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ORIGINAL ARTICLE

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THORACIC

The robotic surgery learning curve of a surgeon experienced in video-assisted thoracoscopic surgery compared with his own video-assisted thoracoscopic surgery learning curve for anatomical lung resections

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Key question

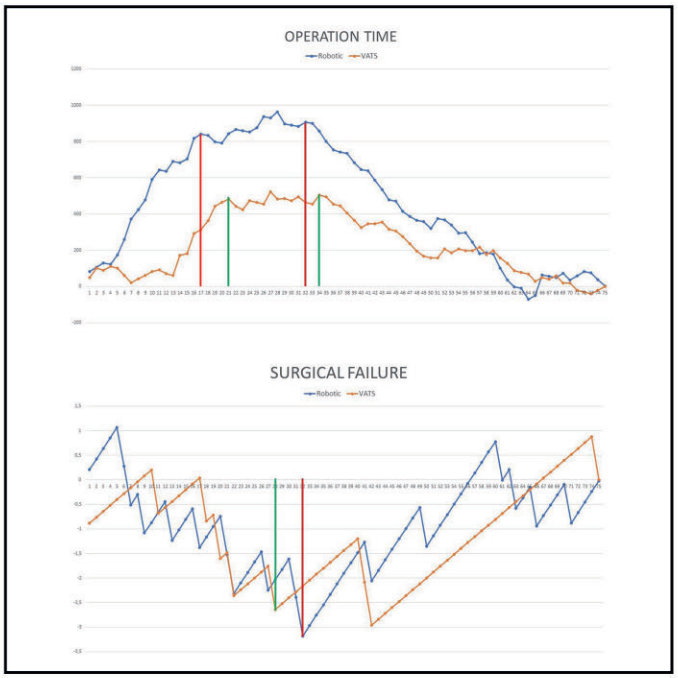
Is the robotic learning curve of a VATS experienced surgeon shorter than his learning curve for VATS for anatomical lung resections?

Key finding(s)

CUSUM charts for operating time and surgical failure were similar in VATS and robotic approaches.

Take-home message

Robotic anatomical resection is associated with a learning curve similar to that of VATS in proficient surgeons.



Abstract

OBJECTIVES: Robotic surgery, although it shares some technical features with video-assisted thoracoscopic surgery (VATS), offers some advantages, such as ergonomic design and a 3-dimensional view. Thus, the learning curve for robotic lung resection could be expected to be shorter than that of VATS for surgeons who are proficient in VATS. The goal of this study was to analyse the robotic learning curve of a VATS experienced surgeon and to compare it to his own VATS learning curve for anatomical lung resections.

Presented at the 29th European Conference on General Thoracic Surgery, 20–22 June 2021 (Virtual Meeting).

METHODS: We conducted a retrospective observational study based on the prospectively recorded data of the first 150 anatomical lung resections performed with VATS (75 cases) and with the robotic (75 cases) approach by the same surgeon in our centre. Learning curves were analysed using the cumulative sum method to assess the trends for total operating time and surgical failure (intraoperative complications, conversion, technical postoperative complications and reintervention) across case sequences. Subsequently, using adequate statistical tests, we compared the postoperative outcomes in both groups.

RESULTS: The median operating time was similar for both approaches ($P = 0.401$). Surgical failure rate was higher for the robotic cases (21.3% vs 12%; $P = 0.125$). Based on cumulative sum analyses, operating time decreased starting with case 34 in the VATS group and with case 32 in the robotic cohort. Surgical failure tended to decline starting with case 28 in the VATS group and with case 32 in the robotic group. Perioperative results were similar in both groups.

CONCLUSIONS: When we compared robotic and VATS learning curves for anatomical lung resection, we did not find any differences. Postoperative outcomes were also similar with both approaches.

Keywords: Learning curve • Lung resection • Video-assisted thoracoscopic surgery lobectomy • Robotic anatomical lung resection lobectomy • Postoperative complications

ABBREVIATIONS

CUSUM	Cumulative sum
ICS	Intercostal space
RATS	Robotic anatomical lung resection
VATS	Video-assisted thoracoscopic surgery

INTRODUCTION

Video-assisted thoracoscopic surgery (VATS) anatomical lobectomy for lung cancer, initially described in 1992 [1, 2], is the standard approach for lung resection in many centres due to reduced postoperative pain, faster recovery, fewer complications and better quality of life compared to conventional thoracotomy [3]. Robotic anatomical lung resection (RATS), reported 1 decade later [4], is increasingly used. Several researchers have showed shorter lengths of stay and lower rates of mortality and morbidity compared with thoracotomy [5–7]. Studies comparing RATS versus VATS approaches have provided mixed results [5–12]. However, to our knowledge, no studies have independently compared the period needed to perform VATS and RATS anatomical lung resection proficiently.

The acquisition of new techniques, even for established consultants, involves some type of learning curve [13]. Studies have shown that learning curves generally 'flatten out' as experience increases, resulting in fewer complications, shorter operating times and infrequent conversion to the standard procedure [14]. Although different training techniques, such as training courses, cadaveric resection and assistance from expert practitioners, have been described to minimize the learning curve, surgeons must gain proficiency and experience by operating on suitable patients.

On the other hand, RATS could be considered a technological improvement of conventional VATS and as sharing some technical features with it. Moreover, most thoracic surgeons performing RATS anatomical lung resections are experts in VATS lobectomy techniques prior to starting RATS lung operations. In addition, RATS offers some improvements such as ergonomic design and a 3-dimensional view. Our hypothesis is that the learning curve for RATS lung resection could be shorter in the hands of proficient VATS surgeons. The goal of this study was to analyse the robotic learning curve of an experienced VATS surgeon and to compare it to his own VATS learning curve for anatomical lung resections. Subsequently, we compared the outcomes of both series of cases.

METHODS

Study population

A retrospective observation study was conducted. We reviewed the prospectively recorded data from 150 anatomical lung resections performed by the same surgeon during 2 different periods of time; 75 cases corresponded to his early VATS series of cases (March 2015 to February 2017) and 75 were RATS anatomical lung resections performed between June 2018 and July 2020. All patients in both series were 18 years or older, selected for non-extended elective anatomical lung resection (segmentectomy, lobectomy, bilobectomy or pneumonectomy), according to standardized selection criteria [15]. The need for Clinical Research Ethics Committee approval was waived according to our institutional law because the study was a retrospective cohort study based on anonymous data of patients.

Surgeon's expertise and training in video-assisted thoracoscopic and robotic anatomical lung resections

All procedures were performed by the same surgeon (M.F.J.). He has more than 20 years of surgical practise and a high level of experience in anatomical resections through a posterolateral thoracotomy (>200 procedures) and a muscle-sparing mini-thoracotomy (>200 procedures). VATS training consisted of a 2-day course on technical skills in VATS lobectomy at the Department of Thoracic Surgery in Copenhagen (Denmark) and more than 50 hands-on sessions with animal simulation models consisting of performing a lobectomy in an *ex vivo* heart-lung porcine block. Before beginning to use the VATS technique for anatomical lung resection, the surgeon had performed more than 200 thoracoscopic procedures of low complexity. For RATS, the surgeon was Intuitive Surgical certified; his training included Da Vinci technology online modules, skill drills with a simulator (>20 h), off-site Da Vinci technology training for a console surgeon (2-day course with hands-on sessions on anatomical specimens in the IRCAD centre in Strasbourg, France), and proctorship for the first procedures. Before beginning to use the robotic technique, the surgeon had performed more than 100 thoracoscopic lobectomies and 7 robotic thymectomies.

Operative technique

a. VATS approach: A 4- to 5-cm anterior utility incision was made on the fourth intercostal space (ICS), just anterior to the latissimus dorsi muscle. The wound was protected by a soft tissue retractor kept in place by 1 ring in the chest cavity and 1 outside the skin. The cavity was evaluated with a 10-mm, 30° angled video thoracoscope. A low anterior 1-cm camera port was positioned at the level of the top of the diaphragm and anterior to the level of the hilum and the phrenic nerve. The camera was operated by an assistant standing at the patient's anterior side, the same side as the surgeon. The final 1.5-cm incision was positioned at the same level but posteriorly, in a straight line down from the scapula and anterior to the latissimus dorsi muscle. The vessels, the fissure and the bronchus were divided with appropriate endostaplers. The specimen was removed in a bag through the utility incision. Finally, one 24-Fr intercostal drain was placed through the camera incision.
b. RATS approach: A four-arm technique was selected. An 8-mm robotic camera trocar was inserted in the eighth ICS at the mid-axillary line. The cavity was evaluated with the 0° angled camera. Two 12-mm robotic trocars were inserted in the eighth ICS at the level of the diaphragm at the anterior axillary line and the scapular line, respectively. An 8-mm robotic trocar was inserted in the eighth ICS at the level of the auscultatory triangle. Finally, a 10-mm auxiliary port was inserted in the ninth ICS just between the camera port and the anterior robotic port, establishing a triangle. We used CO_2 insufflation pressure of 6–10 mmHg. The vessels, the fissure and the bronchus were divided sequentially, with robotic (30% of cases) or manual endostaplers. A specimen was removed inside of a bag by slightly enlarging the anterior port. At the end, one 24-Fr intercostal drain was placed through the camera incision.

Perioperative management

Perioperative management was uniform for all patients throughout the study period. Antibiotic prophylaxis comprised a single dose of cefazolin 2 g, repeated after 6 h if the operation continued. Systematic nodal dissection was performed according to the guidelines of the European Society of Thoracic Surgeons [16]. Patients were extubated in the operating room and, after 6 h in the recovery room, were transferred to the thoracic ward. At the beginning of the procedure, under direct vision, a paravertebral catheter was inserted for postoperative analgesia with bupivacaine and fentanyl infusion for a maximum of 3 days postoperatively. Oral paracetamol and non-steroid anti-inflammatory drugs were indicated thereafter. Nursing care was homogeneous in all cases and included incentive spirometry, early mobilization and standardized intensive physiotherapy as indicated [17].

Statistical analyses

Analysed data included patient demographic characteristics. The analysed outcomes were length of hospital stay, 30-day mortality, overall and cardiopulmonary complications, operating time and surgical failure, which was defined as any perioperative complication related to technical aspects, including non-anaesthetic intraoperative complications, conversion to an open procedure, reintervention and technical postoperative complications [haemothorax, prolonged air leak (defined as an air leakage into the pleural drainage lasting more than 5 days after surgery), pneumothorax with or without air leak requiring drainage, chylothorax, empyema, recurrent palsy, wound haematoma, wound infection and bronchial fistula]. Operative morbidity was defined as any postoperative complication occurring during hospitalization or within the first 30 days after the intervention and included respiratory failure (the need for mechanical ventilation for more than 24 h or the need for reintubation at any time), acute respiratory distress syndrome, atrial arrhythmia, ventricular arrhythmia, atelectasis requiring bronchoscopy, pneumonia, pulmonary thromboembolism, acute myocardial infarction, renal failure, stroke, prolonged air leak, haemothorax, pneumothorax, bronchial fistula, wound dehiscence, wound haematoma, empyema, chylothorax, recurrent nerve paralysis and phrenic nerve paralysis. Cardiopulmonary complications were limited to respiratory failure, need for reintubation, prolonged mechanical ventilation for more than 24 h, pneumonia, atelectasis requiring bronchoscopy, pulmonary oedema, pulmonary embolism, acute respiratory distress syndrome/acute lung injury, arrhythmia requiring treatment, acute myocardial ischaemia, acute cardiac failure, stroke/transient ischaemic attacks and acute kidney injury. These complications were already defined according to the joint report of variable definitions agreed upon by the Society of Thoracic Surgeons and the European Society of Thoracic Surgeons [18]. Finally, 30-day mortality was defined as any postoperative death occurring during hospitalization or within the first 30 days after the operation.

Discrete variables were measured as proportions and percentages and were compared by the χ^2 test or the Fisher's exact test when expected frequencies were below 5. Continuous variables were compared by the Wilcoxon rank-sum test. Analyses were exploratory in nature, and all tests were two-sided, with statistical significance set at a *P*-value of <0.05.

Cumulative sum analysis

Operating time was analysed using the cumulative sum (CUSUM) method to determine the running total of differences between the individual data points and the mean of all data points [19]. Cases were arranged chronologically on the X axis from the earliest case to the latest case. We calculated for each patient the difference between his individual surgical time and the mean time of all the series. Then we calculated the CUSUM of these differences and we represented them graphically on the Y axis. Line 0 in the graph marks the reference value corresponding to the mean of all cases. Surgical failure was analysed by the standard non-adjusted CUSUM chart, which works with a constant risk of failure for each case (the rate of surgical failure in each series of cases). Outcome was categorized as 0 (no surgical failure) and 1 (surgical failure); afterwards, we calculated the difference between each individual patient outcome (0 or 1) and the estimated rate of surgical failure of each series so that, when the patient did not suffer any surgical failure, the award was equivalent to the risk of surgical failure of the series [-(0 - risk of the series)]. However, when the patient suffered any surgical failure, the punishment resulted in -(1 - risk of the series). For graphical representation, cases were chronologically arranged from the earliest case to the latest on the X axis. We then calculated the CUSUM of these differences and represented them graphically on the Y axis.

Statistical analyses were performed using the statistical software Stata/IC 16.1 2020 (StataCorp, College Station, TX, USA).

RESULTS

Patient characteristics are summarized in Table 1. Male sex, diabetes and hypertension rates were significantly higher in the VATS group; predicted postoperative carbon monoxide lung diffusion capacity was significatively higher in the robotic group. Both groups were comparable regarding the rest of the baseline characteristics.

No pneumonectomies and only 'easy' anatomical segmentectomies (a single intersegmental dissection surface) [20] were performed during the study period.

Clinical outcomes and adverse events of both cohorts for this study are summarized in Table 2. No perioperative deaths were observed in the series. Overall, no difference was observed in postoperative complications between the cohorts. Length of hospital stay was significatively shorter in the robotic group. Table 3 contains a detailed description of perioperative adverse events considered as surgical failures.

The CUSUM graph for operating time shows the learning curves for VATS and robotic anatomical resections; they are divided into 3 phases that reflect the stage of mastery: phase 1, the initial learning period, coinciding with the novice stage, which comprised the first 17 cases of the robotic group and the first 21 cases of the VATS group; phase 2, the consolidation period, which comprised the 18th to the 32nd cases of the robotic group and the 22nd to the 34th cases in the VATS group, from which the surgeon can be consider proficient (competent and proficient stages); and phase 3, the experienced period from case 33 in the robotic group and from case 35 in the VATS group, coinciding with the start of the expert stage. Surgical failure tended to decrease from case 28 in the VATS group and from case 32 in the robotic group. CUSUM charts are shown in Figs 1 and 2.

DISCUSSION

According to our results, proficiency with VATS anatomical lung resection was obtained around case 28–34 and that of RATS, around case 32 in this series. Although there were expectations that the technical advantages of the robotic system could shorten the RATS learning curve, the results of this study did not prove this assumption. The learning curve of RATS was like that of VATS even in the hands of a surgeon proficient in both procedures.

Surgical innovation seeks to reduce aggressiveness and to improve postoperative outcomes. After implementing new procedures, surgeons, anaesthetists and nursing teams must integrate new techniques into their practice, which can have an impact on outcomes [14]. For that reason, the process of implementing new surgical techniques must include an evaluation of the learning curve based on objective, measurable outcomes. The goal of this study was to analyse the robotic learning curve for the anatomical lung resection of an expert VATS surgeon (>300 thoracoscopic procedures of which >100 were anatomical lung resections) by comparing results with those of the initial VATS experience in terms of operating time and surgical failure trends and perioperative outcomes. Because the evaluation of technical

Table 1: Patient demographics and baseline characteristics

Characteristics	VATS (n = 75)	Robotic (n = 75)	P-value
Age (years), mean ± SD	64.68 ± 12.17	62.56 ± 10.18	0.249
BMI (kg/m^2), mean ± SD	26.14 ± 4.23	26.63 ± 5.16	0.527
ppoFEV1%, mean ± SD	77.72 ± 10.15	78.49 ± 21.54	0.820
ppoDLCO%, mean ± SD	56.19 ± 15.68	69.71 ± 18.82	<0.001
Male gender, *n* (%)	48 (64)	33 (44)	0.014[a]
Coronary disease, *n* (%)	3 (4)	2 (2.7)	1[b]
Arrhythmia, *n* (%)	1 (1.3)	1 (1.3)	1[b]
CKD, *n* (%)	1 (1.3)	1 (1.3)	1[b]
Stroke, *n* (%)	2 (2.7)	0 (0)	0.497[a]
Diabetes, *n* (%)	10 (13.3)	3 (4)	0.042[a]
Hypertension, *n* (%)	32 (42.7)	20 (26.7)	0.040[a]
Peripheric arteriopathy, *n* (%)	3 (4)	2 (2.7)	1[b]
Previous malignancy, *n* (%)	26 (34.7)	33 (44)	0.242[a]
Tumour size (mm), *n* (%)			0.344[a]
<30	54 (72)	59 (78.7)	
≥30	21 (28)	16 (21.3)	
Type of malignancy, *n* (%)			0.963[a]
Primary neoplasm of the lung	60 (80)	59 (78.7)	
Metastases other than lung	8 (10.7)	8 (10.7)	
No lung cancer	7 (9.3)	8 (10.7)	
Type of resection, *n* (%)			0.116[a]
Lobectomy	67 (89.3)	58 (77.3)	
Bilobectomy	0 (0)	1 (1.3)	
Segmentectomy	8 (10.7)	16 (21.3)	

[a] P-value for the χ^2 test.

[b] P-value for the Fisher's exact test.

BMI: body mass index; CKD: chronic kidney disease; ppoDLCO%: predicted postoperative carbon monoxide lung diffusion capacity; ppoFEV1%: predicted postoperative forced expiratory volume in 1 s; SD: standard deviation; VATS: video-assisted thoracoscopic surgery.

Table 2: Summary of perioperative outcomes

Outcome	VATS (n = 75)	Robotic (n = 75)	P-value
Operating time (min), median (IQR)	120 (100–150)	120 (90–150)	0.401[a]
Surgical failure, n (%)	9 (12)	16 (21.3)	0.125[b]
Operative morbidity, n (%)	12 (16)	18 (24)	0.221[b]
Cardiopulmonary complications, n (%)	6 (8)	4 (5.3)	0.513[b]
Length of hospital stay (days), median (IQR)	5 (4–6)	3 (2–4)	<0.001[a]

[a] P-value for Wilcoxon's rank-sum test.
[b] P-value for the χ^2 test.
IQR: interquartile range; VATS: video-assisted thoracoscopic surgery.

Table 3: Surgical failure

Adverse event	VATS (n = 75)	Robotic (n = 75)	P-value
Intraoperative complication, n (%)	2 (2.7)	4 (5.3)	0.681[a]
Bronchial injury	1	2	
Air leak	0	1	
Incorrect vein division	0	1	
Arterial injury	1	0	
Conversion, n (%)	2 (2.7)	3 (4)	1[a]
Bronchial injury	0	2	
Air leak	0	1	
Arterial injury	1	0	
Lymph node dissection	1	0	
Technical postoperative complications, n (%)	7 (9.3)	15 (20)	0.65[b]
Haemothorax	3	2	
Prolonged air leak	1	7	
Pneumothorax	2	0	
Chylothorax	0	2	
Empyema	0	2	
Recurrent palsy	1	1	
Wound haematoma	0	3	
Wound infection	1	0	
Bronchial fistula	0	1	
Reintervention, n (%)	0 (0)	4 (5.3)	0.12[a]
Empyema	0	1	
Haemothorax	0	2	
Bronchial fistula	0	1	

[a] P-value for the Fisher's exact test.
[b] P-value for the χ^2 test.
VATS: video-assisted thoracoscopic surgery.

proficiency in specific surgical procedures is not easy, we relied on graphical methods of quality control to provide objective evidence on a case-by-case basis and showing changes over time. The main advantages of CUSUM methods are the independence from the sample size and the efficiency in detecting small but continuous shifts in the data.

This study also shows similar surgical times for both procedures. The International VATS Lobectomy Consensus Group stated that 50 cases are needed for technical proficiency in VATS lobectomy, and surgeons need to perform at least 20 cases annually to maintain VATS lobectomy operative skills [21]. In the study of McKenna [22], 50 cases are needed for a surgeon to feel comfortable performing a VATS pulmonary lobectomy. Li et al. [23] evaluated the first 200 VATS lobectomy cases from 2 different senior surgeons at 2 different institutions. They assessed proficiency by evaluating efficiency and consistency. According to this report, achieving efficiency in performing a VATS lobectomy seems to require more than 100 cases of personal experience whereas 200 or more are needed for consistency. The learning period for RATS is variable: between 14 and 40 cases [4, 24–27]. However, to become proficient in more advanced procedures and to further reduce operating times, additional training is required. According to Arnold et al. [28], based on operating time, the learning curve for robotic lobectomy is 22 cases; however, mastery is achieved after 63 cases.

An important factor that can affect the learning curve for robotic lobectomy is previous experience in VATS. Contrary to our findings, Baldonado et al. [29] studied RATS learning curves for experienced VATS surgeons and concluded that there is not a definite learning curve for RATS lobectomy in that population. In the study

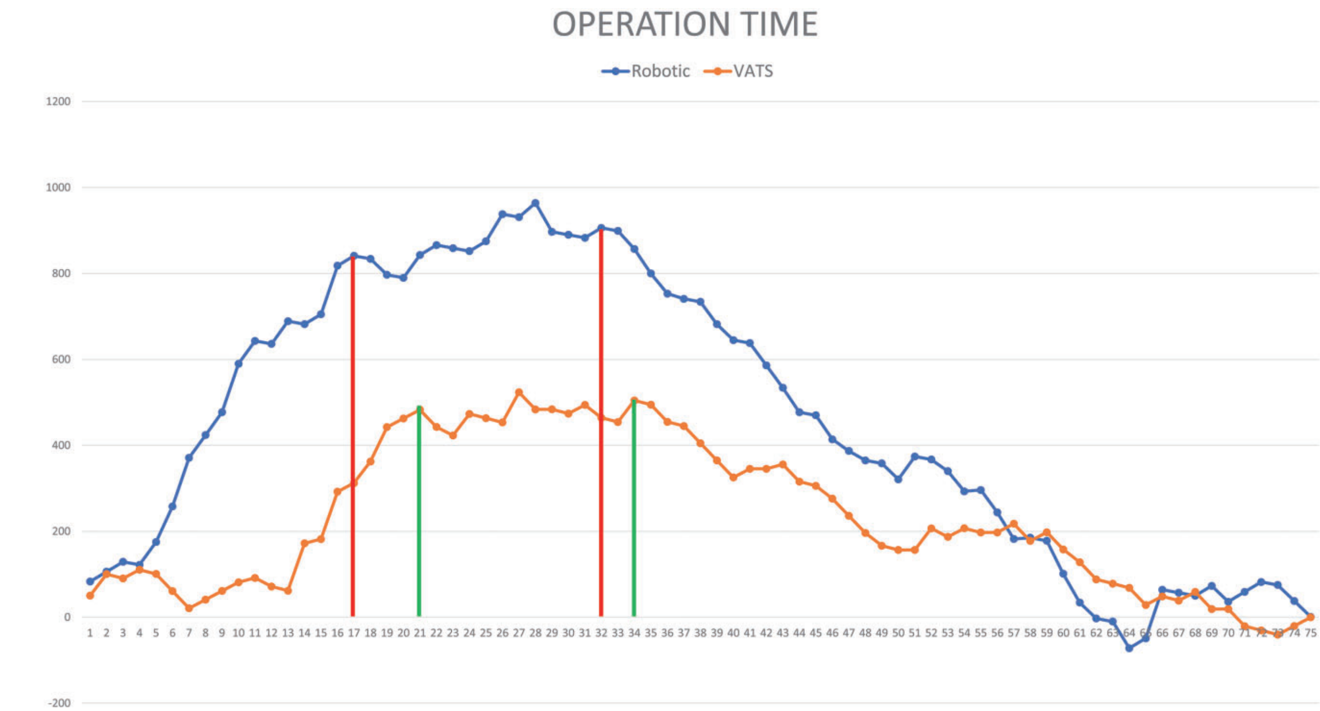


Figure 1: Cumulative sum chart for operating time. As shown in the cumulative sum curve, there were 2 cut-off points observed in each approach. VATS: video-assisted thoracoscopic surgery.

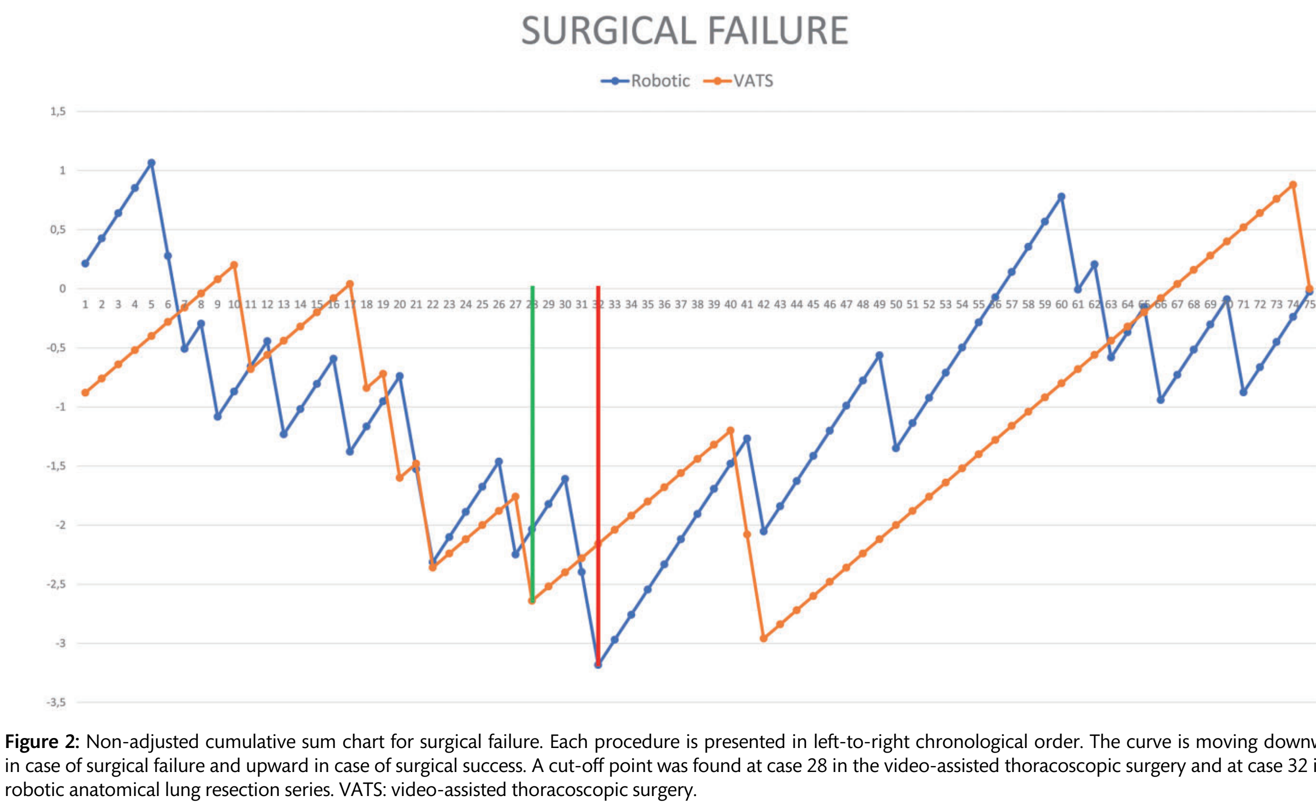


Figure 2: Non-adjusted cumulative sum chart for surgical failure. Each procedure is presented in left-to-right chronological order. The curve is moving downwards in case of surgical failure and upward in case of surgical success. A cut-off point was found at case 28 in the video-assisted thoracoscopic surgery and at case 32 in the robotic anatomical lung resection series. VATS: video-assisted thoracoscopic surgery.

by Gallagher *et al.* [30] of thoracic surgeons who were experts in open lobectomy who started their RATS practice, the conversion rate significantly dropped after the first 40 cases, and operating time approached that of open thoracotomy after 60 cases.

Although operating times varied with the complexity of the individual cases, our chronological plots showed that surgical time decreased over time with both approaches. In contrast to VATS, longer operating time in RATS cases at the beginning of the learning curve could reflect the learning period for docking, manipulating robotic instruments and managing thoracic structures in the absence of tactile sense. Moreover, the robotic assistant's learning curve was longer than that of the VATS assistant independently of his level of expertise since his labour is more demanding. Nevertheless, a multidimensional, complete analysis of learning curves must include technical competence measured as surgical outcomes. CUSUM charts in this report showed that technical competence was achieved slightly earlier in VATS procedures (around case 28) compared to RATS procedures (around case 32); however, no statistical differences were found regarding perioperative adverse events in both approaches, although there were slightly increased operative morbidity and surgical failure rates in the RATS group during the learning curve period. That increase did not translate into a longer hospital stay, which was statistically lower in the robotic group.

Several limitations need to be considered in this study. First, data came from a single surgeon whose expertise level was different at the moment of initiating both the VATS and the the robotic anatomical lung resections (RATSs) because he had performed more than 200 VATS procedures before starting VATS anatomical resections and only 7 robotic thymectomies before starting the robotic lung resections. Thus, that surgeon's previous VATS experience was greater than his previous experience in robotics. However, the surgeon had performed more than 300 thoracoscopic procedures of which more than 100 were anatomical lung resections before starting robotic procedures, which can also facilitate the learning of the robotic approach because both approaches share some features. Moreover, the surgeon was an expert thoracic surgeon with more than 20 years of surgical practice. Thus, more studies are needed to validate and extrapolate these results to surgeons with less overall operative experience. Furthermore, other end points such as performance of a specific procedure efficiently (e.g. complex segmentectomies or sleeve lobectomies) could be considered to evaluate the learning curve in further analyses. Second, we analysed relatively small subgroups for different levels of technical difficulty. Also, some baseline patient characteristics such as sex and predicted postoperative carbon monoxide lung diffusion capacity differ among groups; however, because our analysis was limited to the implementation periods only, bias coming from subjective evaluation of the expected technical complexity of the operation was similar in both approaches. Finally, although patients were operated on during different periods of time (2015–2017 for VATS and 2018–2020 for robotic), the perioperative management was homogeneous, and both groups were included in our chest physiotherapy intensive programme.

CONCLUSION

Surgical time trends and rates of surgical failures were similar in both approaches during the learning curve period. Although RATS shares some features with VATS and offers some advantages, the adoption of the RATS technique requires that individual surgeons go through a new learning curve like that for anatomical lung resection by VATS even when the surgeon is experienced in both open and VATS procedures.

Conflict of interest: none declared.

Author contributions

María Teresa Gómez-Hernández: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Software; Writing—original draft; Writing—review & editing. **Marta G. Fuentes:** Writing—review & editing. **Nuria M. Novoa:** Formal analysis; Writing—review & editing. **Israel Rodríguez:** Writing—review & editing. **Gonzalo Varela:** Conceptualization; Formal analysis; Writing—original draft; Writing—review & editing. **Marcelo F. Jiménez:** Conceptualization; Formal analysis; Writing—original draft; Writing—review & editing.

Reviewer information

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