0)</td>
<td>0.93</td>
<td>0.353</td>
</tr>
<tr>
<td>Weight (kg), median($P_{25}$, $P_{75}$)</td>
<td>9.5(8.5, 12.9)</td>
<td>9.1(8.3, 12.0)</td>
<td>0.32</td>
<td>0.749</td>
</tr>
<tr>
<td>Gender, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>male</td>
<td>34(54.8)</td>
<td>45(68.2)</td>
<td>2.41</td>
<td>0.121</td>
</tr>
<tr>
<td>female</td>
<td>28(45.2)</td>
<td>21(31.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site, n (%)</td>
<td></td>
<td></td>
<td>0.22</td>
<td>0.637</td>
</tr>
<tr>
<td>left</td>
<td>41(66.1)</td>
<td>41(62.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>right</td>
<td>21(33.9)</td>
<td>25(37.9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type, n (%)</td>
<td></td>
<td></td>
<td>0.30</td>
<td>0.586</td>
</tr>
<tr>
<td>ILS</td>
<td>45(72.6)</td>
<td>45(68.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELS</td>
<td>17(27.4)</td>
<td>21(31.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operative pattern, n (%)</td>
<td></td>
<td></td>
<td>0.82</td>
<td>0.663</td>
</tr>
<tr>
<td>sequestrectomy</td>
<td>17(27.4)</td>
<td>21(31.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>partial resection</td>
<td>32(51.6)</td>
<td>35(53.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>lobectomy</td>
<td>13(21.0)</td>
<td>10(15.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preoperative infection, n(%)*</td>
<td>11(17.7)</td>
<td>18(27.3)</td>
<td>1.66</td>
<td>0.198</td>
</tr>
</tbody>
</table>

*p-Value < 0.05 was considered to be statistically significant. RATS: robotic-assisted thoracoscopic surgery; VATS: video-assisted thoracoscopic surgery; ILS: intralobar pulmonary sequestration; ELS: extralobar pulmonary sequestration; *at least once of pulmonary infection before operation.

RATS procedures

Anesthesia

Single-lung ventilation was achieved using selective endobronchial intubation or bronchus blocker which was also conducted in VATS procedure.

Position

The patient was layed in a maximally flexed lateral decubitus position with upper limb flexion on the side of the head.
Docking and robot system position

All the patients were operated by the daVinci Xi Robotic System (Intuitive Surgical, CA, USA). A CO2 inflation was applied at 6 mmHg. The docking was as follows:

1. 1st incision (Camera Arm): 8th intercostal space (ICS) at posterior axillary line;
2. 2nd incision (Anterior Arm): 6th ICS at middle clavicle line line;
3. 3rd incision (Posterior Arm): 8th ICS at subscapular line, ensuring that there was a sufficient distance (5~8cm) between the anterior and posterior arm holes.

A 30-degree scope was introduced through a 8-mm Trocar and secured to the camera arm so the positioning of the other instruments were accomplished under direct vision. Besides, auxiliary incision (5mm Trocar) was placed in 7th ICS at anterior-middle axillary line for suction or gauze. The 5mm incision was extended to place the 12mm Trocar when the endoscopic staplers were needed. The assistant stood at the abdominal side of the patient. The Da Vinci robot located on the backside of patient's head was approached and docked (Fig.1).

Surgical procedure

The right arm of the robot was connected to the Maryland bipolar cautery dissector (Intuitive Surgical, CA, USA) while the left arm was connected to the atraumatic grasper (Cadiere forceps, Intuitive Surgical, CA, USA). Aberrant artery was ligated with silk suture and vascular clips (Hem-o-lok™ Weck Surgical Instrument, Teleflex Medical, Durham, NC, USA). ELS was resected directly which called sequestrectomy. Lobectomy or partial lobectomy (wedge resection and segmental resection) was performed depending on size and location of the ILS by Harmonic ACE® curved shears (Intuitive Surgical, CA, USA) or endoscopic stapler. When the ILS lesion was widely in size in which minimal normal lung tissue remained or close to the hilus pulmonis, lobectomy was performed. When the ILS lesion was basically confined to single segment, segmental resection was performed. Otherwise wedge resection was performed simply if the ILS lesion is relatively small (Fig.2).

VATS procedures

Four 5 mm ports were used and placed similarly as in RATS group. Dissection was performed using the electrocoagulation hook or Harmonic system (Ethicon Endo-Surgery, USA). The procedures for aberrant artery and lesion were similar to those in RATS.

Postoperative management

Postoperatively, patients in two groups were received the same treatment on the thoracic surgery ward. Drainage tube were removed when the output was less than 50 mL for a 24-hour period and there was no air leak. Chest X ray were taken before discharge.

Statistical analysis
Statistical analysis was performed using SPSS.25 software. All quantitative data were non-normal distributed and expressed by median($P_{25}$, $P_{75}$). Categorical data were presented in percentage. Comparisons between the two groups were performed using the chi-squared test for qualitative data and the Wilcoxon test for quantitative data. A $p$-value <0.05 was considered statistically significant.

Results

Intraoperative condition

Neither group had surgical mortality. One case in each group required conversion to thoracotomy (1/62 vs 1/66, $P>0.999$). The median operation time of the RATS group was 77.5(60.0, 111.3) minutes, while the VATS group was 60.0(40.0, 75.0)minutes which had a significant difference ($P<0.001$) between the two groups. Further analysis revealed that in subgroups of lobectomy and sequestrectomy the operation time was significantly longer in RATS versus VATS (Table 2).
Table 2
Intraoperative and postoperative results in RATS and VATS.

<table>
<thead>
<tr>
<th>Variables</th>
<th>RATS group (n = 62)</th>
<th>VATS group (n = 66)</th>
<th>(\chi^2/z) value</th>
<th>(p) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall operative time (min), median (P_{25}, P_{75})</td>
<td>77.5(60.0,111.3)</td>
<td>60.0(40.0,75.0)</td>
<td>3.58</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Sequestrectomy</td>
<td>60.0(40.0, 77.5)</td>
<td>40.0(30.0, 55.0)</td>
<td>2.39</td>
<td>0.017</td>
</tr>
<tr>
<td>Partial lobectomy</td>
<td>70.0(60.0,90.0)</td>
<td>65.0(50.0, 80.0)</td>
<td>1.57</td>
<td>0.116</td>
</tr>
<tr>
<td>Lobectomy</td>
<td>120.0(115.0, 150.0)</td>
<td>70.0(60.0,105.0)</td>
<td>2.94</td>
<td>0.003</td>
</tr>
<tr>
<td>Bleeding (ml)</td>
<td>2.0(1.0,2.0)</td>
<td>5.0(2.0,5.0)</td>
<td>4.91</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Conversion, n (%)</td>
<td>1(1.6)</td>
<td>1(1.5)</td>
<td>Fisher test</td>
<td>&gt; 0.999</td>
</tr>
<tr>
<td>Chest drainage time (days), median (P_{25}, P_{75})</td>
<td>1.0(0.8,1.3)</td>
<td>2.0(1.0,3.0)</td>
<td>4.23</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Postoperative duration (days), median (P_{25}, P_{75})</td>
<td>5.0(4.0,6.0)</td>
<td>6.0(5.0,7.0)</td>
<td>3.22</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Complication, n(%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>hydrothorax</td>
<td>15(24.2)</td>
<td>8(12.1)</td>
<td>3.16</td>
<td>0.075</td>
</tr>
<tr>
<td>pneumothorax</td>
<td>5(8.1)</td>
<td>4(6.1)</td>
<td>0.20</td>
<td>0.658</td>
</tr>
</tbody>
</table>

p-Value <0.05 was considered to be statistically significant. RATS: robotic-assisted thoracoscopic surgery; VATS: video-assisted thoracoscopic surgery.

Postoperative management

RATS was associated with less intraoperative bleeding [2.0(1.0, 2.0) ml vs 5.0(2.0, 5.0)ml, P <0.001], and shorter drainage days [1.0(0.8, 1.3)days vs 2.0(1.0, 3.0)days, P<0.001] and shorter postoperative duration [5.0(4.0, 6.0)days vs 6.0(5.0, 7.0)days, P<0.001] compared with VATS. No significant difference was found for postoperative complications incidence between two groups.

Discussion

PS is a congenital malformation first reported by Pryce in 1946[1], where nonfunctional lung parenchyma with anomalous arterial supply is formed and isolated from the normal bronchial tree. Based on the
visceral pleura at the border of normal lung tissue, PS can be divided into ILS and ELS. Surgery is the treatment of choice, which usually performed by video-assisted thoracoscope. However, there are unique technical challenges associated with VATS such as two-dimensional image and rigid, straight instruments which hindered its adoption in all situations[5]. Therefore, robots have been introduced into surgical procedures in an attempt to facilitate surgical performance. The three dimensional view with depth perception which creates images with increased resolution was a marked improvement over the conventional thoracoscopic camera view. Besides, the increasing degrees of freedom and enhanced dexterity also enhanced the dissection of anomalous vessels and lesions. Al-Mufarrej[4] reported the first robot-assisted thoracoscopic resection of ILS for a 26 years old female in 2009 and then some medical centers have been attempting robot-assisted excisions of the sequestrations.

Although, the robot technology is more and more widely used in adults, it started relatively late in the field of pediatrics, and the number of operations carried out in children is far less than that in adults. Arellano et al reported 6 cases of RATS from 2015 to 2018, including 3 cases of diaphragm folding, 2 cases of lobectomy and 1 case of bronchial cyst resection. Durand et al reported 7 cases of robotic lobectomy for bronchiectasis in children. Meehan et al reported 11 cases of RATS, including 4 cases of lung surgery in which only one case was performed for ILS. Due to the low incidence of PS and the unpopularity of robot in pediatric patients, no single study has been reported a large number of PS cases treated by RATS. Our study with 62 cases of pediatric RATS maybe the one of the largest research ever carried out.

Up to now, there is no consensus on the choice of the minimum age of RATS all over the world. Because the robot system needs a certain amount of space between the arms (usually the distance between two arms should be 8cm), the patients who are too young may not be operated due to limited anatomic space. Denning et al [6] considered that the robotic instruments size would be prohibitively large for the intercostal space of a child weighing 5 kg or less. Molinaro et al [7] conducted a retrospective analysis of robotic surgery in two paediatric surgery centers in Italy, and considered a weight above 7kg be appropriate for RATS. Ballouhey et al [8] reported cases that performed robotic surgery on two children with esophageal atresia (body weight 3.0kg and 3.1kg, respectively), but they eventually converted to thoracotomy. Meehan et al[9, 10] underwent 4 cases of robot-assisted lobectomy in infant with congenital cystic adenomatoid malformation or PS. The average age was 7 months and the average body weight was 7.9kg. They also planned to perform RATS on a newborn child (weight 2.5kg) with diaphragmatic hernia, but converted to VATS because the chest was too small. Based on the previous reports and our experiences, the criterion for RATS in our study were over 6 months and 7kg for minimum weight.

Furthermore, there is also no international consensus that has been reached regarding the optimal age for surgery of PS. Children with asymptomatic sequestration are at risk for pulmonary infection and abscess especially with the ILS[11]. As the infection rate of PS significantly increased with age, surgery in such cases were difficult, the operative time, intraoperative bleeding, and length of hospital stay were significantly increased. With the fact that most cases develop these complications within the first year of life, many experts prefer to perform resection between 6 and 12 months of age[2, 12, 13] which also carried out by our medical center. Although the operation time for PS was basically suitable for
requirements of the RATS, we considered that VATS was more practical for the infant with polypnea or recurrent infections in the early postnatal period. So in our study, there were four patients who were younger than 5 months all underwent VATS.

Compared with the looser requirements for the placement of 5mm Trocar in VATS, RATS had stricter discipline for each ports and docking. Da Vinci surgical system recommends that the distance between each Trocar should be about 8cm, we think that the distance around 5cm also workable as Ballouhey reported. The robotic ports placing was adjusted over the experiences of our operation making sure that each arm could not be interfered in small chest. The overall arrangement was fan shaped which was similar to adults procedure[14]. “W modified” shape was also reported by Durand[15]. Besides, there is a very special type of ELS, which the PS is located in diaphragm. In that case, the placement of the robotic arm is quite different from usual procedure. The docking is as follows: (1) 1st incision (Camera Arm): 2th ICS at midaxillary line; (2) 2nd incision (Anterior Arm): 4th ICS at middle clavicle line; (3) 3rd incision (Posterior Arm): 4th ICS at subscapular line. The auxiliary hole was made in 3th ICS at the anterior axillary line. The assistant standed in the head side of the patient. The robot located on the backside of patient's abdomen was approached and docked. The diaphragm was dissected and the lesion was carefully liberated, and the feeding arteries and reflux veins were ligated and cut. The diaphragm was sutured to prevent iatrogenic diaphragmatic hernia after the lesion was removed. We had performed sequestrectomy in 10 children using this method which were not included in this study.

The conversion rate of robotic lobectomy was 4.7–9.2% in adults with the main reasons of bleeding and adhesion. Furthermore, due to anatomical reasons, the conversion rate of upper lobectomy was relatively high up to 17.5%[16–18]. Although the conversion rate of robotic lobectomy in adults was reported lower than that of VATS[19], no significant difference between two groups was showed in our study. The overall conversion rate in groups of RATS and VATS were 1.61% (1/62) and 1.51% (1/66) respectively (P > 0.999). These two cases all occured in lobectomy procedure. So when calculated only in subgroup of lobectomy, the conversion rate of RATS and VATS were 7.69% (1/13) and 10% (1/10) respectively. According to current less information in pediatric patient the overall conversion rate of robotic surgery was 2.5–4.7%[20, 21] regardless of the operative site. Moreover, Cundy et al [21] showed that the conversion rate of robotic thoracic surgery in children was about 10%. Durand et al[15] reported the surgical treatment of 18 children with bronchiectasis, including 7 cases with RATS and 11 cases with VATS and the fact that no conversion in the RATS while five conversion cases in the VATS. However, it was impossible to make accurate statistics data because of few cases. As the number of robotic surgery for pediatric patient continued to increase all over the world, the data might become more accurate. Although preoperative pulmonary infection was considered to be the crucial factors for conversion, we believed effective single-lung ventilation as the another important factor for both type of surgery. In RATS group, a 7-month patient with ILS suffered conversion due to the displacement of bronchus blocker and failure of single-lung ventilation in the process of dissecting the bronchia. Because of the short bronchi and lack of proper bronchus blocker, it was difficult to perform satisfying single-lung ventilation in pediatric patient especially in low-weight patient. While in the VATS group, a 4 years-old patient with ILS
suffered conversion because of the severe pleural adhesion and bleeding due to preoperative recurrent infection.

The median operation time in the RATS group was 77.5(60.0, 111.3) minutes, compared with 60.0(40.0, 75.0) minutes in the VATS group which had a significant difference (P < 0.001). Further analysis revealed that in subgroups of sequestrectomy and lobectomy, the median operation time was significantly longer in RATS versus VATS [60.0(40.0, 77.5) vs 40.0(30.0, 55.0) and 120.0(115.0, 150.0) vs 70.0(60.0, 105.0) minutes respectively]. These results were similar to Durand's study[15] in which the mean operative time of lobectomy was significant longer in RATS compared with VATS (247 ± 50 vs 152 ± 57 min). Due to the higher proportion of preoperative infections (e.g., infected congenital pulmonary malformation, primary ciliary dyskinesia, post-viral infection) in their study, the operation time in either group was longer than ours. Besides, we timed the installation and withdrawal procedure separately. The installation time was within 10–15 minutes, and the withdrawal time was within 3–5 minutes. So we thought that the extra time was mainly due to the replacement of robotic instruments during the operation.

Although the operation time in RATS was longer than VATS, the advantage of less intraoperative blood loss [2.0(1.0, 2.0) ml vs 5.0(2.0, 5.0) ml] and a shorter postoperative hospital duration [5.0(4.0, 6.0) days vs 6.0(5.0, 7.0) days] in RATS was showed up in our study and in other reports[5, 22, 23]. Because of its great three-dimensional visualization and improved maneuverability around anatomic structures, RATS enabled a safer, more precise dissection of aberrant vessels and sequestered pulmonary tissue which might result in less bleeding. Due to the reduction hospital stay length and overall nursing care costs, robotic surgery decreased a portion of costs which partly offset additional expenses of application the robotic system. Another study[24] showed the significantly shorter completion time of knot-tying in RATS using a pediatric thoracoscopic model. Besides, there were no significant differences in perioperative complications.

**Conclusion**

Although there was limitation of application of RATS in low-age, low-weight infants, RATS was a feasible and safe approach for pediatric patients with PS over 6 months and more than 7kg in weight. Furthermore, due to the enhanced vision and hand-wrist control, RATS had some advantages over VATS with less intraoperative blood loss and shorter postoperative drainage time and hospital duration. Larger international multicenter studies are required to strongly determine the strengths and weaknesses of robotic surgery over thoracoscopy in pediatric patients.

**Declarations**

**Acknowledements**

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References


**Figures**
Figure 1

Preoperative procedure: (A) patient position and port placement; (B) robotic docking.
Figure 2

Robotic surgical procedure in ELS: (A) dissecting the aberrant artery; (B) ligating and cutting the aberrant artery; (C) resecting the ELS lesion by Harmonic ACE® curved shears; (D) suturing the surface of wound.