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Incidence, management and outcomes of intraoperative catastrophes during robotic pulmonary resection

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Abstract

Background: Intraoperative catastrophes during robotic anatomical pulmonary resections are potentially devastating events. The present study aimed to assess the incidence, management, and outcomes of these intraoperative catastrophes for patients with primary lung cancers.

Methods: This was a retrospective, multi-institutional study that evaluated patients who underwent robotic anatomical pulmonary resections. Intraoperative catastrophes were defined as events necessitating emergency thoracotomy or requiring an additional unplanned major surgical procedure. Standardized data forms were collected from each institution, with questions on intraoperative management strategies of catastrophic events.

Results: Overall, 1,810 patients underwent robotic anatomical pulmonary resections, including 1,566 (86.5%) lobectomies. Thirty-five patients (1.9%) experienced an intraoperative catastrophe. These patients were found to have significantly higher clinical TNM stage ($p=0.031$) and lower FEV1 (81% vs 90%, $p=0.004$). A higher proportion of patients who had a catastrophic event underwent preoperative radiotherapy (8.6% vs 2.3%, $p=0.048$), and the surgical procedures performed differed significantly compared to non-catastrophic patients. Patients in the catastrophic group had higher perioperative mortality (5.7% vs 0.5%, $p=0.018$), longer operative duration (195 min vs 170 min, $p = 0.020$), and higher estimated blood loss (225 ml vs 50 ml, $p<0.001$). The most common catastrophic event was intraoperative hemorrhage from the pulmonary artery, followed by

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injury to the airway, pulmonary vein, and the liver. Detailed management strategies were discussed.

Conclusions: The incidence of catastrophic events during robotic anatomical pulmonary resections was low, and the most common complication was pulmonary arterial injury. Awareness of potential intraoperative catastrophes and their management strategies are critical to improving clinical outcomes.

There has been an steady growth in the number of robotic pulmonary resections performed for patients with primary lung cancer.[1] Large series have demonstrated the feasibility and favorable perioperative outcomes of robotic lung resections compared to conventional thoracotomy.[2,3] Long-term oncological outcomes of robotic lobectomies for early stage non-small cell lung cancer (NSCLC) also appear to be acceptable, and consistent with video-assisted thoracoscopic surgery (VATS) and thoracotomy approaches.[4] Evolved techniques, clinical education and conference workshops have also helped to promote the popularization of robotic VATS internationally.[5–7]

Despite these encouraging trends for robotic thoracic surgery, there is a paucity of robust clinical data on intraoperative catastrophes, partly due to their relative rarity in institutional reports, and also due to limited data collection from national databases for individuals.[1,3,8] Previous studies on these devastating events during conventional VATS have been well presented by Flores and Decaluwe, who outlined the nature and management of major injuries encountered during thoracoscopic surgery.[9,10]

To improve the understanding of catastrophic events during robotic surgery, the present study aimed to assess the incidence, management, and outcomes of these events for patients with primary lung cancer who underwent anatomical pulmonary resections. Secondary aims of the study were to assess the potential contributing factors associated with intraoperative catastrophes and to identify successful management strategies.

Patients and Methods

Data collection and patient selection criteria

This was a retrospective, multi-institutional study that evaluated consecutive patients who underwent robotic anatomic lung resections from November 2002 to April 2018 using the da Vinci Surgical system (Intuitive Surgical, Sunnyvale, CA). Standardized data forms were collected from six participating centers after institutional ethics approval, with a data transfer agreement made to Memorial Sloan Kettering Cancer Center, New York, United States (Approval Protocol # 17–627). Patients over 18 years old with pathologically confirmed primary lung cancers who underwent robotic anatomical pulmonary resections were included for analysis. Patients with benign lesions, small cell lung cancers, or who underwent wedge resections were excluded. Potential catastrophic events were screened for all patients who 1) underwent an emergency thoracotomy after robotic docking and/or 2) required an additional major surgical procedure other than the planned anatomical pulmonary resection. Patients who underwent elective conversion or additional procedure for oncological reasons were excluded from statistical analysis, consistent with previous reports.

[9,10] Standardized questions were presented to participating surgeons to outline their intraoperative management strategies and potential alternative approaches.

Operative techniques

Robotic techniques from the participating institutions included the completely portal and assisted approaches, as defined by the consensus statement by Cerfolio et al. and described previously.[11–15] In brief, segmentectomies, lobectomies, bilobectomies or pneumonectomies were performed through 4 to 5 incisions without rib-spreading, using videoscopic monitors for visualization. Hilar dissection was performed with identification and division of individual pulmonary vessels and bronchi. Complete lymph node dissection was routinely performed using monopolar and/or bipolar instruments according to laterality. Operative times were recorded from the time of skin incision to the time of skin closure.

Study variables

Baseline patient characteristics, surgeon experience, and treatment-related variables were collected for statistical analysis in relation to catastrophic events according to a predefined and standardized datasheet form. Patient-related factors included age, gender, pack years smoking, Eastern Cooperative Oncology Group (ECOG) performance status, percentage predicted forced expiratory volume in 1 second (FEV1), diffusing capacity for carbon monoxide (DLCO), body mass index (BMI), clinical stage, and histopathological type. The primary surgeon's experience was classified as being ≤ 20 cases or > 20 cases at the time of recorded catastrophic event, consistent with previous reports on the learning curve for robotic pulmonary resections.[16,17] Treatment-related factors included neoadjuvant radiotherapy, neoadjuvant chemotherapy, previous thoracic surgery to the ipsilateral side, and the surgical procedure performed. Clinical outcomes of patients with and without catastrophic events were compared for operative duration, estimated blood loss, and perioperative mortality, defined as death within 30 days or within the same admission, whichever was longer.

Statistics

Comparative analyses were performed for patients who experienced a catastrophic event versus patients who did not. The chi-squared or Fisher's exact test was used to determine significant differences in categorical variables, and the Mann-Whitney U test was used to compare the distributions of continuous variables for univariable analysis. Multivariable logistic regression was used by including all variables with a p-value ≤ 0.1 on univariable analysis with intraoperative catastrophe as the primary outcome. A significant difference was predetermined to be a p-value ≤ 0.05. Statistical analyses were performed using IBM SPSS Statistics for Windows, Version 25 (IBM Corp, Armonk, NY).

Results

Incidence, predictors, and outcomes of catastrophic events

Overall, 1,810 patients underwent robotic anatomical pulmonary resections, including 1,566 (86.5%) lobectomies, 205 (11.3%) segmentectomies, 34 (1.9%) bilobectomies and 5 (0.3%) pneumonectomies. One hundred and twenty-eight patients underwent conversion to thoracotomy (7.1%), and 35 patients (1.9%) experienced an intraoperative catastrophic event, as defined by the study protocol. A summary of patient characteristics and clinical outcomes is presented in Table 1. The median age within the catastrophic group was 70 years, with 51.4% males. The median number of pack years smoked was 40, with 48.4% of patients reported as ECOG ≥1. The median values for FEV1 and DLCO in this group were 81% and 68.5%, respectively, and the median BMI was 27. Patients who experienced a catastrophic event were found to have significantly higher clinical TNM stage ($p = 0.031$) and lower FEV1 (81% vs 90%, $p = 0.004$) compared to patients who did not experience a catastrophic event. A higher proportion of patients in the catastrophic group were operated by a surgeon who had ≤ 20 cases experience (17.1% vs 10.4%), but this did not reach statistical significance. Previous ipsilateral thoracic surgery and preoperative chemotherapy were not significantly different between the two groups, but a higher proportion of patients who had a catastrophic event underwent preoperative radiotherapy (8.6% vs 2.3%, $p = 0.048$). The surgical procedures performed differed significantly, with more patients who experienced a catastrophic event having undergone a left upper lobectomy, bilobectomy or pneumonectomy ($p < 0.001$). On multivariable analysis, FEV1 ($p = 0.029$) and surgical procedure ($p = 0.002$) remained to be statistically significant, with a summary presented in Supplementary Table 1. Regarding clinical outcomes, patients who experienced a catastrophic event had longer operative duration (195 min vs 170 min, $p = 0.020$), higher estimated blood loss (225 ml vs 50 ml, $p < 0.001$) and higher perioperative mortality (5.7% vs 0.5%, $p = 0.018$). While there were no intraoperative deaths, both of the two reported perioperative deaths followed significant bleeding from pulmonary artery injuries. Postoperative complications were recorded in 13 out of 35 patients (37.1%), including prolonged air leak, blood transfusion, pneumonia, empyema, and death. Excluding two perioperative mortalities, the median length of hospitalization in the catastrophic group was 6.5 days (interquartile range 5 – 9 days), compared to 4 days (3 – 6) in the non-catastrophic group.

Catastrophic events, contributors and management strategies

Out of the reported catastrophic events, the most common was intraoperative hemorrhage from a pulmonary artery or pulmonary vein injury, which occurred in 28 (80%) and 2 (6%) patients, respectively. Injury to the airways occurred in 4 patients (11%), and liver injury occurred in 1 patient (3%). Within the catastrophic group, 31 patients (89%) underwent a conversion to thoracotomy, and two patients underwent an unplanned pneumonectomy. Detailed management strategies for each individual patient and their summarized perioperative outcomes are presented in Supplementary Table 2 and Table 2, respectively.

The most common contributing factor to a pulmonary vessel injury listed by the surgeons was adherent hilar lymphadenopathy, including fibrotic lymph nodes after neoadjuvant therapy, malignant involvement, granulomatous disease, calcification, or bulky lymph nodes. Other contributing factors included anatomical variations, small caliber of pulmonary arterial branches, and suboptimal exposure due to thickened tissue, emphysematous lung, or excessive adipose tissue. Vascular injuries occurred at various points of dissection, isolation or stapling. Although the specific management for each individual patient differed, there were some common approaches to pulmonary vascular injuries, as outlined below:

Airway injury occurred in 4 patients, with 3 patients requiring conversion to thoracotomy and repair or reconstruction of the airway. One patient experienced massive air leak from an unknown source, and underwent VATS exploration and pleural tent, with subsequent improvement in the air leak. Membranous parts of the airways were especially vulnerable to thermal injury, particularly when complete lymphadenectomy was performed at lymph node stations such as station 7, and when lymphadenopathy was present. Conversion to thoracotomy not only allowed better assessment of the extent of the injury, but also enabled the surgeon to attach vascularized flaps to the repaired airway.

The only reported intra-abdominal injury occurred when the robotic bipolar forceps injured the diaphragm and liver whilst retracting the diaphragm downwards during the introduction of a stapler. An elevated diaphragm contributed to the cause of this injury, and the bleeding resolved after a thoracotomy was made to allow adequate compression using a sponge stick. A suggested alternative approach by the surgeon was to apply direct compression through the utility incision, instead of performing a thoracotomy.

Comment

Robotic pulmonary resection has been recognized as a safe and efficacious alternative to conventional VATS for patients with primary lung cancers, and both minimally invasive approaches offer superior perioperative outcomes compared to open thoracotomy.[19,20] With the popularization of the robotic technique, there is an urgent need to establish management strategies of intraoperative catastrophes to improve patient outcomes during these infrequent events. The 1.9% of patients who experienced a catastrophic event in the present study had significantly higher perioperative mortality, with increased blood loss and duration of operation. Predictors of catastrophic events included lower FEV1 and the surgical procedure performed. The most frequent catastrophic events included pulmonary artery injury, followed by airway injury, pulmonary vein injury, and liver injury.

Previous studies on conventional VATS have reported comparable findings, with catastrophic rates of 1 – 1.5%.[9,10] Flores et al. presented an institutional report with 12 patients (1%) who experienced injuries to the pulmonary artery, vein, airway, or spleen, and emphasized the need to establish anatomical relationships and judicious conversion to thoracotomy when required.[9] Similar to our findings, the authors did not report any intraoperative mortalities, and the most common catastrophes included pulmonary arterial and venous injuries. However, these injuries included complete transection of 3 arteries and 1 vein, which were not reported in our series. Superior 3D videoscopic vision and direct surgeon-controlled camera positioning may offer better appreciation of vascular anatomy and structural relationships. This comprehensive report was followed shortly after by a multi-institutional study from the Minimally Invasive Thoracic Surgery Interest Group.[10] Decaluwe and colleagues reported a conversion rate of 5.5%, which was lower than our reported incidence of 7.1%. After excluding patients who underwent thoracotomy for oncological or technical reasons, this study identified 46 (1.5%) cases of major intraoperative complications. In addition to the injuries identified in our series, the authors also described esophageal and cardiac injuries, which were rare but potentially fatal. Similar to our findings, neither of these two previous studies on conventional VATS found surgeons' experience to be statistically significant in predicting catastrophic outcomes. Possible explanations for this included the low number of complications and the tendency for more experienced surgeons to operate on more advanced or complicated malignancies.[10] Although national databases lack the granularity to present detailed data on catastrophic events, a report by Kent et al. reported the bleeding complication rates for open thoracotomy, conventional VATS and robotic VATS to be 1.9%, 1.3% and 1.9%, respectively.[21]

More recently, Louie and Cerfolio also described the management of pulmonary arterial bleeding during robotic pulmonary resections, and found the upper lobes, particularly the left upper lobe, to be a common source of hemorrhage.[22,23] Both authors also elucidated the multi-factorial decision making process to convert to a thoracotomy, including immediate threat to life, hemodynamic stability, oncological outcomes, and surgical experience.[22,23] When a pulmonary artery injury occurs, the immediate management is compression. If a pre-rolled sponge was immediately available, this could be held by a robotic instrument to compress the bleeding vessel. The anterior robotic instrument is preferred, as this will allow the removal of posterior instruments by the bedside assistant, and allows a posterolateral thoracotomy to be performed in a timely fashion, preferably by a senior assisting surgeon. If a robotic-assisted procedure was being performed, immediate direct compression can be performed with a sponge stick through the utility port by the bedside assistant. Similarly, a 12mm port may allow the introduction of a sponge stick, or enlarged slightly if necessary. Any undue tension on the pulmonary vessel, such as a retraction arm exposing the vessel, should be relaxed appropriately. If a totally endo-portal robotic procedure was being performed, the CO_2 insufflation device can be increased to 15mmHg, whilst being cognizant of potential complications such as pulmonary embolism, bradycardia and compromised venous return. If a pre-rolled sponge was not available, the lung parenchyma may be used as an alternative to compress against the bleeding vessel, if it was already adequately dissected. In addition, bipolar forceps or Cadieres have also been used to compress the bleeding vessel, but this is not recommended as the initial approach by inexperienced surgeons, as further damage to the vessel may occur.

Simultaneously, the anesthesia team should be informed of the vascular injury and attain blood products immediately. Senior surgical assistance should be requested to help with thoracotomy and repair. If the surgeon at the surgical console can obtain satisfactory control of the bleeding source with pressure, patience is warranted, as several surgeons stated that a thoracotomy may have been avoided as the bleeding had stopped once a thoracotomy was performed and the pressure on the bleeding source was released. Experienced surgeons may also attempt to repair the injury to the vessel directly using robotic clips or prolene sutures using robotic needle drivers, but these approaches should be reserved for selected circumstances such as minor bleeding in well exposed conditions.[22,23] If a conversion to thoracotomy is deemed necessary, the unused instruments should be removed first, followed by transfer of direct pressure from the robotic arm to a hand-held sponge stick by the bed-side assistant. The robotic arm holding the pre-rolled sponge and the camera should then be undocked from the robot, followed by removal of the robot away from the patient whilst maintaining visualization using the hand-held camera. Proximal control of the vessel and subsequent repair is then attained through the open thoracotomy approach.

Injuries to airways and intra-abdominal organs such as the spleen or liver were less frequent in the present series, and intraoperative management was possible in a less time-critical manner. Thoracotomy was performed in most cases to obtain complete exposure and allow complex repairs to be performed, such as bronchoplasty and pedicled flaps. Proposed alternative approaches to these injuries included direct pressure through the utility incision, or laparoscopic exploration if there is a high index of suspicion for intra-abdominal injury.

Limitations of the present study include its retrospective nature, and intrinsic biases associated with this study design. The extensive experience of participating tertiary institutions with specialty-trained thoracic surgeons may not be representative of clinical outcomes from all robotic thoracic programs. In addition, a large proportion of patients in our cohort had clinical Stage I-II disease, with a limited number of patients who underwent neoadjuvant therapy, and this may not be representative of all patients diagnosed with NSCLC. Furthermore, we were not able to compare robotic catastrophic events with patients who underwent conventional VATS or open thoracotomy through our centralized database, and suggested management of catastrophic events were based on anecdotal evidence, rather than randomized data.

In summary, the present study represents one of the largest series of catastrophic events from robotic pulmonary resections to date. Although uncommon, these complications were found to be associated with increased mortality. By identifying risk factors and describing management plans for these adverse outcomes, we hope to improve the clinical outcomes of patients who undergo robotic resections.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

References

1. Rajaram R, Mohanty S, Bentrem DJ, et al. Nationwide Assessment of Robotic Lobectomy for Non-Small Cell Lung Cancer. Ann Thorac Surg 2017;103:1092–100. [PubMed: 28109575]
2. Park BJ, Flores RM. Cost comparison of robotic, video-assisted thoracic surgery and thoracotomy approaches to pulmonary lobectomy. Thorac Surg Clin 2008;18:297–300, vii. [PubMed: 18831506]
3. Adams RD, Bolton WD, Stephenson JE, Henry G, Robbins ET, Sommers E. Initial multicenter community robotic lobectomy experience: comparisons to a national database. Ann Thorac Surg 2014;97:1893–8; discussion 9–900. [PubMed: 24726600]
4. Park BJ. Robotic lobectomy for non-small cell lung cancer: long-term oncologic results. Thorac Surg Clin 2014;24:157–62, vi. [PubMed: 24780419]
5. Novellis P, Alloisio M, Cariboni U, Veronesi G. Different techniques in robotic lung resection. Journal of Thoracic Disease 2017;9:4315–8. [PubMed: 29266101]
6. Veronesi G, Cerfolio R, Cingolani R, et al. Report on First International Workshop on Robotic Surgery in Thoracic Oncology. Frontiers in Oncology 2016;6.
7. Cerfolio RJ, Cichos KH, Wei B, Minnich DJ. Robotic lobectomy can be taught while maintaining quality patient outcomes. J Thorac Cardiovasc Surg 2016;152:991–7. [PubMed: 27292875]
8. Dylewski MR, Ohaeto AC, Pereira JF. Pulmonary resection using a total endoscopic robotic video-assisted approach. Semin Thorac Cardiovasc Surg 2011;23:36–42. [PubMed: 21807297]

9. Flores RM, Ihekweazu U, Dycoco J, et al. Video-assisted thoracoscopic surgery (VATS) lobectomy: catastrophic intraoperative complications. J Thorac Cardiovasc Surg 2011;142:1412–7. [PubMed: 22014713]
10. Decaluwe H, Petersen RH, Hansen H, et al. Major intraoperative complications during video-assisted thoracoscopic anatomical lung resections: an intention-to-treat analysis. Eur J Cardiothorac Surg 2015;48:588–98; discussion 99. [PubMed: 26385060]
11. Melfi FM, Ambrogi MC, Lucchi M, Mussi A. Video robotic lobectomy. Multimedia manual of cardiothoracic surgery : MMCTS 2005;2005:mmcts.2004.000448.
12. Park BJ, Flores RM, Rusch VW. Robotic assistance for video-assisted thoracic surgical lobectomy: technique and initial results. J Thorac Cardiovasc Surg 2006;131:54–9. [PubMed: 16399294]
13. Cerfolio RJ. Total port approach for robotic lobectomy. Thorac Surg Clin 2014;24:151–6, v. [PubMed: 24780418]
14. Veronesi G. Robotic lobectomy and segmentectomy for lung cancer: results and operating technique. Journal of Thoracic Disease 2015;7:S122–30. [PubMed: 25984357]
15. Cerfolio R, Louie BE, Farivar AS, Onaitis M, Park BJ. Consensus statement on definitions and nomenclature for robotic thoracic surgery. J Thorac Cardiovasc Surg 2017;154:1065–9. [PubMed: 28623099]
16. Gharagozloo F, Margolis M, Tempesta B, Strother E, Najam F. Robot-assisted lobectomy for early-stage lung cancer: report of 100 consecutive cases. Ann Thorac Surg 2009;88:380–4. [PubMed: 19632377]
17. Veronesi G, Agoglia BG, Melfi F, et al. Experience with robotic lobectomy for lung cancer. Innovations (Philadelphia, Pa) 2011;6:355–60.
18. Dunning J, Walker WS. Pulmonary artery bleeding caused during VATS lobectomy. Annals of Cardiothoracic Surgery 2012;1:109–10. [PubMed: 23977478]
19. Cao C, Manganas C, Ang SC, Yan TD. A systematic review and meta-analysis on pulmonary resections by robotic video-assisted thoracic surgery. Annals of Cardiothoracic Surgery 2012;1:3–10. [PubMed: 23977457]
20. Cao C, Manganas C, Ang SC, Peeceeyen S, Yan TD. Video-assisted thoracic surgery versus open thoracotomy for non-small cell lung cancer: a meta-analysis of propensity score-matched patients. Interact Cardiovasc Thorac Surg 2013;16:244–9. [PubMed: 23169877]
21. Kent M, Wang T, Whyte R, Curran T, Flores R, Gangadharan S. Open, video-assisted thoracic surgery, and robotic lobectomy: review of a national database. Ann Thorac Surg 2014;97:236–42; discussion 42–4. [PubMed: 24090577]
22. Louie BE. Catastrophes and complicated intraoperative events during robotic lung resection. Journal of Visualized Surgery 2017;3. [PubMed: 29078566]
23. Cerfolio RJ, Bess KM, Wei B, Minnich DJ. Incidence, Results, and Our Current Intraoperative Technique to Control Major Vascular Injuries During Minimally Invasive Robotic Thoracic Surgery. Ann Thorac Surg 2016;102:394–9. [PubMed: 27344281]

Preparation:

access to thoracotomy tray, blood products and senior help available in a timely fashion if required; the patient should be adequately exposed during draping for a thoracotomy to be performed.

Pressure:

use of pre-rolled sponge or ‘cigar’, sponge stick, lung parenchyma, robotic bipolar forceps or Cadiere.

Patience and poise:

apply compression and wait for at least 10 minutes before re-evaluation.[18]

Prolene:

direct repair after obtaining proximal control with vessel loops or clamp.

Table 1.

Patient characteristics, surgeons' experience, treatment factors and clinical outcomes for robotic anatomical pulmonary resections in patients with primary lung cancer.

	All patients (n=1810)	Catastrophic Event (n=35)	No Catastrophic Event (n=1775)	p-value
Patient characteristics				
Age (years)	**69 [62–75]***	**70 [62–73]***	**69 [62–75]***	**0.954**
Male	**803 (44.4%)**	**18 (51.4%)**	**785 (44.2%)**	**0.397**
Pack years	**25 [2–45]***	**40 [12–54]***	**24 [2–45]**	**0.065**
ECOG ≥ 1	**725 (44.1%)**	**15 (48.4%)**	**710 (44.0%)**	**0.716**
FEV1 predicted	**90 [76–103]***	**81 [67–92]***	**90 [77–103]***	**0.004**
DLCO predicted	**77 [64–93]***	**68.5 [61–86]***	**77 [64–93]***	**0.136**
BMI	**26 [23–30]***	**27 [24–31]***	**26 [23–30]***	**0.290**
Clinical stage				**0.031**
I	1301 (72.1%)	18 (52.9%)	1283 (72.5%)	
II	311 (17.2%)	8 (23.5%)	303 (17.1%)	
III	179 (9.9%)	7 (20.6%)	172 (9.7%)	
IV	13 (0.7%)	1 (2.9%)	12 (0.7%)	
Histopathology				**0.444**
Adeno	1291 (71.3%)	22 (62.9%)	1269 (71.5%)	
Squamous	307 (17.0%)	8 (22.9%)	299 (16.8%)	
Large Cell	20 (1.1%)	1 (2.9%)	19 (1.1%)	
Carcinoid	105 (5.9%)	1 (2.9%)	105 (5.9%)	
Other	83 (4.7%)	3 (8.6%)	83 (4.7%)	
Surgeon characteristics				
Experience ≤ 20	**191 (10.6%)**	**6 (17.1%)**	**185 (10.4%)**	**0.258**
Treatment factors				
Re-do operation	**44 (2.4%)**	**1 (2.9%)**	**43 (2.4%)**	**0.581**
Pre-op chemo	**156 (8.6%)**	**3 (8.6%)**	**153 (8.6%)**	**1.000**
Pre-op XRT	**43 (2.4%)**	**3 (8.6%)**	**40 (2.3%)**	**0.048**
Procedure				**<0.001**
RUL lobectomy	591 (32.7%)	9 (25.7%)	582 (32.8%)	
RML lobectomy	118 (6.5%)	1 (2.9%)	117 (6.6%)	

	All patients (n=1810)	Catastrophic Event (n=35)	No Catastrophic Event (n=1775)	p-value
RLL lobectomy	286 (15.8%)	3 (8.6%)	283 (15.9%)	
LUL lobectomy	358 (19.8%)	12 (34.3%)	346 (19.5%)	
LLL lobectomy	213 (11.8%)	3 (8.6%)	210 (11.8%)	
Segment	205 (11.3%)	3 (8.6%)	202 (11.4%)	
Bilobectomy	34 (1.9%)	2 (5.7%)	32 (1.8%)	
Pneumonectomy	5 (0.3%)	2 (5.7%)	3 (0.2%)	
Clinical outcomes				
Operation (min)	**170 [129–214]** *	**195 [144–305]** *	**170 [129–213]** *	**0.020**
Blood loss (mL)	**50 [20–100]** *	**225 [55–500]** *	**50 [20–100]** *	**<0.001**
Mortality	**11 (0.6%)**	**2 (5.7%)**	**9 (0.5%)**	**0.018**

* Continuous variables are reported as median and interquartile range. ECOG, Eastern Cooperative Oncology Group; FEV1, percentage predicted forced expiratory volume in 1 second; DLCO, diffusing capacity for carbon monoxide; BMI, body mass index; RUL, right upper lobe, RML, right middle lobe; RLL, right lower lobe; LUL, left upper lobe; LLL, left lower lobe;

Table 2.

Summary of catastrophic injuries and perioperative outcomes after robotic anatomical pulmonary resections.

Patient	Procedure	Site	Location of injury	Conversion?	Intraoperative result	EBL (ml)	LOS	Complications
1	Pneumonectomy	LUL	PA	Y	Return to operating room for repair	6000	-	POD 1 death; multiorgan failure
2	Lobectomy	LLL	PA	Y	Repair	2500	-	POD 2 death; right ventricular failure
3	Lobectomy	LUL	PA	Y	Repair	3000	5	Transfusion
4	Lobectomy	RUL	PA	Y	Repair	2000	7	Transfusion
5	Lobectomy	RLL	PA	Y	Repair	1100	8	
6	Lobectomy	LUL	PA	Y	Repair	950	8	PAL, transfusion
7	Lobectomy	LUL	PA	Y	Repair	800	4	Transfusion
8	Lobectomy	LUL	PA	Y	Repair	800	12	PAL, empyema, transfusion, pneumonia
9	Segmentectomy	RUL	PA	Y	Repair	700	5	Transfusion
10	Lobectomy	LLL	PA	Y	Repair	700	5	None
11	Segmentectomy	LLL	PA	Y	Repair	650	3	None
12	Lobectomy	LUL	PA	Y	Repair	500	8	None
13	Lobectomy	RUL	PA	Y	Repair	500	6	None
14	Lobectomy	RLL	PA	Y	Ligation	500	8	None
15	Lobectomy	RUL	PA	Y	Repair	300	5	None
16	Lobectomy	LUL	PA	Y	Repair	250	5	None
17	Lobectomy	LUL	PA	Y	Ligation	250	3	None
18	Lobectomy	RUL	PA	Y	Repair	250	6	None
19	Lobectomy	RUL	PA	Y	Repair	200	3	None
20	Lobectomy	LLL	PA	Y	Repair	200	10	NA
21	Bilobectomy	RUL/RML	PA	Y	Compression	200	4	None
22	Bilobectomy	RUL/RML	PA	Y	Repair	180	2	None
23	Pneumonectomy	LUL	PA	Y	Completion pneumonectomy	100	12	NA
24	Lobectomy	RLL	PA	N	Repair	70	2	None
25	Lobectomy	LUL	PA	N	Repair	30	10	NA
26	Lobectomy	LUL	PA	N	Repair	NA	14	NA

Patient	Procedure	Site	Location of injury	Conversion?	Intraoperative result	EBL (ml)	LOS	Complications
27	Lobectomy	RUL	PA	Y	Compression	NA	7	Transfusion
28	Lobectomy	LUL	PA	Y	Repair	NA	5	None
29	Lobectomy	RUL	PV	Y	Ligation	380	14	PAL
30	Lobectomy	RUL	PV	Y	Ligation	100	6	Pneumonia
31	Segmentectomy	RUL	Airway	Y	Repair	300	2	None
32	Lobectomy	LUL	Airway	Y	Repair	150	6	None
33	Bilobectomy	RML	Airway	Y	Biilobectomy, bronchoplasty	50	7	
34	Lobectomy	LUL	Airway	N	Return to operating room for pleural tent and repair	200	10	PAL
35	Lobectomy	RML	Liver	Y	Compression, diaphragm repair	25	9	Pneumonia, transfusion

RUL, right upper lobe, RML, right middle lobe; RLL, right lower lobe; LUL, left upper lobe; LLL, left lower lobe; PA, pulmonary artery, PV, pulmonary vein; EBL, estimated blood loss; NA, not available; LOS, length of stay; POD, postoperative day; PAL, prolonged airleak