Original Article

Thoracoscopic complex basilar segmentectomies: an analysis of 63 procedures

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Background: Thoracoscopic complex basilar segmentectomies are technically demanding and challenging. We review our experience to check whether this complexity can lead to specific surgical issues or increased post-operative morbidity.

Methods: Complex basilar segmentectomies were defined as the anatomical resection of at least one segment composing the basilar pyramid, excluding S^6. Data of patients who had an intention-to-treat thoracoscopic complex basilar segmentectomy were retrospectively collected from 2007 to 2019: indications, preoperative assessment, clinical features, operative technical aspects and early post-operative outcome.

Results: Sixty-three patients, 26 men (41%) and 37 women (59%) with a median age of 66 years and a median body mass index (BMI) of 26 kg/m2 were included. Interventions performed were mostly S^{9+10} (n=32) and S^8 (n=12) segmentectomies. Forty-five planned operations (71%) were completed. Extension to a larger resection was necessary in 17 patients (27%) and 4 patients underwent conversion to open surgery (6%). Median operative time was 168 minutes with a median intraoperative bleeding of 30 mL. Complications occurred in 11 patients (17%). There was no mortality. Median length of pleural drainage was 2 days (range, 1–2 days) and median hospital stay 4 days.

Conclusions: The extension rate of complex basilar segmentectomy is higher than that of other sublobar resections but their post-operative morbidity is identical.

Keywords: Thoracoscopy; sublobar resection (SLR); segmentectomy; basilar segmentectomy; complex segmentectomy

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Introduction

Interest in sublobar resections (SLRs) for early-stage non-small cell lung cancer (NSCLC) is increasing and their indications are gradually expanding (1). The objective of SLRs is to spare respiratory function while expecting to perform a resection respecting the same oncological principles than a lobectomy. The functional benefit of SLR is optimal when the number of resected segments is limited (2). Thus, when the surgeon needs to remove a benign lesion, a solitary metastasis or a pure ground glass

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opacity (GGO) localized in the lower lobe, it might be more beneficial to spare the maximum of lung parenchyma possible thus performing a limited resection of one or two segments than directly performing a basilar segmentectomy. Nevertheless, the partial resection of the basilar segments is a complex and challenging procedure, especially when performed thoracoscopically (3,4). Reasons are multiple and include high anatomical variability, difficult intersegmental plane (ISP) delineation and three-dimensional (3D) stapling of the ISP caused by the pyramidal shape of the lower lobe (3,5). For these reasons, complex basilar segmentectomy (CBS) are often precluded due to the perceived augmented risk of failure and for augmented potential post-operative complications. The aim of this study was to verify if the technical difficulties related to this complexity resulted in a high rate of extension to a larger resection, or conversion to thoracotomy, or early post-operative morbidity. Long-term outcome and survival are not part of this work and have been analyzed in another study (6).

We present the following article in accordance with the STROBE reporting checklist (available at https://dx.doi.org/10.21037/jtd-20-3521).

Methods

A single-center retrospective analysis was performed in our center from January 2007 to December 2019 for patients with an intention-to-treat thoracoscopic CBS. Intraoperative and postoperative data were prospectively recorded in a database that was approved from our Institutional Review Board (CEPAR 2013-002). The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Ethical Committee for Clinical Research of the French Society for Thoracic and Cardiovascular Surgery (CERC-SFCTCV-2020-07-03---13-SEAG) and individual consent for this retrospective analysis was waived. In this article, we considered as CBS every partial anatomical resection of the lower lobe excluding S^6. It is assumed that segmentectomy means "anatomical segmentectomy" with individual control of the broncho-vascular pedicle and intersegmental lymph node resection. Data collected included the type of segmentectomy planned, clinical features [gender, age and body mass index (BMI)], intraoperative characteristics (length of surgery and intraoperative bleeding) and post-operative characteristics (final pathology, length of pleural drainage, length of hospital stay). Thirty-day post-operative complication was assessed following the Clavien-Dindo classification (7). Reasons for extension and conversion were analyzed. Thirty- and 90-day mortality was included. We defined "extension" as a larger resection than expected, including adjacent segment, the entire basilar segments, i.e., S^{7-10} or S^{8-10})—or the whole inferior lobe. Indication for CBS was posed: (I) in patients with highly suspected or proven metastases that was unresectable by mere wedge resection; (II) in patients with highly suspicious and evolutive GGO; (III) in patients with proven or suspected cT1aN0 NSCLC considered to be poor candidates for lobectomy because of impaired cardiopulmonary function or major comorbidities; (IV) in patients with a previous lobectomy for NSCLC presenting with synchronous early-stage lesions.

For patients operated on for NSCLC, postoperative staging was assessed using the 8th edition of the tumor, nodes and metastasis (TNM) classification.

Technique

For all patients, a full thoracoscopic fissure-based multiple ports approach was used as previously described (8,9). Briefly, an extensive dissection of the pulmonary artery branches in the fissure is performed, followed by a tunneling technique to separate S^6 from S^{10}, to facilitate the exposure and resection of the arterial branches (10). The proper bronchus—or bronchi—are carefully dissected to avoid any tear of the veins that usually run behind them and are stapled after a reventilation test. In the rare patients with classical venous anatomy, i.e., inferior basilar vein, superior basilar vein and V^6, the segmental veins could be controlled at the hilum level. Otherwise, especially when the venous anatomy makes this dissection hazardous, they are controlled within the parenchyma once the bronchus and artery have been divided (*Figure 1*). Before ISP division, hilar structures are released to allow an easier exposure of the stumps to be resected in particular concerning the intersegmental bronchus and vein.

In our preliminary experience, ISP was determined using a conventional insufflation-deflation method. We then attempted intrabronchial injection of methylene blue in the whole segment to be resected via electromagnetic navigation bronchoscopy (ENB). Since November 2017, these two methods were abandoned and we switched to near-infrared imaging (IRI) with systemic injection of indocyanine green (ICG) (*Figure 2*).

In case of malignancy, all peri-bronchial (station 11), interlobar and intersegmental (stations 12 and 13) lymph nodes are cleared (*Figure 3A*). In case of patients operated

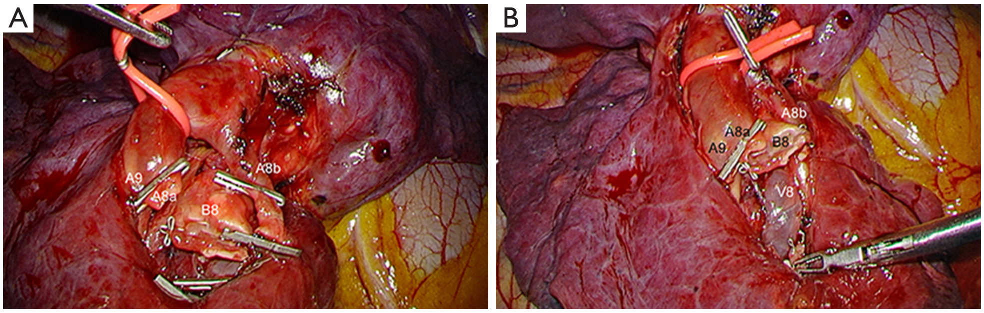

Figure 1 Control of the segmental vein. (A) Exposure of A^8a, A^8b and B^8 resected during a thoracoscopic S^8 segmentectomy; (B) exposure of the underlying V^8 after the resection of the bronchus.

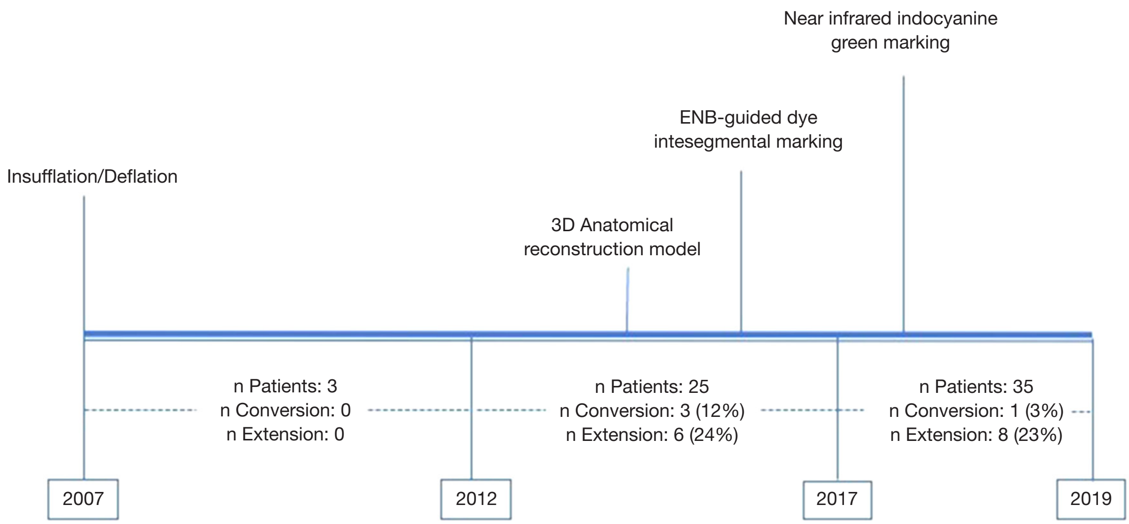

Figure 2 Timeline showing the distribution of patients and technological adoptions during the analyzed period of the study.

for malignancies, intersegmental lymph nodes and safety margins (*Figure 3B*) are always examined by frozen section. The procedure is transformed into a basilar segmentectomy if insufficient safety margins or into lobectomy in case of invaded intersegmental lymph nodes. In patients with primary NSCLC, the segmentectomy is completed by a radical hilar and mediastinal lymph node dissection.

Results

From September 2007 to November 2019, 646 full thoracoscopic SLR have been performed in our department. Of these, 63 full thoracoscopic anatomical intention-to-treat CBSs were included. Fifty-four segmentectomies were intentional with indication to treat early-stage small size (i.e., T1aN0) lesions (n=20, 32%) or pure GGO (n=4, 6%), proven or highly suspected typical carcinoid tumor (n=6, 10%), proven or highly suspected metastatic lesion otherwise unresectable via wedge resection (n=20, 31%) proven benign pathology (n=4, 6%). Nine segmentectomies were unintentional due to second synchronous or metachronous lung cancer (n=4, 6%), or proposed to patients with impaired cardiopulmonary function or major comorbidities (n=5, 8%). Data are presented as absolute numbers or in median (lower and upper quartiles). There were 26 men (41%) and 37 women (59%) with a median age of 66 years (57–71 years), a median BMI of 26 kg/m^2 (22–29 kg/m^2) and a median forced expiratory volume in the first second (FEV1) of 90% (75–102%) and a diffusing capacity of lung for carbon monoxide (DLCO) of 75% (65–82%). The types of planned CBS are summarized in *Table 1*. Forty-five procedures (71%) were completed.

Table 1 Planned operation and finally procedures performed

Type of planned basal segmentectomy (n)	Total N	Total %	Right	Left	Accomplished	Extension	Conversion	Conversion and Extension
S^{9+10}	32	51	15	17	22	8: 5 lower lobectomies; 3 basal segmentectomies	0	2: 1 lower lobectomy; 1 basal segmentectomy
S^{8}	12	19	4	8	9	2 basal segmentectomies	1	0
S^{7+8}	6	10	6	0	4	2 basal segmentectomies	0	0
S^{6+10}	5	8	2	3	5	0	0	0
S^{10}	5	8	2	3	3	1 S^{9+10}	0	1 basal segmentectomy
S^{8+9}	2	3	0	2	1	1 basal segmentectomy	0	0
S^{7+10}	1	2	1	0	1	0	0	0
Total	63		30	33	45 (71%)	14 (22%)	1 (2%)	3 (5%)

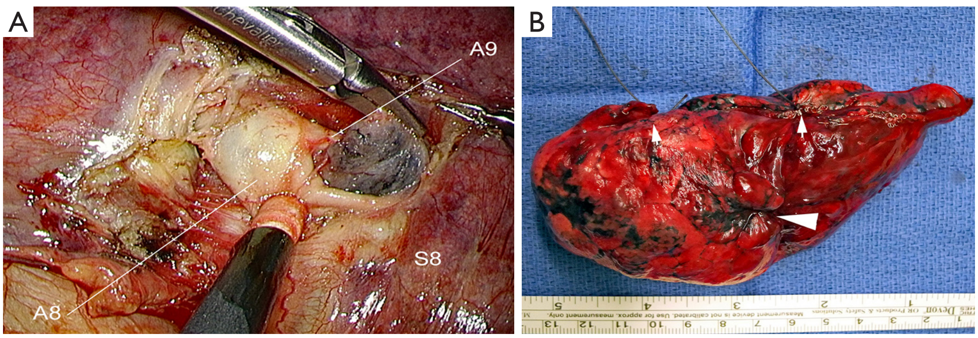

Figure 3 Intraoperative examination of segmental lymph nodes and margins. (A) Intersegmental lymph nodes dissected and removed for frozen section, during a left S^{9+10} segmentectomy; (B) intraoperative examination of safety margins during a left S^{10} segmentectomy. Large arrow = tumor; small arrows = marking of the portion of the staple line to be examined.

Extension to a larger resection was necessary in 17 patients (27%). In particular, to a basilar segmentectomy (S^{7-10} on the right side or S^{8-10} on the left side) in 10 patients, to an adjacent segment (S^{10} to S^{9+10}) in 1 patient and to a lower lobectomy in 6 patients. Conversion to thoracotomy was required in 4 patients (6%). The reasons for extension and conversion are reported in *Table 2* and include hemorrhage, positive or doubtful intersegmental margins at frozen section and technical difficulties during bronchial dissection or dividing the ISP. Final pathological diagnoses and pathological staging are reported in *Table 3*. In 5 patients (8%) the targeted lesion was not found in the final specimen thus requiring extension to a larger resection and in 3 cases the lesion was finally located following extension. In one patient operated for a 11 mm lesion with a pancreatic metastatic disease under chemotherapy, no lesion was found at final pathology. Post-operative follow-up with serial computed tomography (CT)-scan didn't detect suspicious lesion or recurrence. In a second patient, a S^{8} segmentectomy was performed with no lesion at final pathological examination. A post-operative bronchoscopy showed that the lesion—a typical carcinoid tumor—was still in place. Due to post-operative complications, in particular a bilateral pulmonary embolism, this elderly patient was not re-operated and he is currently under surveillance without disease progression. From July 2015 3D CT reconstruction and modelization was used (5). Median length of surgery was 168 minutes (133–213 minutes) with a median intraoperative blood loss of 30 mL (35–150 mL). Median length of pleural drainage was 2 days (1–2 days) and a median hospital stay was 4 days (3–5 days). Post-operative complications occurred in 11 patients (17%): 4 prolonged air leak (6%, Clavien-Dindo I), 2 atrial fibrillation (3%, Clavien-Dindo II), 1 unilateral pneumonia (2%, Clavien-Dindo II) and 2 pulmonary

Table 2 Reasons for extension and conversion and post-operative complications

Variables	N [%]	Clavien-Dindo classification
Reasons of extension		
Hemorrhage	2 [3]	–
Positive intersegmental margins	3 [5]	–
Technical difficulties in intersegmental stapling	3 [5]	–
Segmental bronchial tear	1 [2]	–
Target nodule not found	5 [8]	–
Total	14 [22]	–
Reasons of conversion		–
Hemorrhage	3 [5]	–
Technical difficulties in intersegmental stapling	1 [2]	–
Total	4 [6]	–
Post-operative complications		
Prolonged air leak	4 [6]	I
Pneumonia	1 [2]	II
Atrial fibrillation	2 [3]	II
Pulmonary Embolism	2 [3]	II
Contralateral pneumothorax	1 [2]	IIIA
Gastric perforation	1 [2]	IVA
Total	11 [17]	

Table 3 Post-operative pathology and TNM staging for lung cancer

Variables	N [%] (n=63)
Pathology	
Primary malignancy	33 [52]
Adenocarcinoma	22 [35]
Squamous cell carcinoma	3 [5]
Carcinoid tumor	7 [11]
Localized SCLC	1 [2]
Metastatic lesions	20 [32]
Bowel and colon cancer	12 [19]
Renal cancer	4 [6]
Breast cancer	1 [2]
Hepatocellular carcinoma	1 [2]
Endometrial carcinoma	2 [3]
Benign lesions	9 [14]
Hamartochondroma	3 [5]
Pulmonary sequestration	3 [5]
Aspergilloma	2 [3]
Bronchogenic cyst	1 [2]
Unknown	1 [2]
TNM staging for primary lung cancer	
pT1a	12 [36]
pT1b	13 [39]
pT1c	3 [9]
pT2a*	4 [12]
ypT0**	1 [3]

*, T2a staging related to visceral pleura infiltration; **, for SCLC. SCLC, small cell lung cancer.

embolisms (3%, Clavien-Dindo II). In one patient (2%) a contralateral pneumothorax occurred in the immediate post-operative time requiring a pleural drainage insertion (Clavien-Dino IIIa) while one other patient (2%) had an iatrogenic diaphragmatic puncture from trocar insertion, resulting in a gastric perforation requiring surgical reparation followed by peritonitis, leading to a prolonged hospital stay of 63 days (Clavien-Dindo IVa). There was no 30- or 90-day mortality attested. Intraoperative characteristics and post-operative complications are resumed in *Table 4*.

Discussion

At first sight, the benefit of performing a partial anatomical segmentectomy of the basal pyramid may seem unclear. However, indications are many and various: some benign conditions such as sequestrations or solitary metastases whose size and deep localization make them inaccessible to a wedge resection, typical carcinoid tumors, pure ground glass opacities and some stage I NSCLC. Handa *et al.* have recently shown that survival after complex SLR is similar to lobectomies for stage Ia NSCLC (11). In these various indications, the benefit of resecting 1 or 2 segments rather than the lower lobe or the basal pyramid allows for an optimal preservation of the respiratory function. According to Nomori et al, the whole lung function is significantly spared after segmentectomy compared to lobectomy

Table 4 Time of surgery, length of pleural drainage, intraoperative blood loss, length of hospital stay

Variables	Median	25th–75th quartiles
Duration of surgery (minutes)		
Total	168	133–213
Planned thoracoscopic CBS completed	165	130–215
Thoracoscopic extension	174	156–208
Conversion to open surgery	220	202–303
Intraoperative bleeding (mL)		
Total	30	35–150
Planned thoracoscopic CBS completed	50	20–150
Thoracoscopic extension	50	42–130
Conversion to open surgery	500	150–650
Duration of chest drainage (days)		
Total	2	1–2
Planned thoracoscopic CBS completed	2	1–2
Thoracoscopic extension	2	1–2
Conversion to open surgery	3	2–4
Duration of postoperative stay (days)		
Total	4	3–5
Planned thoracoscopic CBS	4	3–5
Thoracoscopic extension	4	3–5
Conversion to open surgery	5	4–33

CBS, complex basilar segmentectomy.

($P < 0.001$) (12). Segmentectomy spares the function of the operated lobe with 48%±21% of the preoperative function, not only because of the preservation of the parenchyma but also because it increases the function of the ipsilateral non-operated lobe. The result is optimal when the resection is limited, i.e., when only 1 or 2 segments are removed (2). The surgical complexity of the partial resections of the basal pyramid is mostly related to the numerous anatomical variations of the bronchovascular pedicle and to the pyramidal shape of the lower lobe that makes the ISP division difficult. Indeed, according to Sato *et al.* these SLR are the most complex to be performed (3).

Anatomical difficulties

From July 2015, a 3D modelization was performed to detect any anatomical variation and plan the optimal surgical strategy (*Figure 4*). During a thoracoscopic procedure, whatever the quality of vascular dissection, there is no way to apprehend the distal distribution of the segmental vessels. For example, we know that, on both sides, the distribution into a common trunk A^{9+10} with a separate A^8 artery is only valid in 90% of the cases (4). In 10% of patients, the distribution of arteries is different, with a common trunk A^{8+9} and a separate A^{10} artery, or even 4 independent arteries (13). Without a modelization, knowing which patient exhibits this anatomical variation is unpredictable. Furthermore, on the right side, the A^7 artery may be missing in about 15% of patients. An additional sub-segment, known as S*, located between segments 6 and 10, is present in 6% of cases and may cause identification concerns (4). Venous drainage may also vary. The typical distribution of the inferior pulmonary vein (IPV) into 3 main drainage branches is actually rare (14% of cases) (4). More often a V^6 vein and a common basal trunk are found or, on the contrary, an IPV receiving multiple segmental branches which are impossible to discriminate. For these several reasons, it seems almost impractical to embark on a partial basal segmentectomy without a 3D lung anatomical reconstruction. The software we are using (Visible Patient™, Strasbourg, France) allows investigating the anatomical landmarks, but also provides the useful functions such as simulation of the resection, volumetry of the segments and virtual identification of safety margins. Results and benefits of preoperative modelization have been widely reported (5,13) and it has been shown that concordance between radiological images and intraoperative findings is superior to 95% (14). Three-D printing, if available, is also an option (15,16).

Separating segments 9 and 10 from segment 6

One of the main concerns with CBS is to identify and to respect the veins draining segments 9 and 10 without injuring the V^6 vein. One way to do this is to create a tunnel following the direction of the V^6 vein (10). In this technique, the V^6 vein is approached posteriorly, at the hilum level, and then in the fissure, creating a tunnel in the avascular zone. The plane between segment 6 and segments 9 and 10 is then stapled, thus exposing the entire basal vascularization (*Figure 5*). We now use this technique on a routine basis, but

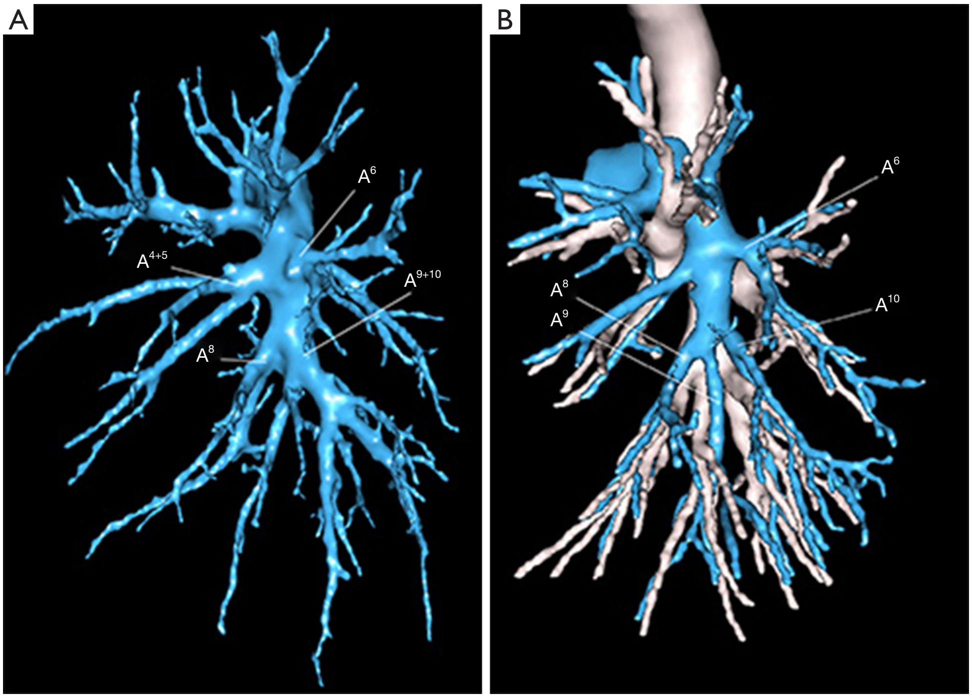

Figure 4 3D modelization of the arteries to the left basilar segments. (A) Usual pattern with a common arterial trunk A^{9+10} and separate A^8; (B) less usual pattern with a common arterial trunk A^{8+9} and separate A^9.

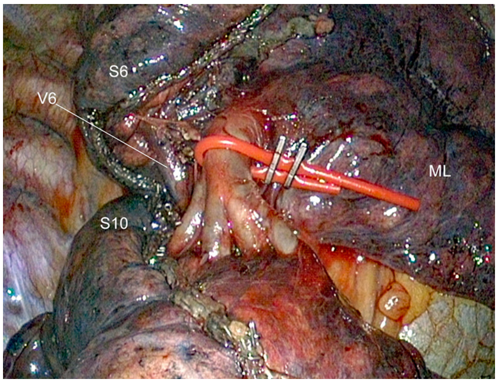

Figure 5 Exposure of basilar arteries after division of the plan between segment 6 and segments 9 and 10.

its realization is sometimes tricky, especially when the lower lobe is difficult to mobilize. Other authors have proposed a purely posterior access (3,17), retracting the V^6 vein and approaching the bronchus and the A^9 and/or A^{10} arteries from behind. As pointed out by Endoh *et al.*, this approach has however the disadvantage of precluding dissection of the intersegmental lymph nodes (17).

Management of the ISP

Intersegmental plan represents one of the most delicate issues of CBS. Unlike linear or V-shaped ISP, described by Sato *et al.* (18), the pyramidal shape of the lower lobe requires a 3D stapling. The collapse of the pulmonary parenchyma by split ventilation can lead to spatial disorientation and makes stapling even more difficult. Sato *et al.* have developed a technique named virtual-assisted lung mapping (VAL-MAP) by virtual bronchoscopy (18). The technique makes it possible to mark both the target lesion and the ISP demarcation lines by instilling indigo carmine under fluoroscopic control. Initially we used a similar technique, injecting methylene blue under ENB guidance in the whole segment to be resected or as "spots" on the ISP plane defined by the IS vein, to identify the nodule and the boundaries of the adjacent segments (5). In the long run, this technique resulted tedious and, above all, not very accurate. We replaced it with a systemic ICG marking under IRI, after division of both arteries and veins of the segment to be resected (*Figure 6*). It permits precise identification of the ISP in all directions and facilitates stapling (15). Once the plane is marked, a step-by-step

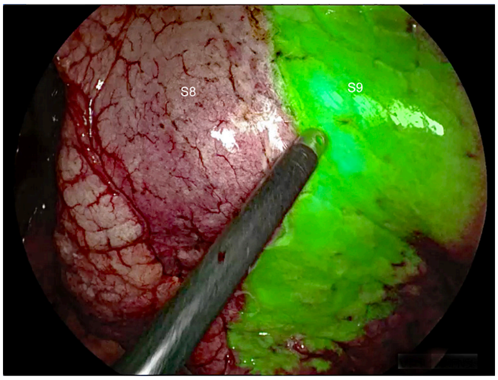

Figure 6 Delineation of the intersegmental plane by near-infrared imaging during a left S^{9+10} segmentectomy.

progression of stapling using small size reloads is advisable. That is safer and more precise than a direct stapling seeking to load the maximum amount of parenchyma with 60-mm cartridges.

Intersegmental lymph nodes analysis

The analysis of intersegmental lymph nodes during SLR is crucial. We have previously shown that intraoperative examination of these lymph nodes may lead to a surgical extension of the planned resection (19). Failure to examine these lymph nodes exposes the patient to the risk of recurrence and may explain the poorer results of some SLR series. In addition, some patients who had no intersegmental lymph node clearance can be understaged and do not benefit from an adjuvant treatment. Whitson *et al.* and, more recently, Fang *et al.* have shown that the survival after SLRs is equivalent to that after lobectomies when lymphadenectomy is accurately performed (20,21). Huang *et al.* have demonstrated that the number of harvested lymph nodes ≥6 is independently associated with improved recurrence free survival for NSCLC patients undergoing segmentectomy (22).

Safety margins analysis

In this series of CBS, an extended resection was needed in 3 patients because of positive or highly suspicious intersegmental margins at frozen section. Compared to lobectomies, CBS may have an increased risk of local recurrence compared to a basal segmentectomy or—even more—to a lower lobectomy, if resection margins are inadequately close to the lesion. Schuchert *et al.* demonstrated that for patients with a stage I NSCLC, the results of SLR were comparable to lobectomy, but recurrence was more frequent in patients with a margin/tumor ratio lower than 1 (23). The distance between the lesion and the staple line of the ISP is therefore decisive. Safety margins can be anticipated by preoperative modelization (24). On our 3D model we can add a virtual safety margin. This leads to extend the resection to the adjacent segment if the intersegmental plan seems compromised. At completion of the segmentectomy, the staple line is examined by frozen section. We know a negative safety margin is not an absolute guarantee against the risk of local recurrence as clusters of malignant cells may be ignored during the intraoperative examination, but it represents nevertheless an additional security.

Extension and conversion

Analysis of our results showed that the conversion rate to thoracotomy (6%) is slightly higher than our overall conversion rate for other thoracoscopic segmentectomies that was previously reported to be 3.1% (19). Recently, Igai *et al.* found that their conversion rate for so-called "uncommon segmentectomies" was 5.4% (25). Our extension rate raises more questions. A total of 17 patients initially planned for CBS had a larger resection (27%), either to the adjacent segment or to the entire basal segmentectomy or even lower lobectomy. One of the reasons is the need for obtaining safe margins in patients operated on for malignancy, which resulted in an extended resection in 3 patients of our series. This point is crucial to prevent local recurrence, as recently highlighted (26). Two other explanations for extension are more specific to CBS: difficulties in stapling the ISP (3 patients) and localization and finding of the target nodule (5 patients). The fact that we could not find the nodule in the firstly resected parenchyma may surprise surgeons unfamiliar with these procedures. In fact, the lack of digital palpation and the pyramidal shape of the basal segments may lead to insufficient resection when the lung is collapsed by selective ventilation. We must point out that for the 5 cases of target nodule not found on the specimen, ICG was not available, suggesting inadequate stapling of the ISP based on doubtful ISP delineation using ventilation technique. The usefulness of IRI to achieve proper oncological margins has been demonstrated by Mehta *et al.* (26).

This study reports some limitations that should be cited. Although it represents a relatively large case series in the literature, our study describes a retrospective, single-center, heterogeneous patient's population during a long-lasting analyzed period in which improvements in the surgical technique throughout the learning curve, and the adoptions of several technologies may have altered the outcomes.

In conclusion, partial segmentectomies of the basal pyramid are justified in a number of indications. Technical complexity may be reduced by the use of preoperative 3D modelling, mapping and ISP marking. Despite those aids, these interventions remain demanding. However, in our experience, morbidity is low and post-operative results are satisfactory. In patients with NSCLC, intraoperative analysis of safety margins and intersegmental lymph nodes is an oncological prerequisite and extension should be performed every time margins are insufficient or when positive intersegmental lymph node are intraoperatively confirmed (27).

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Ethical Committee for Clinical Research of the French Society for Thoracic and Cardiovascular Surgery (CERC-SFCTCV-2020-07-03---13-SEAG) and individual consent for this retrospective analysis was waived.

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