European Journal of Cardio-Thoracic Surgery 48 (2015) 588–599
doi:10.1093/ejcts/ezv287

ORIGINAL ARTICLE

Cite this article as: Decaluwe H, Petersen RH, Hansen H, Piwkowski C, Augustin F, Brunelli A *et al*. Major intraoperative complications during video-assisted thoracoscopic anatomical lung resections: an intention-to-treat analysis. Eur J Cardiothorac Surg 2015;48:588–99.

Major intraoperative complications during video-assisted thoracoscopic anatomical lung resections: an intention-to-treat analysis†

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Received 24 May 2015; received in revised form 14 July 2015; accepted 20 July 2015

Abstract

OBJECTIVES: A multicentre evaluation of the frequency and nature of major intraoperative complications during video-assisted thoracoscopic (VATS) anatomical resections.

METHODS: Six European centres submitted their series of consecutive anatomical lung resections with the intention to treat by VATS. Conversions to thoracotomy, vascular injuries and major intraoperative complications were studied in relation to surgeons' experience. Major complications included immediate life-threatening complications (i.e. blood loss of more than 2 l), injury to proximal airway or other organs or those leading to unplanned additional anatomical resections. All cases were discussed by a panel and recommendations were drafted.

RESULTS: A total of 3076 patients were registered. Most resections (90%, $n = 2763$) were performed for bronchial carcinoma. There were 3 intraoperative deaths, including 1 after conversion for technical reasons. In-hospital mortality was 1.4% ($n = 43$). Conversion to open thoracotomy was observed in 5.5% ($n = 170$), of whom 21.8% ($n = 37$) were for oncological reasons, 29.4% ($n = 50$) for technical reasons and 48.8% ($n = 83$) for complications. Vascular injuries were reported in 2.9% ($n = 88$) patients and led to conversion in 2.2% ($n = 70$). In 1.5% ($n = 46$), major intraoperative complications were identified. These consisted of erroneous transection of bronchovascular structures ($n = 9$); injuries to gastrointestinal organs ($n = 5$) or proximal airway ($n = 6$); complications requiring additional unplanned major surgery ($n = 9$) or immediate life-threatening complications ($n = 17$). Twenty-three percent of the in-hospital mortalities ($n = 10/43$) were related to major intraoperative complications. Eight pneumonectomies (five intraoperative and three postoperative at 0.3%) were a consequence of a major complication. Surgeon's experience was related to non-oncological conversions, but not to vascular injuries or major complications in a multivariable logistic regression analysis.

CONCLUSION: Major intraoperative complications during VATS anatomical lung resections are infrequent, seem not to be related to surgical experience but have an important impact on patient outcome. Constant awareness and a structured plan of action are of paramount importance to prevent them.

Keywords: VATS • Lobectomy • Complication • Conversion • Experience • Lung cancer

INTRODUCTION

Minimally invasive surgery for anatomical lung resections is unevenly utilized among European Thoracic Services. It is only in dedicated centres that the majority of lobectomies are performed by video-assisted thoracoscopic surgery (VATS) [1]. These comprised <25% of the voluntary European Society of Thoracic Surgeons (ESTS) database in 2013, but a clear rise in the use of VATS has been observed over recent years [2]. A further increase is to be expected as analysis of large databases shows fewer perioperative

†Presented at the 23rd European Conference on General Thoracic Surgery, Lisbon, Portugal, 31 May–3 June 2015.

complications compared with thoracotomy and equal oncological results, encouraging the adoption of VATS in Stage I non-small cell lung cancer (NSCLC) as per the American College of Chest Physicians guidelines [3–6].

Most surgeons agree that there is an important learning curve associated with VATS anatomical resections [7, 8]. Reports on specific intraoperative complications during VATS anatomical resections are rare and publications based on large societal databases such as the Society of Thoracic Surgeons or ESTS do not accurately capture conversions to thoracotomy or additional resections such as emergency pneumonectomies [2, 7–11].

Although a clear relation between reporting errors and better outcome has yet to be clearly demonstrated, one can only assume that awareness of major intraoperative complications and understanding of their causes can lead to a reduction in their frequency [9, 12].

The primary objective of this study was to report major intraoperative complications and unplanned additional surgery by an intention-to-treat analysis. Secondary objectives were to identify possible causative factors of these complications, draft recommendations to avoid these and investigate the relation between experience and non-oncological conversions, vascular injuries, major intraoperative complications and in-hospital mortality.

METHODS

Data collection

The study sites were required to contribute with a minimum of 200 cases, have a 3-year experience with minimally invasive anatomical lung resections and a prospectively handled registry including all patients undergoing anatomical lung resections. The centres were encouraged to send their complete dataset including early experience. The surgeon responsible for each operation was coded and his/her previous experience with VATS anatomical resections was documented.

VATS anatomical resections included pneumonectomies, lobectomies and segmentectomies without direct intrathoracic view or use of a rib spreader. The hilar bronchovascular structures were individually divided. All centres endorse a lymph node dissection for bronchial carcinoma resections in accordance to the ESTS guidelines. All centres employed a multiportal technique. The vast majority of patients were operated by an anterior approach, with or without partial opening of the anterior part of the fissure. Two authors open the fissure at the beginning of the operation, either by dissection, or completely with staplers between the parenchyma and bronchovascular structures. These techniques have been described previously [13–15].

All consecutive patients with intention to undergo a VATS anatomical resection were included. Patients in whom no resection was performed for oncological reasons or the anatomical resection was not commenced via VATS were excluded from the study. Collected data included age, gender, previous chemo- or radiotherapy, indication (benign, primary or metastatic tumour), final pTNM if applicable, location, date of surgery, type of surgery, conversion, vascular injuries, major intraoperative complications, additional unplanned surgery and in-hospital mortality.

Reasons for 'conversions' to thoracotomy were divided into three groups:

- Oncologic: extensive disease requiring open thoracotomy to accomplish complete resection, e.g. unforeseen mediastinal lymphadenopathy, need for sleeve resections, doubt concerning indication for pneumonectomy.
- Technical: surgical technical reasons leading to conversion, excluding complications, e.g. severe adhesions, hilar fibrosis or unsuccessful single-lung ventilation.
- Complication: conversion for intraoperative complications such as vascular injuries or major intraoperative complications as described below.

We assumed that more experienced surgeons would engage frequently with oncological challenging cases by VATS with a higher chance for conversion. As the focus of the paper concentrated on surgical complications, we excluded conversions for oncological reasons from further statistical analysis.

Injury to the pulmonary artery (PA), veins or their segmental branches or sudden blood loss of more than 500 cc, were recorded as a 'vascular injury'.

'Major intraoperative complications' were defined including the following:

- Immediate life-threatening situations including sudden blood loss of more than 2000 cc
- Erroneous transections of bronchovascular structures
- Injuries to other organs
- Intraoperative events that led to additional major surgery including repair of major thoracic vessels, airway or unforeseen anatomical resections for non-oncological reasons during the same surgery or within the first 30 days postoperatively. Special attention was directed to identify non-oncological reasons for bilobectomies and pneumonectomies.

A VATS index was calculated for each patient by dividing the number of VATS anatomical resections over total anatomical resections performed in the same year at the same centre.

An author interviewed the primary responsible surgeon at each centre. The mechanism, contributing factors, treatment and prevention strategies were then further discussed with the members of the ESTS Minimally Invasive Thoracic Surgery Interest Group (MITIG).

Ethics

Institutional Review Board approval was obtained. The data were obtained and anonymized in accordance to the International Conference on Harmonization Guidelines of Good Clinical Practice.

Statistics

A logistic regression model was used to evaluate the relation with surgical experience of the following binary outcomes: (non-oncologic) conversion, vascular injuries, in-hospital mortality and major intraoperative complication. The experience was quantified as the number of previous VATS anatomical resections performed at the time of operation. This was estimated by the sum of the experience before the study period and included patients of the same surgeon at the moment of the event. Hence, the experience was variable within a surgeon. Restricted cubic splines (using four knots) were used to allow non-linearity (on the logit scale) in the relation [16]. The following variables were added as possible confounders in the model: gender, age, side, pathology and previous chemo- or radiotherapy. Pathology was divided between benign, early tumour stage (p Stage 2a or lower), advanced tumour stage

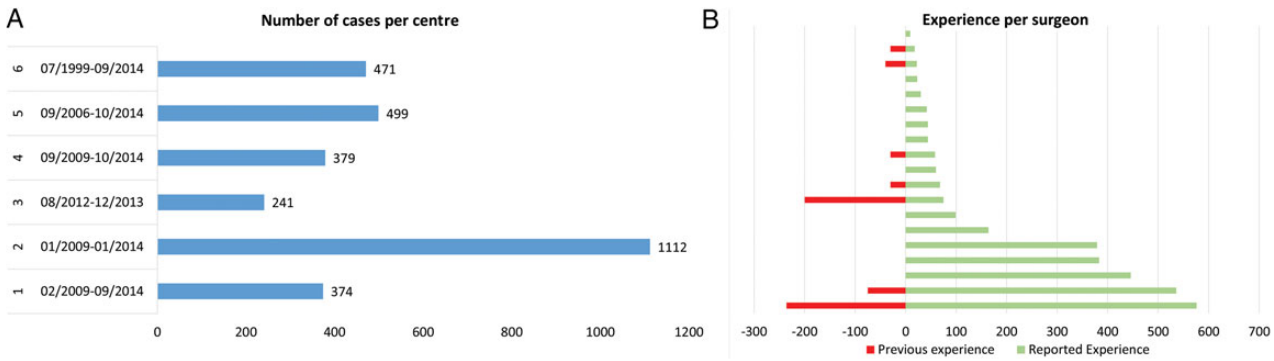

Figure 1: (**A**) The study period and number of reported cases per centre (in random order). (**B**) Previous experience and the number of reported cases per surgeon.

(p Stage 2b or higher) and metastasis. Since patients are clustered within surgeons and surgeons clustered within centres, surgeon and centre were added as random effects in the logistic regression model, yielding a so-called multilevel (three-level) logistic regression model. Since the variability due to centre and surgeon could not be estimated simultaneously in the three-level model containing predictors, only centre or surgeon (depending on fit statistics) were included as random effect in models correcting for the confounders. The models with confounders had been fitted on the 98.4% of the subjects with full information on the confounders. Mann–Whitney *U*-test was used to compare the median VATS index (number of VATS over open surgeries in the same year at the same centre) of patients with or without major intraoperative complications. *P*-values smaller than 0.05 were considered significant. All analyses have been performed using the SAS software, version 9.2, of the SAS System for Windows. Due to the relatively low number of events, models considering random effects of experience where computationally not feasible.

RESULTS

A total of 3076 patients were planned to undergo a VATS anatomical resection by 19 surgeons in six centres. An overview of the study period and contribution per centre is recorded in Fig. 1. The median contribution per surgeon was 43 cases [interquartile range (IQR) 22–340, Fig. 1]. The median experience per surgeon before the start of the study was zero cases (IQR 0–30). The median experience of the surgeon at the time of the operation was 224 cases (IQR 78–372). More than half of the patients (53.7%) were operated by surgeons with a cumulative experience of more than 200 cases, 18.2% were operated by surgeons with an experience of 50 or less cases. Indication for surgery was bronchial carcinoma in 90% (*n* = 2763). Patients' demographics, performed procedure, pathological stage (if applicable), previous chemo- or radiotherapy and the experience of the surgeon are available in Table 1.

Table 1: Demographics

	n	%
Gender		
Male	1587	51.6
Female	1489	48.4
Age		
Mean (SD)	64.4 (± 10.8)	
Tumour group		
Tumour	2763	89.8
Metastasis	193	6.3
Benign	120	3.9
Previous chemo- or radiotherapy		
None	2960	96.2
Chemotherapy	91	3
Radiotherapy	3	0.1
Radio- and chemotherapy	22	0.7
Performed procedure		
Open bilobectomy	6	0.2
Open lobectomy	138	4.5
Open pneumonectomy	13	0.4
Open segmentectomy	13	0.4
VATS bilobectomy	48	1.6
VATS lobectomy	2650	86.1
VATS pneumonectomy	18	0.6
VATS segmentectomy	190	6.2
Side		
Left	1271	41.3
Right	1805	58.7
p Stage (in tumour group, *n* = 2763)		
0	11	0.4
IA	1080	35.1
IB	767	24.9
IIA	398	12.9
IIB	191	6.2
IIIA	230	7.5
IIIB	3	0.1
IV	34	1.1
Not specified	49	1.6
Surgeon experience (number of surgeons)		
0–50 (16)	561	18.2
51–100 (10)	386	12.5
101–200 (7)	476	15.5
200+ (6)	1653	53.7

SD: standard deviation.

Non-oncological conversions

Conversion to open thoracotomy was observed in 5.5% of patients (*n* = 170): 21.8% (*n* = 37) for oncological reasons, 29.4% (*n* = 50) for technical reasons and 48.8% (*n* = 83) for complications.

The probability of conversion for non-oncological reasons was significantly related with the experience of the surgeon. After correction for the confounders, the odds for a conversion was 2.4% lower [odd's ratio = 0.976 (confidence interval: 0.96–0.99), *P* = 0.0002] for a surgeon having 10 or more surgeries as cumulative experience. In the lower region of experience, the probability of conversion decreased as experience increased and stabilized thereafter. However, this deviation from linearity was not

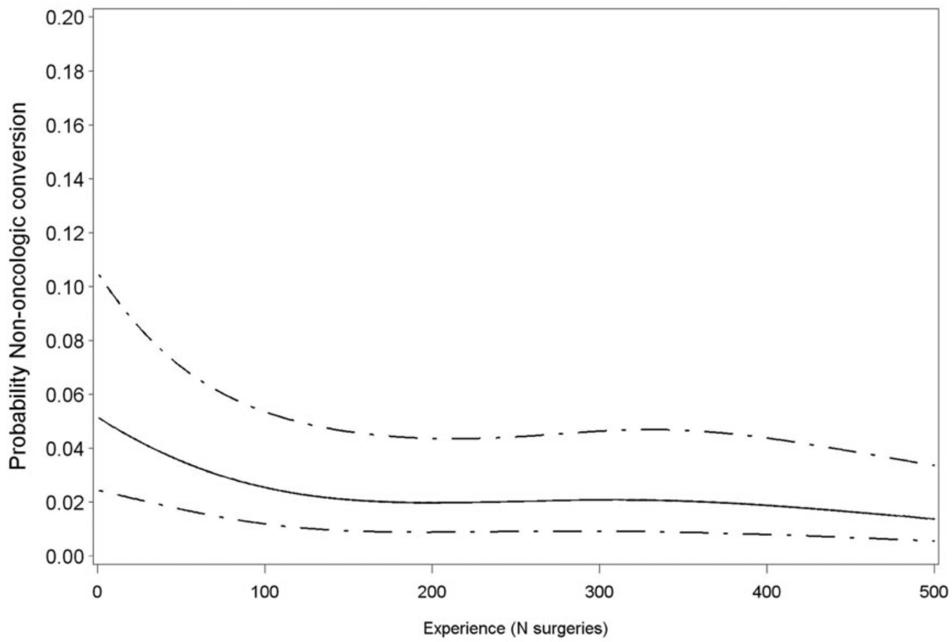

Figure 2: The probability of conversion for non-oncological reasons is significantly related to the experience of the surgeon with or without correction for confounders. In the lower region of experience, the probability of conversion for non-oncological reasons decreases as experience increases and stabilizes thereafter, although this deviation from linearity (in this figure without correction for confounders) was not significant.

Table 2: Multivariable logistic regression model for both non-oncological conversions and major intraoperative complications

	Non-oncological conversions		Major intraoperative complications	
	Odds ratio (95% CI)	*P*-value	Odds ratio (95% CI)	*P*-value
Surgical experience (10 surgeries)	0.98 (0.96; 0.99)	**<0.0001**	0.99 (0.98; 1.01)	0.73
Gender				
Female	0.81 (0.57; 1.16)	0.26	1.49 (0.82; 2.70)	0.19
Age	1.01 (0.99; 1.03)	0.15	1.02 (0.99; 1.06)	0.13
Left side	0.71 (0.49; 1.02)	0.065	0.86 (0.47; 1.57)	0.62
Pathology		0.17		0.98
Advanced tumour	3.06 (0.71; 13.23)	0.13	1.39 (0.17; 11.57)	0.76
Early tumour	1.99 (0.48; 8.34)	0.34	1.52 (0.2; 11.39)	0.68
Metastasis	1.91 (0.38; 9.52)	0.43	0.00 (ND)	0.13
Benign	#		#	
Previous chemo- or radiotherapy	2.13 (1.09; 4.16)	**0.027**	4.63 (1.86; 11.53)	**0.0010**

Advanced tumour: p Stage 2b or higher; early tumour: p Stage 2a or lower. Discriminative ability and goodness-of-fit tests: non-oncological conversion, AUC = 0.663 (95% CI: 0.62; 0.71), GoF test $\chi^2 = 1.83$, df = 8, *P* = 0.99; major intraoperative complication, AUC = 0.649 (95% CI: 0.57; 0.72), GoF test $\chi^2 = 8.85$, df = 8, *P* = 0.35.
#: reference category; ND: not defined.

significant (*P* = 0.17, Fig. 2). There was a significant inter-centre variability (or between-surgeon variability), which for the largest part can be explained by differences in experience [without correction $\chi^2 = 13.45$ (*P* = 0.0001) for the effect of centre, whereas after correction for experience and after correction for experience and patient characteristics, $\chi^2 = 3.3$ (*P* = 0.035) and $\chi^2 = 4.95$ (*P* = 0.013), respectively]. After previous chemo- or radiotherapy (*n* = 116) overall conversion rate and the non-oncological conversion rate was 12.9% (*n* = 15) and 9.5% (*n* = 11), respectively. Previous chemo- or radiotherapy was an independent risk factor for non-oncological conversion in a multivariate logistic regression analysis (Table 2).

Vascular injuries

Vascular injuries were reported in 2.9% (*n* = 88) of patients and led to conversion in 2.3% (*n* = 70). The incidence on the right side was 3.2% (*n* = 57/1805) and on the left side 2.4% (*n* = 31/1271). Cases with sudden blood loss of more than 2 l or resulting in an emergency pneumonectomy are further discussed below.

We found no evidence for a relation with surgical experience, neither without, nor with correction for confounders, even if non-linearity was allowed in the relation. There was significant between-surgeon variability, even in the model with confounders.

THORACIC

Major intraoperative complications

In 1.5% (*n* = 46), major intraoperative complications were identified (Table 3). Prevalence in each lobe is listed in Table 4. Twenty-three percent (*n* = 10) of the in-hospital mortalities (overall 1.4%, *n* = 43) were related to major intraoperative complications. For both in-hospital mortality and major intraoperative complications, we found no evidence of a relation with surgical experience, neither with nor without correction for confounders. This finding also holds if non-linearity was allowed in the relation. Previous chemo- or radiotherapy was given to 13% (*n* = 6/46) of patients with major intraoperative complications and was an independent risk factor in a multivariate logistic regression analysis (Table 2). There was no evidence for between-centre or between-surgeon heterogeneity.

The observed major intraoperative complications included erroneous transection of bronchovascular structures (*n* = 9); injuries to gastrointestinal organs (*n* = 5) or proximal airway (*n* = 6); complications requiring additional unplanned major surgery (*n* = 9) or immediate life-threatening complications (*n* = 17). In order to find all unplanned additional resections resulting from a complication, the reasons for bilobectomy or pneumonectomy were identified. The 18 pneumonectomies completed by VATS were all performed to achieve complete resection. There were 13 pneumonectomies after conversion to thoracotomy, 8 for oncological reasons and 5 for major complications discussed below. There were 6 bilobectomies by thoracotomy, 2 for oncological reasons and 4 because of complications. Two of the 46 VATS bilobectomies were complication related and are discussed below. Postoperatively, additional resections were necessary in 9 patients due to complications: 3 completion lobectomies after trisegmentectomy, 3 middle lobe resections (resulting in bilobectomies) and 3 completion pneumonectomies. The 46 cases with major complications (Table 3) were discussed among the members of MITIG-ESTS. Recommendations were drafted when appropriate (Table 5).

Erroneous transections of a bronchovascular structure

In 3 patients scheduled for VATS right upper lobectomy, the complete PA (Case 1) or lower division of the PA (Cases 2 and 3) were accidentally transected together with the upper lobe vein (ULV). Failure to recognize the pulmonary artery posterior to the right ULV was the direct cause for the erroneous transections. In the first patient, the dissection was hindered by the central location of the tumour and fibrosis induced by induction radiochemotherapy. In the other 2 cases, the superior trunk of the PA was visualized but not the lower part. The latter was then accidently encircled and stapled together with the ULV. In the second case, a semi-inflated lung obscured the operating field. Surgery was performed with a non-high-definition system in the third patient. In this patient, the diagnosis was made postoperatively by computed tomography (CT) scan (Fig. 3).

In 4 patients, a vein was transected due to anatomical misjudgement. In the first case, the left lower lobe vein was transected with the ULV after involuntarily intrapericardial dissection. In 2 patients, the middle lobe vein was transected together with the right ULV. In the last case, the remaining lingular vein was too small after an upper trisegmentectomy.

In 2 patients, the intermediate bronchus was unintentionally transected. The first case was planned for right lower lobectomy. The fissure was incomplete and a 'hilum first technique' was used. After transection of the lower lobe vein, poor visualization resulted in surrounding the intermediate bronchus instead of the lower lobe bronchus. The other patient, with a planned right upper lobectomy, suffered from morbid obesity and significant emphysema resulting in a poorly deflated lung. A posterior approach was used. A ventilation test with clamped bronchus revealed ventilation of the upper lobe, but this was ignored and consequently the intermediate bronchus was transected.

Injuries to gastrointestinal organs

In 4 patients, an injury of the oesophagus occurred. The tip of the stapler caught the oesophagus when transecting the posterior part of the fissure in one. The other 3 were presumably caused by monopolar electrocautery during lymph node dissection.

A spleen injury occurred in one patient, presumably during excessive pressure on the diaphragm and underlying spleen. Hypovolaemia was noticed at the end of a lower lobectomy procedure although there was no obvious blood loss witnessed. Ultrasound of the abdomen revealed free fluid and a spleen saving laparotomy was performed. There was a minor tear in the spleen without an associated visible lesion to the diaphragm.

Injuries to a proximal airway

Intraoperative injuries to bronchi consisted of three perforations by a double-lumen tube (DLT) and three intraoperative tears. The DLT perforations were probably caused by overinflation of the balloon in one, manipulation of the tube with an inflated balloon in the other, and lymph node dissection of position 7 during a left lower lobectomy causing a small injury resulting in a full tear at the level of the balloon. In 3 patients, the intermediate bronchus was injured, in one the cause could not be identified, in one this happened when encircling the middle lobe bronchus during an upper bilobectomy and in the third a tear occurred when firing a stapler on the lower lobe bronchus.

Complications requiring additional unplanned major surgery

Massive parenchymal air leak necessitated a pneumonectomy in 1 patient after right upper lobectomy hampered by important adhesions. Parenchymal bleeding without obvious signs of torsion or vascular problems lead to extra anatomical resections in 2 patients. A torsion of the left lower lobe resulted in a completion pneumonectomy after upper lobe resection. The responsible surgeon mentioned failure to monitor lung re-inflation and check the bronchovascular structures and staple lines at the end of the operation. A completion lobectomy was performed due to lingular torsion after upper trisegmentectomy.

In 3 patients, a bronchial kinking occurred, resulting in bronchial rupture and completion pneumonectomy in 2 patients and in-hospital mortalities in 2. The events happened after upper lobe resection, in the first case in combination with a S6 segmentectomy of the right lower lobe. In 1 patient, a bronchial dehiscence occurred after bronchoplasty.

Immediate life-threatening complications

Ventricular fibrillation occurred in 1 patient before the bronchovascular structures were transected. Massage was started after

Table 3: List of major intraoperative complications

	Major complication	M/F	Age	pSt	Planned resect.	Surg's exp	VATS index	Mechanism of complication contributing factors	Conv	Treatment	Add. resect.	Hosp stay	IHM	90DM	*n*	%
Group I: erroneous transection of bronchovascular structure															9	0.3
1	Main PA with ULV	M	59	IB	RUL	200+	0.8	Def CRT, PA not visualized, central tumour	Yes	Reimplantation	No	3	No	No		
2	Lower PA with ULV	F	74	IB	RUL	101–200	0.8	PA not visualized, semi-inflated lung	Yes	Reimplantation	No	48	No	No		
3	Lower PA with ULV	F	55	IA	RUL	101–200	0.4	PA not visualized, non HD system	No	D1 Reimplantation, middle lobectomy	Yes	12	No	No		
4	LLV with ULV	M	60	IB	LUL	200+	0.8	Lower lobe vein not identified	Yes	Reimplantation	No	14	No	No		
5	MLV with ULV	M	52	IA	RUL	0–50	0.5	Middle lobe vein not identified	No	Bilobectomy superior	Yes	6	No	No		
6	MLV with ULV	M	67	IB	RUL	0–50	0.4	Middle lobe vein not identified	No	D4 Middle lobectomy	Yes	8	No	No		
7	Lingular V with LUTS V	F	55	IA	LUTS	101–200	0.3	Second lingular vein not identified	No	D6 Open lingulectomy	Yes	20	No	No		
8	Interm Br instead of LLBr	F	67	Bngn	RLL	101–200	0.4	Incomplete fissure, no ventilation test	No	Middle lobectomy	Yes	15	No	No		
9	Interm Br instead of ULBr	M	64	IIA	RUL	0–50	0.3	Ventilation test neglected	Yes	Sleeve	No	22	No	No		
Group II: injuries to gastrointestinal organs															5	0.2
10	Oesophagus	F	80	IIB	RUL	200+	0.7	Stapling posterior fissure: tip not visualized	Yes	Suture on oesophagus	No	10	No	No		
11		M	56	IIA	RPn	200+	0.3	Monopolar coagulation subcarinal LND	No	D6 suture; omentopl, fenestration	No	120	No	No		
12		F	62	IIA	RUL	200+	0.8	Monopolar coagulation subcarinal LND	No	D9 thoracotomy, stent	No	7	No	No		
13		F	69	IB	RLL	200+	0.8	Monopolar coagulation subcarinal LND	No	D25 thoracotomy, stent	No	129	Yes	No		
14	Spleen	F	77	IA	LLL	51–100	0.3	Ecartment of diaphragm (no lesion)	No	Laparatomy, spleen saving mesh	No	12	No	No		
Group III: injuries to proximal airway															6	0.2
15	DLT perforation	M	64	IB	RUL	101–200	0.3	Balloon hyperinflation	Yes	Repair	No	8	No	No		
16		F	71	IB	RUL	200+	0.8	DLT retracted with inflated balloon	No	Repair	No	14	No	No		
17		M	64	IA	LLL	200+	0.8	Tear at level balloon, subcarinal LND	No	Repair	No	2	No	No		
18	Operative tear of intermediate bronchus	M	73	IB	RLL	51–100	0.4	Unknown cause	Yes	Repair	No	10	No	No		
19		M	65	IV	RUM	101–200	0.9	CTh, injury encircling MLBr	Yes	Repair by sleeve (oncological bilobecotmy)	No	14	No	No		
20		F	65	IB	RLL	101–200	0.8	Bronchial tear at stapling of LLBr	Yes	Bilobectomy	Yes	10	No	No		
Group IV: complications requiring additional unplanned major surgery															9	0.3
21	Air leak	M	74	IIA	RUL	0–50	0.6	Massive adhesions, postop major air leak	No	D14 completion pneumonectomy	Yes	56	No	No		
22	Torsion lower lobe	F	63	IA	LUL	0–50	0	Position of lung not controlled at closure	Yes	D8 completion pneumonectomy	Yes	44	No	No		
23	Torsion lingula	F	61	IA	LUTS	101–200	0.2	Lingular torsion	No	D2 VATS lingulectomy	Yes	11	No	No		
24	Bronchial kinking	F	69	IB	RUL & S6	200+	0.5	Devascularized long free Br after S6 and RUL, kinking, bronchopleural fistula, necrosis	No	D8 fixation lobe on diaphragm, D13 sleeve, D28 pneumonectomy	Yes	47	Yes	Yes		
25		F	70	IB	LUL	51–100	0.6	D1 stent for kinking of ULBr, perforation	No	D1 repair of tear tracheobronchial corner	No	18	No	No		
26		F	50	IA	RUL	0–50	0.6	Unknown, atelectasis	No	D8 middle lobe resection	Yes	17	Yes	Yes		

Continued

Table 3: Continued

	Major complication	M/F	Age	pSt	Planned resect.	Surg's exp	VATS index	Mechanism of complication contributing factors	Conv	Treatment	Add. resect.	Hosp stay	IHM	90DM	*n*	%
27	Leak after bronchoplasty	M	79	IIIA	RML	200+	0.8	Leak after bronchoplasty	No	D1 Sleeve repair, D9 bilobectomy	Yes	9	Yes	Yes		
28	Middle lobe bleeding	M	66	IB	RUL	101–200	0.3	Bleeding in parenchyma, no vasc injury, no torsion	No	D1 Middle lobe lobectomy	Yes	13	No	No		
29	Lingula bleeding	F	65	IA	LUTS	101–200	0.8	Bleeding in parenchyma, no vasc injury, no torsion	No	D8 VATS lingulectomy	Yes	16	No	No		
Group V: immediate life-threatening complications															17	0.5
30	Ventricle fibrillation	F	76	IIB	RLL	200+	0.2	History of MI and PTCA	Yes	Cardiac massage	No	27	No	No		
31	Cardiac perforation	F	75	IA	Segm	200+	0.4	CTh, Cardiac perf. trocart tip, fragile tissue	Yes	Cardiac surgeon ass, no repair possible	No	0	Yes	Yes		
32	Sudden peroperative bleeding of more than 2 l or bleeding only controllable by emergency pneumonectomy	M	63	IIA	RUL	200+	0.8	Probably missed diagnosis PHT	Yes	PA ruptured when clamping (after conversion)	NA	0	Yes	Yes		
33		F	63	IB	RUL	200+	0.8	CTh, probably missed diagnosis PHT	Yes	Repair, pneumonectomy	Yes	17	No	No		
34		F	68	IIA	LLL	200+	0.8	Rupture PA stump in recovery, folded artery	No	Repair unsuccessful	No	0	Yes	Yes		
35		F	78	IA	RUL	200+	0.8	Lesion A2, failed attempt at VATS suture	Yes	Clamp, repair, cardiac massage	No	0	Yes	Yes		
36		F	54	IA	LUTS	101–200	0.3	Lesion A2, failed attempt at VATS suture	Yes	Clamp, repair	No	10	No	No		
37		M	79	IA	LUL	51–100	0.6	Tear when stapling superior trunk PA	Yes	Clamp, repair	No	19	Yes	Yes		
38		F	67	IA	RUM	0–50	0.6	Tear when stapling superior trunk PA	Yes	Clamp, repair (oncologic bilobectomy)	No	22	No	No		
39		F	68	IB	RLL	200+	0.8	Lesion A2	Yes	Clamp, repair	No	5	No	No		
40		M	62	IIB	RUL	200+	0.8	Lesion A2, liver cirrhosis, EF 40%, AAA	Yes	Clamp, repair	No	8	Yes	Yes		
41		F	66	IB	RUL	200+	0.3	CTh, bleeding PA	Yes	Pneumonectomy	Yes	92	No	No		
42		M	55	IIIA	RUL	0–50	0.6	Def CRT, bleeding PA	Yes	Pneumonectomy	Yes	12	No	No		
43		M	66	IIA	LLL	51–100	0.8	Fragile PA, infiltrating tumour and nodes	Yes	Pneumonectomy	Yes	15	No	No		
44		M	82	IA	LLL	200+	0.8	Unknown	Yes	Repair	No	22	No	Yes		
45		F	72	IIIA	LLL	200+	0.8	Lower lobe PA tear when applying stapler	Yes	Clamp, repair	No	10	No	No		
46		M	74	IIB	LUL	0–50	0.9	Fragile PA, infiltrating nodes	Yes	Pneumonectomy	Yes	18	No	No		
Total															46	1.5

M: male; F: female; pSt: pathological stage; Bngn: benign; resect.: resection; surg's exp: surgeon's experience at the moment of operation; VATS index: VATS over total amount of anatomical resections in the same centre in the same year; Conv: conversion; Add.: additional; IHM: in-hospital mortality; 90DM: 90-day-mortality; PA: pulmonary artery; ULV: upper lobe vein; RUL: right upper lobectomy; Def CRT: definitive chemoradiotherapy; HD: high definition; Dx: postoperative day X; LLV: lower lobe vein; LUL: left upper lobectomy; MLV: middle lobe vein; V: vein; LUTS: left upper trisegmentectomy; Interm Br: intermediate bronchus; LLBr: lower lobe bronchus; RLL: right lower lobectomy; ULBr: upper lobe bronchus; RPn: right pneumonectomy; LND: lymphadenectomy; Omentopl: omentoplasty; LLL: left lower lobectomy; DLT: double-lumen tube; CTh: chemotherapy; RUM: right upper and middle lobectomy; MLBr: middle lobe bronchus; LLBr: lower lobe bronchus; FEV1: forced expiratory volume in 1 s; S6: Segment 6 segmentectomy; ULBr: upper lobe bronchus; RML: right middle lobectomy; LLL: left lower lobectomy.

Table 4: Incidence of conversion (overall and non-oncologic), vascular injury and major complication grouped by oncological indicated resection

Oncological indicated resection	Total	Conversion		Non-oncological conversion		Vascular injury		In-hospital mortality		Major complication						
	n	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	I	II	III	IV	V
Right upper lobe	975	66	6.8	53	5.4	38	3.9	19	1.9	20	2.1	1, 2, 3, 5, 6, 9	10, 12	15, 16	21, 24, 26, 28	32, 33, 35, 40, 41, 42
Left upper lobe	697	34	4.9	24	3.4	17	2.4	7	1	5	0.7	4			22, 25	27, 46
Right lower lobe	517	27	5.2	24	4.6	14	2.7	9	1.7	6	1.2	8	13	18, 20		30, 39
Left lower lobe	421	13	3.1	9	2.1	8	1.9	4	1	6	1.4		14	17		34, 43, 44, 45
Right middle lobe	186	4	2.2	4	2.2	1	0.5	3	1.6	1	0.5				27	
Bilobectomy superior	23	3	13.0	3	13.0	2	8.7	1	4.3	2	8.7			19		38
Bilobectomy inferior	28	2	7.1	1	3.6	0	0	0	0	0	0					
Left pneumonectomy	16	5	31.3	1	6.3	1	6.3	0	0	0	0					
Right pneumonectomy	10	3	30	1	10.0	1	10.0	0	0	1	10.0		11			
Segmentectomy	203	13	6.4	13	6.4	5	2.5	1	0.5	5	2.5	7			23, 29	30, 36
Total	3076	170	5.5	133	4.3	87	2.8	44	1.4	46	1.5					

The identifier of the cases with major complication correspond with Table 3.
I: Erroneous transection of bronchovascular structure.
II: Injuries to gastrointestinal organs.
III: Injuries to proximal airway.
IV: Complications requiring additional unplanned major surgery.
V: Immediate life-threatening complications.

conversion and resection continued. A minor tear of the heart with a trocar tip or electrocautery before trocar insertion resulted in an un-repairable lesion and mortality, although assistance from a cardiac surgeon was provided. The patient had previously undergone chemotherapy and had remarkably fragile tissues.

Major pulmonary bleeding occurred in 15 patients, including sudden blood loss of more than 2 l ($n = 10$), emergency pneumonectomy ($n = 2$) or both ($n = 3$). In almost half of them bleeding occurred during right upper lobe resection ($n = 7$) (Tables 3 and 4). Altogether, there were six in-hospital mortalities after major bleeding, of whom three intraoperative and one immediate postoperatively.

Two patients had upon operation clinical signs of undiagnosed pulmonary hypertension. In the first case, conversion was performed before major bleeding. The PA ruptured when applying a clamp, resulting in a mortality. The patient's history included asbestosis, chronic obstructive pulmonary disease and pulmonary embolism. In the other, an emergency pneumonectomy was performed. This patient had a history of deep venous thrombosis and induction chemotherapy.

Two major bleedings occurred when an attempt was made to suture an arterial bleeding without clamping, one resulted in an intraoperative death. Two major bleedings occurred during application of staplers on the superior trunk of the PA. Three were related with the right A2 artery.

One patient died after surgery in recovery. He had on autopsy a rupture of the PA stump, which was partially folded. This might be the result of pushing the stapler too deep around the artery.

The majority of patients ($n = 10/16$, Table 3) with major bleeding were operated by surgeons with an experience of more than 200 cases. The number of VATS over total anatomical resections in the same year at the same centre (VATS index) reached a median of 0.62 (IQR 0.29–0.81, $n = 3076$). This was identical to the median VATS index of the 46 patients with major complications (0.62, IQR 0.34–0.83). In the subgroup of the 16 patients with major bleeding, the median of the VATS index was 0.82 (IQR 0.57–0.83) versus 0.62 (IQR 0.29–0.81) in patients without major complications ($P = 0.0085$).

THORACIC

DISCUSSION

Main findings

The prevalence of major intraoperative complications was 1.5% in this multicentre intention-to-treat analysis of 3076 consecutive patients planned for VATS anatomical lung resection. These included erroneous transections of bronchovascular structures, injuries to gastrointestinal organs or proximal airway and events leading to additional major surgery or immediate life-threatening complications. The occurrence of major intraoperative complications does not seem to correlate with experience. This can be interpreted in different ways. There are (i) too few events to reach statistical significance or (ii) the learning curve is longer than observed in this series, (iii) such major complications might be an unavoidable part of (VATS) lung surgery or (iv) experienced surgeons take on more difficult cases with a higher risk of major complications, balancing the effect of experience. We corrected the statistical analysis for possible confounders such as pathological stage and previous chemo- or radiotherapy. We did see a significant correlation between experience and non-oncological

Table 5: Recommendations resulting from panel discussion of the observed major intraoperative complications

Erroneous transections of a bronchovascular structure

Reveal the structures to be spared before transection of the target bronchovascular structures

- Use high-definition video systems, wait for sufficient deflation of the lung, change vantage points if necessary, and verbally define structures to assisting surgeons.
- Identify the pulmonary artery posterior to the right upper lobe vein during right upper lobectomies.
- Visualize all veins before transection, especially on the left where an early confluence is common. Incision of the inferior ligament helps to identify the lower lobe vein.
- Bronchi
  - The use of a ventilation test is recommended, although it does not provide a complete guarantee due to cross-ventilation. Some authors have witnessed ventilation across (incompletely) closed stapling devices prior to firing and advocate using a clamp.
  - Bronchial blockers can hinder deflation of the lung after the test and, therefore, the use of double-lumen tube is generally advisable.
  - Utilize resection techniques resulting in an optimal view on the bronchial anatomy, remove intrafissural lymph nodes. Some authors open the fissures partially or complete at an early stage of the operation, or plan the operation with steps resulting in the bronchial transection as the last point.
- Segmentectomies
  - Inspect the CT scan carefully for anatomical variations.
  - Perform a complete anatomical dissection within the fissures.
  - Consider sparing the intersegmental vein if possible.
  - Look for a lingular artery within the fissure when performing upper trisegmentectomies as the lingular artery often originates near the superior trunk.

Injuries to gastrointestinal organs

- Visualize the tip of the stapler.
- Care should be applied during lymph node dissection with monopolar coagulation, blunt dissection in combination with bipolar systems is favourable.
- Oesophageal perforation should promptly be diagnosed and treated, although clinical symptoms might present late and possibly emerge only after discharge.
- Consider an intra-abdominal blood loss when a patient has symptoms of volume loss during or after a left-sided VATS surgery without obvious bleeding, even without clear lesion on the diaphragm.

Injuries to a proximal airway

- The anaesthesia team should be experienced with thoracic surgery and management of double-lumen tubes (DLTs).
- Ideally, the anaesthesia team is equipped with a video bronchoscope and a separate video system. This allows surgeons and anaesthetists to interact when placing double-lumen tubes and before firing the stapler on the bronchus.
- Half of the panel routinely requests DLTs positioned in the contralateral lung.
- Perform an under-water test to detect any air leak from the bronchial stump or the main bronchi.

Complications requiring additional unplanned major surgery

- Monitor lung re-inflation and check the bronchovascular structures and staple line to detect torsions. Consider fixation of the lingula to the lower lobe after trisegmentectomy or middle lobe to the lower lobe after right upper lobectomy.
- Perform bronchial sleeve resections instead of bronchoplasties, these seem to cause more tension on the sutures.
- The parenchyma of the lower lobe will migrate towards the apex after upper lobectomy. Kinking and subsequently necrosis of the bronchus might follow. It is unclear how this might be prevented. When kinking is obvious, sleeve resection might seem an option, but this has a higher complication rate than lobectomy and is therefore not advised as a standard preventative measure.

Immediate life-threatening complications

- Trocars should be placed under vision.
- History suggesting pulmonary hypertension should be investigated appropriately.
- Difficult vascular dissection should be recognized. It should be a reason for conversion especially in case of early experience. With increasing experience, central control of the PA can be obtained with a snare or silicon vascular tape before further lobar dissection is resumed [17].
- Bleeding can often be controlled by simple pressure, but suturing of the artery should not be attempted without prior appropriate clamping.
- In case of emergency conversion, the location of the thoracotomy incision should not be influenced by the position of the thoracoscopic incisions.
- Free the artery circumferentially from all adhesions, hilar lymph nodes and pleura and provide a clear exit point for the stapler tip.
- Prevent folding of the artery within the stapler (too short stapler, too deep placed).
- Allow a small visible proximal stump when transecting proximal arterial branches.
- When retracting the stapler following firing, allow gentle rotational movements in order to facilitate disengagement of tissue and staplers from the device.

conversions with a trend of stabilization after the first 100 cases, although this deviation from linearity was not significant.

Half of the patients were operated by surgeons with an experience of more than 200 VATS anatomical resections at the time of the operation and 18% were operated during the early experience of 50 cases or less, so all levels of experience were well represented.

Eleven of the 17 patients with an immediate life-threatening complication, including 3 intraoperative deaths, were operated by surgeons with a VATS experience of more than 200 cases. One intraoperative death occurred after technical conversion before major bleeding started, but was included as this is an intention-to-treat analysis. During panel discussion, it appeared that experienced VATS surgeons face more challenging cases with higher risk for major bleeding. A subgroup analysis was performed using an index of VATS over total anatomical resections per year per centre. The VATS index was similar when comparing the 46 patients with major complications versus the rest. However, in the subgroup with the 16 patients with major bleeding the median VATS index was significantly higher than in the other patients [0.82 (IQR 0.57–0.83) vs 0.62 (IQR 0.34–0.83), $P = 0.0085$]. This finding reinforces the assumption that the risk of major bleeding rose when surgeons were less selective and more willing to start operations by VATS. It remains unclear what percentage of these major bleedings could have been prevented by a more early conversion.

Sixty percent of all patients operated for bronchial carcinoma had pathological stage I. Previous chemo- or radiotherapy was recorded in 3.8%. We noticed a statistical significant effect of previous chemo- or radiotherapy on occurrence of non-oncological conversions and major intraoperative complications in a logistic regression analysis. Future research on the role of VATS after chemo- or radiotherapy should be conducted as publications on this topic are scarce [18].

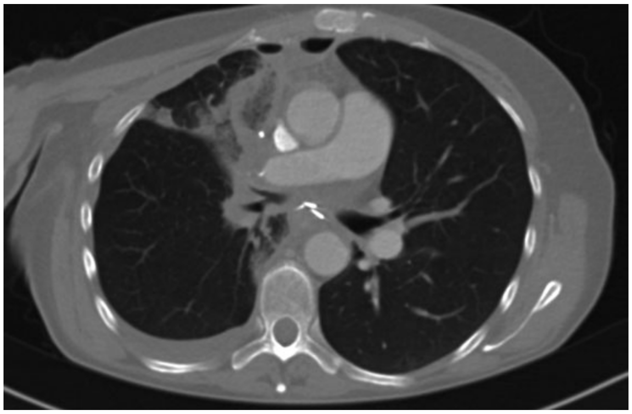

Figure 3: CT scan revealing a staple line on the main pulmonary artery after right upper lobectomy. There are signs of ischaemia in the middle lobe. The PA was consequently repaired through an anterior thoracotomy and a middle lobectomy was performed. The lower lobe was spared due to the bronchial circulation and flow through the inferior pulmonary vein (Table 3, Case 3).

The different types of major intraoperative complications are uncommon but have an important impact on the patient outcome. Overall in-hospital mortality was 1.4% ($n = 43$). Twenty-three percent ($n = 10/43$) were related to major intraoperative complications. Eight pneumonectomies (5 intraoperative and 3 postoperative, 0.3%) were a consequence of a major complication. Flores *et al*. reported unplanned pneumonectomy in one of the every 200 cases (0.47%) [9]. Furthermore, they reported 3 cases of transections of the main PA, 2 erroneous bronchial transections and 1 venous transection in 633 patients (0.9%). We found 9 erroneous transections in 3076 patients (0.3%). One might try to explain the difference by the level of experience. The study by the group of Memorial Sloan Kettering was conducted between 2002 and 2010. In contrast to our current study, patients were operated by 10 surgeons in their early experience of VATS anatomical resections. However, erroneous transections seemed to happen at all levels of experience (Table 3). Another factor is the surgical technique. Amer *et al*. reported three erroneous bronchial transections and referred to the 'fissure last technique' as a potential cause of confusion [19]. All nine erroneous transections in this study happened at an early stage of the operation. The learning point from this combined experience should be to always obtain a good overview before bronchovascular structures are divided [8]. Some surgeons therefore continue to open the fissure before transection of bronchovascular structures, especially if the fissure is somewhat developed [20]. Moreover, it is technically possible to develop the most incomplete fissures with staplers by using a 'tunnel' technique before transection of bronchovascular structures [13]. In any case, one should be vigilant and identify the anatomical structures that should stay intact, by counting the veins, find the remaining artery and identify the correct bronchus.

Vascular injuries were reported in 2.9% ($n = 88$). Bleeding accounted for 41.2% ($n = 70/170$) of all conversions. Mei *et al.* reported a vascular injury rate of 4.1% of in a series of 414 VATS anatomical resections [21]. Kawachi *et al.* reported an 8.2% incidence of vascular injuries in 73 patients undergoing VATS lobectomy compared with only 1.7% of 176 patients in the open group. Mean blood loss was not significantly different [22]. In our data, a significant between-surgeon variability was seen concerning vascular injuries. This remained significant within a model with model correcting for the following confounders: age, gender, side, pathology and previous chemo- or radiotherapy. Other than true inter-surgeon variability, we can think of two possible reasons for this finding. Firstly, confounding factors were not captured in the database and not used in the model such as previous lung surgery and location of the tumour. Secondly, only 18 of 88 vascular injuries were dealt with by VATS. In the publication of Mei *et al.*, 88% were managed without conversion [21]. A variety of surgeons and centres participating in this study might have resulted in underreporting of vascular injuries in the local databases, especially if the bleeding did not result in a conversion or was not clinical significant [7–9]. In the absence of randomized controlled trials, it remains unclear whether the incidence of vascular injuries is truly higher in VATS anatomical resections. A general impression might be that these events are not typical VATS complications and that it is all part of lung surgery. A new technique is looked at with scrutiny. Databases are captured more carefully when starting a new surgical procedure. In open surgery, one continues with the same access when a major complication occurs. There is, therefore, no easily reportable parameter such as a conversion during VATS resection. On the other hand, if we eagerly accept many reports suggesting a lower incidence of overall morbidity of VATS [3, 4], we should acknowledge the reports on the potential higher rate of vascular injuries [22]. Reasons can be early experience with a new technique, change of landmarks, lack of overview or inadequate instrumentation [8]. Injuries without clinical consequences in open surgery can potentially be more difficult to deal with by VATS [8]. It is important to learn how to adequately react bleeding, but even more important is to develop the skills to recognize a dangerous situation before bleeding actually occurs. If bleeding is to be expected or cannot quickly be dealt with by VATS, it is advisable to convert before uncontrollable haemorrhage occurs [8].

Limitations

The present study was performed by six high-volume centres in Europe; therefore, conclusions regarding the frequency of major intraoperative complications during VATS anatomical resections in other centres are guarded. Although surgeons with early VATS experience were included in the study, we cannot disregard the prior extensive volume of all these centres with open surgery.

A further limitation of the study was the exclusion of the denominator. This combines the total group of patients who underwent VATS anatomical resection, resection by thoracotomy or non-surgical local treatment. Selection criteria can play a role in the incidence of conversions and complications. This is not completely captured in an index of the number of VATS over open anatomical resections. Some centres provide care to a complete population area and others get more referrals from other centres resulting in a difference in complexity of cases. An index of VATS over open surgery in Stage I NSCLC cases only, partially excludes this bias. However, we did not obtain the full data of staging of patients after open surgery in the same time period. Therefore, this study should not be used to compare the outcome of VATS versus open anatomical resections. The study aimed at providing an honest report of all major intraoperative complications, hoping that a better understanding of the causative factors can help to prevent them in the future. This report is furthermore useful for patient counselling during consultation.

The strength lies in the large number of VATS resections collected in a prospectively recorded database at each centre. We are confident that we included all conversions and emergency pneumonectomies. Fortunately, not all published major complications were witnessed in this series. Personal communications with other VATS surgeons include but are not limited to resection of the wrong lobe, narrowing of the remaining bronchus during upper lobectomies and stapler misfires. Increasing the awareness by reporting major complications is probably the best way to avoid them [9]. Reporting of near-miss events can also be useful as seen in non-medical reporting systems [23]. To identify these complications in a large database, an intention-to-treat field should be added, including the planned surgical access and planned resection [2, 10].

CONCLUSION

This multicentre series based on prospectively recorded local databases shows a prevalence of 1.5% of major intraoperative complications after VATS anatomical lung resections. Multivariate analysis did not show a relationship with increasing surgeon experience.

In contrast, previous chemo- or radiotherapy was associated with both a higher incidence of non-oncological conversions and major intraoperative complications. Occurrence of these complications has an important impact on the patient outcome. We believe that some events can be prevented by raising awareness, leading to meticulous identification and dissection of hilar structures during VATS anatomical resections.

ACKNOWLEDGEMENTS

We are grateful to all the thoracic surgeons from the different centres, contributing with patient data. We thank the members of MITIG for their contribution in drafting useful recommendations. Members of the MITIG include Henrik Hansen, Didier Schneiter, Martin Hürtgen, Herbert Decaluwe, René Horsleben Petersen, Cezary Piwkowski, Florian Augustin, Alessandro Brunelli, Thomas Schmid, Kostas Papagiannopoulos, Jan Siebenga, Diego Gonzalez Rivas and Dominique Gossot. Many thanks to Steffen Fieuws, Leuven Biostatistics and Statistical Bioinformatics Centre (L-Biostat), for the statistical support. The Minimally Invasive Thoracic Interest Group (MITIG) is a workgroup founded in 2013 within the European Society of Thoracic Surgeons. The aim is to support education in minimally invasive surgery, collect data, perform studies and quality control, establish and define standard operating procedures and promote minimally invasive thoracic surgery in dedicated centres.

Funding

This paper was supported by an unrestricted grant from Covidien (Medtronic).

Conflict of interest: none declared.

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APPENDIX. CONFERENCE DISCUSSION

Dr R. Flores *(New York, NY, USA)*: I congratulate you on a unique contribution that exemplifies genuine purpose, collaboration and execution. Not many studies can have an immediate impact on patient care, but this one will; this paper will save lives. It is not easy for a thoracic surgeon to speak publicly about complications, but communication of these unfortunate events is critical in order to improve the delivery of care to the next patient. When you know what can go wrong, then you are in a better position to avoid it.

Studies from large databases such as the STS are inherently flawed because they clearly miss such complications. They are ripe with selection bias in favour of VATS lobectomy. Such complications get included in the thoracotomy group, which makes the thoracotomy group look worse and the VATS lobectomy group look better. Studies like this one are not meant to make VATS lobectomy look bad, but are meant to give a more realistic picture and to facilitate the safer implementation of VATS lobectomy.

Conversion, as you have described, can be looked at in many different ways and have many different definitions, but a conversion to avoid a complication and a conversion to fix a complication are two very different things. There is one word to describe a conversion to avoid an anticipated complication: smart. So how do you describe the surgeon who has 300 VATS lobectomies without a single complication or a conversion? Full of crap.

Studies like this are the reason why we went into medicine, to continuously improve and optimize care to our patients. You have not only done an outstanding job by presenting data that is sorely missing from the literature, but you have also shown by example what all of us as doctors should strive to emulate.

I have several questions/comments for you. One, what is the role of obesity or body habitus in the development of these complications and how does this come into play when an emergency complication occurs? Two, can you describe in detail this kinking? What is the presumed mechanism and how does necrosis occur with this?

Three, in the manuscript you describe taking down the inferior pulmonary ligament to identify the lower lobe vein. This can be done without taking down the inferior pulmonary ligament, and I would recommend keeping it in place whenever you do upper lobectomies, because that level 9 lymph node in stage I cancers is never positive and this will decrease your risk of torsion.

And four, a difficult case open is usually a very difficult or even a deadly case by VATS as demonstrated in your pneumonectomy experience. If we do 200–300 VATS lobectomies and we get one pneumonectomy or a catastrophic complication, is it worth doing this procedure in the other successful 200–300 patients? Could we state that this would have happened if this case were done open, is this just thoracic surgery, and is it that we are looking at VATS lobectomies with much more scrutiny than we do the open cases?

Dr Decaluwé: Thank you, Dr Flores, for these nice words.

The first question was on BMI. We had a lot of missing BMI values. I would have loved to have included them in the multivariate analysis, but this was not possible. Within the major complications there were two patients with a high BMI. One was a patient with an erroneous transection of both veins, and this was probably not due to the high BMI but due to the fact that the surgeon inadvertently went intrapericardial, lost the overview, and didn't look for the second vein. Then there was the other patient where the intermediate bronchus was transected. This patient had extreme emphysema, obscuring the view. I am not sure if the erroneous transection was related to a high BMI.

Concerning erroneous transections, visibility is very important, so a good deflated lung and a high definition camera system are important. For emergencies in case of high BMI, I agree that an emergency thoracotomy might be slower, but we don't have the data to really say that it is significant.

You asked a question on kinking of the bronchus. We had three patients with kinking. The first case was a right upper lobe and the mid lobe became atelectatic postoperatively. The patient developed pneumonia, and the surgeon performed a middle lobe resection on the eighth day; the patient died of ARDS and cardiac failure. It probably happened because the middle lobe was not fixed to the lower lobe.

Then there was one patient, a 70-year-old woman, where there was a kinking soon after left upper lobe resection. They put in a stent and this caused a perforation at the tracheobronchial corner. It was revised and this patient survived.

The third patient underwent a right upper lobectomy together with a segment 6 resection. There was a long segment of devascularization of the bronchus. After kinking and atelectasis, a fixation of the remaining lower lobe on the diaphragm was performed. Because of bronchial dehiscence, a sleeve resection followed, and then a pneumonectomy. This patient died. The strategies to prevent kinking are not clear, but I think if you devascularize the bronchus for a long distance, it can be really problematic.

You had a question on the incision of the pulmonary ligament. I agree this is historical and that we learnt that from open surgery. We always take all reachable lymph nodes, also position 9, and I think it helps to identify the lower lobe vein and to go to position 7 if you take that ligament. I am not sure if leaving the ligament will prevent torsion. Some surgeons, like Dr McKenna, are confident that torsion happens at the moment that you reinflate the lung. So you have to really check the position of the lobe when you are reinflating.

Then you had a very good question on whether it was worth doing 300 VATS resections which benefit those 300 patients, if one patient dies, or undergoes an emergency pneumonectomy. I agree that it is not clear whether the complications are related to the lung surgery or to the VATS surgery.

I remember a technical note from the '90s that was left by Professor Deneffe, the mentor of our current boss, stressing that you have to be careful not to take the main artery together with the right upper lobe vein. So these complications also happened in open surgery but we don't have the reports.

If you think that it's all related to learning the VATS technique, then you would expect that, with experience, the numbers of major complications would decrease. However, there might be several other reasons why we didn't find that connection with experience. Possibly the events are too few to find a statistical correlation, the learning curve might even be longer than the one that we are looking at in this study, and experienced surgeons are performing more difficult cases and this is levelling out the effect of experience.

For erroneous transections, I really think it is about technique, and I don't mean VATS or open. I think that with both VATS and open surgery you can master a technique where you can identify all structures before you take them down.

For the vascular lesions the story is a little bit different, because cases which are easy to deal with by open surgery can be difficult by VATS, but to say that you cannot do VATS because you had this one case where you had a major bleeding, this is a philosophical question. In reality, VATS is here to stay and we should try to make both open and VATS surgery safer.

Dr N. Chaudhuri *(Leeds, UK)*: I just want to come back to what the discussant said about the pulmonary ligament. It crops up every now and then at meetings and we don't know what to do, really. I struggle, because there are non-contrast CT scans for many of my VATS lobectomies, and I feel at ease if I tell my trainees, "don't forget to dissect the pulmonary ligament and identify a separate inferior vein", because then I know my complications won't be high and my trainee can say the same, and it is mainly a safety measure.

Can I ask either of you your opinion as to what we should do in a non-contrast CT scan? Should we not be taking out the pulmonary ligament? Another thing, also, is there any validity, for instance in emphysematous patients, where you worry that if you don't take the pulmonary ligament out you will be left with a space? Is that true anymore? I mean, what is the reason other than torsion for not taking the pulmonary ligament?

If the moderators allow, maybe a show of hands around the room to see how many people will take the pulmonary ligament during an upper lobectomy; we have quite a sizeable forum here.

(Show of hands). Large majority

Dr Decaluwé: And then maybe who is not taking the ligament?

(Show of hands). Few hands

Dr Chaudhuri: Okay. So in a group of peers, most people still take the pulmonary ligament. I am reassured.

Dr Decaluwé I think that is your answer.