

Thoracoscopic anatomic segmentectomies for lung cancer: technical aspects

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Abstract: Although the interest for thoracoscopic sublobar resections (TSLR) is rising, its use for treating non-small cell lung carcinoma (NSCLC) is still controversial because publications dealing with survival and recurrence rate provide contradictory results. If applied to the resection of lung cancer, thoracoscopic segmentectomies must be performed according to oncological criteria. The aim of this technical paper is to give some technical details on thoracoscopic segmentectomies for the treatment of malignancies. Our experience is based on 235 thoracoscopic anatomical segmentectomies performed in 232 patients for a malignant lesion between January 2007 and July 2016. Indication for segmentectomy was a proven or suspected NSCLC in 184 and suspected metastasis in 51 patients. Intraoperative and postoperative data were recorded in a prospective manner. There were eight conversions into a posterolateral thoracotomy (3.4%) and seven unplanned additional pulmonary resections for an oncological reason (3%). We discuss some technical refinements that could minimize these adverse events and make thoracoscopic segmentectomy a safe and reliable procedure.

Keywords: Segmentectomy; sublobar resection; thoracoscopy; VATS

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Although results of trials comparing sublobar to lobar resections for lung cancer are still pending, interest for thoracoscopic sublobar resections (TSLR) is growing because of the increased incidence of clinical stage I non-small cell lung carcinoma (NSCLC) and ground glass opacities (GGO). Indeed, several studies have demonstrated that the postoperative morbidity is less after SLR than after lobectomy (1,2) and the thoracoscopic approach has a better outcome than thoracotomy, especially with regard to pulmonary complications (3,4). Some publications report a satisfactory overall survival (OS) (3,5,6) whereas other report a better OS after lobectomy (7). Until now and while waiting for the results of ongoing trials, lobectomy remains the standard

treatment (8). If applied to early stages of lung cancer, thoracoscopic segmentectomies must be performed according to some oncological principles as defined by the International Association for the Study of Lung cancer (IASLC): free resection margins proved microscopically, systematic nodal dissection or lobe-specific systematic nodal dissection, no extracapsular nodal extension of the tumor; and the highest mediastinal node removed must be negative (9). The aim of this article is to describe our technique, basing on our experience of 235 TSLR for pulmonary malignancy. We will not deal with technical details that are not directly related to cancer indication. Whatever the approach—multiple or single ports—most of the technical points hereby described should be valid.

Table 1 Types of planned segmentectomies

Planned segmentectomy	N
Right lung	
S1	1
S2	1
S1+2	41
S3	4
S6	23
S7+8	2
S8	1
S9+10	2
S7+8+9+10	23
Total	98
Left lung	
S2	1
S1+2	18
S1+2+3	39
S4+5	17
S3+4+5	2
S6	34
S8	2
S9+10	5
S8+9+10	18
S6+2	1
Total	137

Experience

From January 2007 to July 2016, 235 thoracoscopic anatomical segmentectomies have been performed in 232 patients. Indication for segmentectomy was a proven or suspected NSCLC in 184 and metastasis in 51. Patients had both oral and written information about the procedure. Intraoperative and postoperative data were recorded in a prospective manner in a database that was approved from our Institutional Review Board (CEPAR 2013-002). Four patients had two procedures, either for synchronous bilateral metastasis (three patients) or for two metachronous NSCLC (one patient). The types of segmentectomy are summarized in *Table 1*.

Segmentectomies are performed according to a previously reported technique based on a full thoracoscopic and fissure-first approach (10-12).

There was 1 intraoperative death whose case has been reported (13). In the remaining 234 surgical procedures median operation time was 150 min (range, 50-332 min).

The median estimated blood loss was 60 mL [ranged from 0 (non-measurable) to 900 mL].

There were eight conversions into a posterolateral thoracotomy (3.4%). Among these, an unplanned additional resection was performed in one patient (a S1+2 segmentectomy transformed into an upper lobectomy because of a vascular injury), while in the seven other patients; the initially planned segmentectomy was completed. One additional patient had a secondary thoracotomy at day 5 for a lingular ischemia after a trisegmentectomy.

Ten other patients had an intraoperative unplanned resection (eight lobectomy and two basilar resections) that did not require thoracotomy and another patient had a lingular ischemia after a left trisegmentectomy that required a thoracoscopic lingulectomy at D2.

With respect to the ten additional resections, seven were for oncological reasons (3%). In one patient, an intersegmental lymph node was invaded at frozen section (*Figure 1*) and in six patients the parenchymal section line was too close to the tumor to be considered as free resection margins.

Postoperative mortality rate was 0.8%. One patient died from an acute respiratory distress syndrome and a second one from acute proximal pulmonary embolism. All but 37 patients had an uneventful postoperative course (15.7%). The two cases of postoperative lingular ischemia required a reoperation for completion lingulectomy, i.e., these patients had finally a left upper lobectomy. The median drainage duration was 3 days (range, 1-13 days) and the median hospital stay was 5 days (range, 2-21 days).

Preoperative modelisation

Several teams have demonstrated the study of preoperative computed tomography (CT) three-dimensional reconstruction helps asserting the number and direction of arteries with good correlation (14-16). With the vascular pattern in mind the surgeon can perform a safer dissection of the pulmonary artery branches, especially when the fissure is fused and/or when lymph nodes are present. In the first phase of our experience, patients selected for a segmentectomy had a multidetector row preoperative CT angiography with three-dimensional volume-rendering reconstruction of arterial and venous anatomy. This method had several drawbacks: (I) it was time consuming for the radiologist; (II) there was no possibility to study the anatomy by focusing on a single element, e.g., venous or arterial pattern; and (III) the surgeon could not manipulate

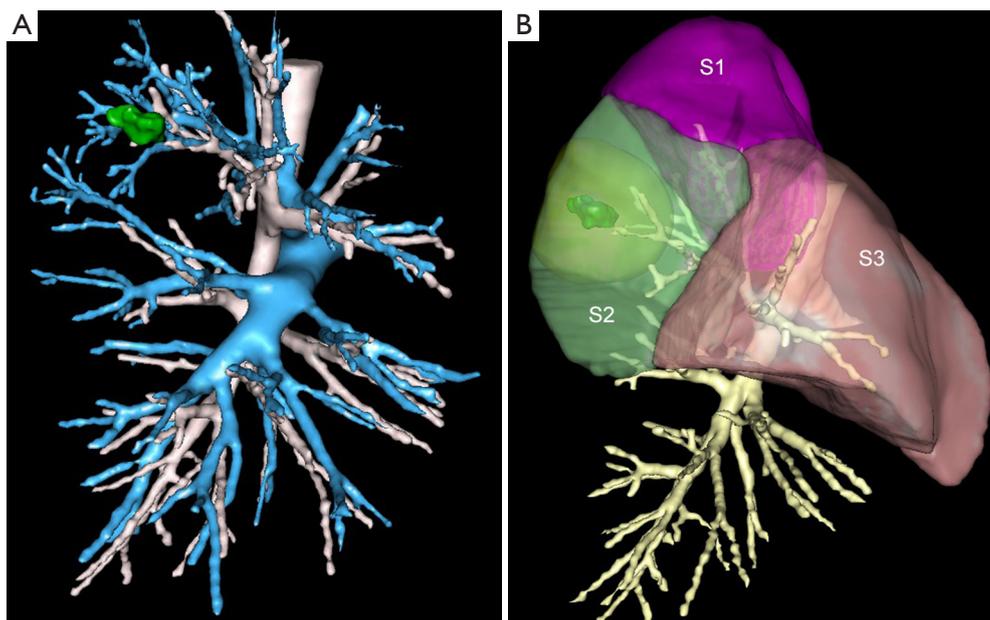


Figure 1 Right S2 segmentectomy for a cT1a lung carcinoma. (A) Preoperative modelisation of the bronchial and arterial pattern; (B) preoperative modelisation demonstrating a sufficient and safe margin (pale yellow).

the model and/or fuse broncho-vascular elements.

Currently, we use an online service that provides patient's 3D modeling from medical DICOM images (Visible Patient™, Strasbourg, France). The images are anonymized and then uploaded by the surgeon on a secured dedicated web portal. A 3D model from these images is created according to the surgeon's needs. The 3D model can be used via a Virtual Planning software and manipulated from any direction or any point of reference, either on a laptop, on a tablet or smartphone. All members of the surgical team have a direct access to the images on their own phone or tablet so that strategy and technical issues can be discussed within the group at any time. The software not only allows studying the main anatomical landmarks, in total or separately, but provides the following helpful functions:

- ❖ Display of virtual resections by clicking on a selected bronchus;
- ❖ Calculation of segment volumetry;
- ❖ Calculation and simulation of a safety margin, actually twice the larger diameter of the tumor, which is represented by a yellow halo around the tumor. This helps visualizing if the foreseen segmentectomy will respect a security margin, or if a more extended resection must be preferred.

Most patients whose renal function is compatible with an injected CT-scan have a preoperative modeling. Some

patients don't have this reconstruction, either because they cannot afford an injected CT-scan or because the surgeon is reluctant asking for an injected CT if the patient has already undergone a non-injected CT just before the operation.

Figures 1 and *2* demonstrate two situations where simulation helps choosing the appropriate treatment: *Figure 1* demonstrates a typical example where a right posterior segmentectomy has been foreseen (*Figure 1A*). Three-dimensional reconstruction shows the safety margin was widely sufficient (*Figure 1B*). *Figure 2* illustrates the case of a patient with very limited pulmonary function and comorbidities. The small nodule visible on CT was a squamous cell carcinoma, proven by percutaneous biopsy under CT guidance. On CT, this nodule looked like being located in segment S3 and an anterior segmentectomy was foreseen (*Figure 2A*). However, preoperative modelisation demonstrates the nodule was actually not in S3 but in S1 (*Figure 2B*). By adding a safety margin, it can be seen that a bisegmentectomy S3 + S1 had to be performed (*Figure 2C*). Surgery was abandoned and the patient was finally referred for stereotactic body radiation therapy (SBRT).

Instrumentation

As for thoracoscopic lobectomies, only dedicated thoracoscopic instruments are used (Delacroix-Chevalier®,

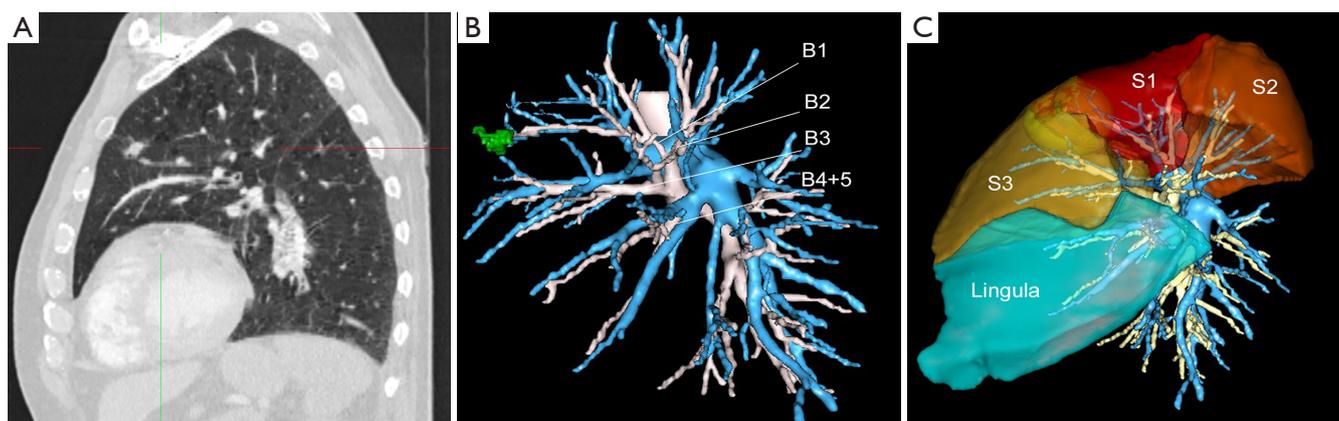


Figure 2 Planned left S3 segmentectomy for a cT1a squamous cell lung carcinoma in a patient with impaired pulmonary function. (A) CT-scan; (B) preoperative modelisation of the bronchial and arterial pattern demonstrating the nodule is actually in segment S1; (C) preoperative modelisation demonstrating an insufficient safety margin (pale yellow), requiring S1 and S3 segmentectomies. CT, computed tomography.

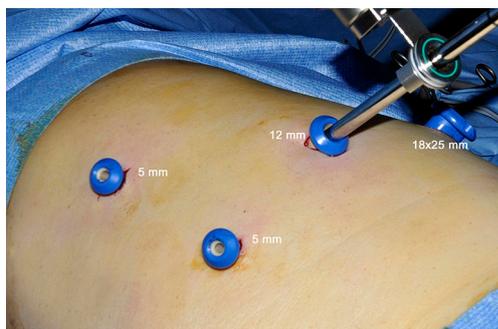


Figure 3 Usual placement of trocars for a right side segmentectomy.



Figure 4 Use of 3-legs retractor for exposure of station seven on the left side to ease lymph node dissection (17).

Available online: <http://www.asvide.com/articles/1231>

Paris, France). These are inserted through three to four trocars (*Figure 3*). Depending on the type of inserted instruments, their diameter is comprised between 3 and 25 mm. The control of large vessels is accomplished with endostaplers while hemostasis of small caliber vessels is performed with clips or with a bipolar vessel sealing device (Enseal™, Ethicon) or with a combination of both. The intersegmental plane is divided by a combination of bipolar sealing device (for its peripheral and thin portion) and stapling (for its central and thick portion) (Endo-GIA™, Medtronic). As for oncological needs, we have developed special instruments facilitating exposure of station 7 (*Figure 4*) and lymph node grasping forceps whose aim is avoiding, or at least, minimizing crushing nodes during dissection. As manual suturing of the bronchial stump can be necessary, e.g., for a tumor at the origin of a segmental bronchus (*Figure 5*), a suture kit and the corresponding skills must be available in the OR.

Imaging system

We use a deflectable scope housing a distal CCD (LTF™, Olympus®, Tokyo, Japan) connected to a high definition camera system (HDTV) (9). The new generation scopes have a heating feature that efficiently prevents fogging. In addition, we have developed a specially designed trocar that deflects blood drops from the scope's tip, so that we can keep a clear image throughout the procedure. The endoscope is held by a mechanical (Olympus SH-1) or robotized (Viky®, Endocontrol™) scope holder and the image is displayed on three monitors.



Figure 5 Example of manual division of the bronchus during a left lingula-sparing upper lobectomy for carcinoid tumor. At frozen section, the bronchial margin was not free and was then cut back (18). Available online: <http://www.asvide.com/articles/1232>



Figure 6 Example of a full thoracoscopic approach for anatomic segmentectomy. In this case, a left S9+10 segmentectomy for a ground glass opacity (19). Available online: <http://www.asvide.com/articles/1233>

General technical aspects (Figure 6)

The procedure is performed under general anesthesia with split ventilation using a double-lumen endotracheal tube. Patients are positioned in lateral decubitus as for a thoracotomy. The surgeon stands at the back of the patient for right side resections and on the front for left resections (Figure 7). For patients operated on for lung cancer, intersegmental lymph nodes are analyzed by frozen section to confirm the indication of segmentectomy (10). Demarcation between the resected and preserved segments is usually made possible by gentle reventilation and adequate application of a long 5-mm lung forceps whose position is adapted according to the inflation-deflation line. When the remaining segment is mobile and at risk of torsion, it is anchored to the adjacent lobe by stitches or by stapling using a TA endostapler. An additional radical lymphadenectomy is performed for all patients operated on for a suspicion of primary NSCLC. No utility incision is used. On completion of the segmentectomy, the specimen is wrapped into an endobag and retrieved through one of the port sites that are enlarged to a length of 2 to 4 cm, depending on the specimen size. The use of a rib spreader is never required for this task. For patients operated on for NSCLC, intraoperative pathological examination is done on the portion of the staple line facing the tumor if the latter is at less than 2 cm from the resection margin. In most cases, only one chest tube is placed through one of the port site.

Conversions

There were eight intraoperative conversions into

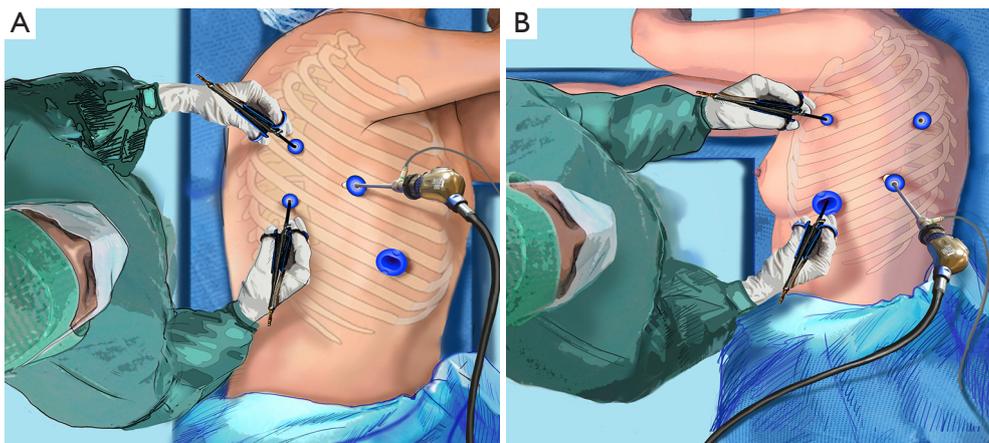


Figure 7 Patient's position and trocar location. (A) For right segmentectomies, the surgeon stands in patient back; (B) for left segmentectomies, he/she faces him.

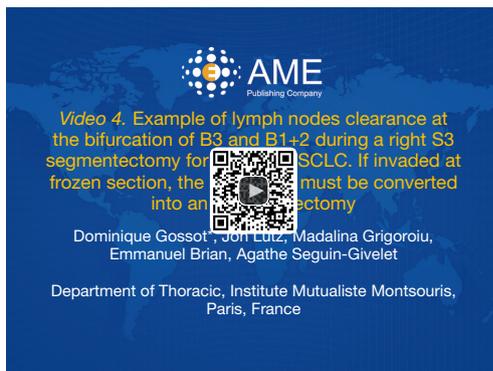


Figure 8 Example of lymph nodes clearance at the bifurcation of B3 and B1+2 during a right S3 segmentectomy for cT1aN0 NSCLC. If invaded at frozen section, the procedure must be converted into an upper lobectomy (22). NSCLC, non-small cell lung carcinoma.

Available online: <http://www.asvide.com/articles/1234>

thoracotomy in our series (3.4%). Apart of the recent study of Witte *et al.* reporting a 30% conversion rate (20), switches to thoracotomy are rare in most series, ranging from 0% to 5%. A 0% rate seems surprising and one may wonder whether there could be a bias related to a non-intention-to-treat analysis in some series.

In our series 5 out of the 8 conversions were related to a vascular (n=4) or parenchymal injury (n=1). There was only one conversion for oncological reason in which the nodule could not be found during the exploration step, leading to a manual palpation by thoracotomy. This stresses the importance of a preoperative localization technique or a preoperative biopsy, whatever the method (hook wire or dye marking under CT scan guidance or endobronchial electronavigation).

Margins

Compared to lobectomies, SLR comprise an increased risk of local recurrence as resection margins tend being closer to the tumor. Schuchert *et al.* have clearly demonstrated that segmentectomies outcomes compare favorably with lobectomy for stage I NSCLC but that margin/tumor ratios of less than one are associated with a higher rate of recurrence (21). When the margin/tumor diameter ratios exceeded one, it was associated with a significant reduction in recurrence rates compared with ratios of less than 1 (25.0% *vs.* 6.2%; $P=0.0014$). In their study, the rate of local recurrence was 7.7% and was correlated in most cases with

a tumor margin less than 2 cm. In our series, the margin was insufficient in six patients leading to extend the segmentectomy to the adjacent segment or to the lobe. It should be noticed that a borderline margin sometimes came as a surprise to the surgeon who thought section was widely distant from the tumor. Preoperative modeling can help making decision and plan the adequate TSLR. On the Visible Patient™ software, preoperative visualization of the safety margin can help avoiding several unplanned extensive resections.

Lymph nodes

As shown on *Figure 8*, lymph nodes are frequently encountered at the origin of a segmental bronchus. These nodes must be cleared and analyzed during the procedure. Would the nodes be invaded at frozen section, the procedure should be transformed into a lobectomy. There are consistent data in the literature suggesting intersegmental lymph node clearance to be of major importance during thoracoscopic segmentectomies (8,23). Wolf *et al.* have demonstrated that in small NSCLC, lobectomy was associated with longer overall and recurrence-free survival. Sublobar resections were associated with an increased rate of local recurrence (16% *vs.* 8%, $P=0.1117$). However, when lymph nodes were sampled during segmentectomy, local recurrence rate and overall and recurrence-free survival distributions were similar to those for lobectomy (23). In the beginning of our experience, we were clearing all intersegmental lymph nodes but asked for frozen section only when these looked suspicious. However, since we have discovered neoplastic cells in small intersegmental lymph nodes that looked macroscopically benign, we now always ask for an intraoperative pathological analysis. Swanson has suggested checking a representative intersegmental or “sump” node and convert to a lobectomy if the latter is positive (24). However deciding which one is the sump node—which besides can be negative on Pet-scan—is not obvious and could be a research topic aiming at determining a sentinel node (25). At that time we do prefer analyzing all intersegmental lymph nodes during the procedure.

Localization error

In one patient, the nodule could not be localized and a thoracotomy was necessary for digital palpation. This is not a specific issue of SLR as such a failure can be faced during any video-assisted procedure. In this patient, a preoperative localization technique could have avoided a

thoracotomy. However, marking the nodule is only helpful if the target is not too far away from the pleural surface. Marking can be done either with methylene blue labeling or by a hook-wire placement under CT-scan guidance or can be bronchoscopically achieved (26) depending on surgeon's preference and available technology. But, for all deeply located nodules, preoperative marking does not help much because it does not ease resection which is limited by the tissue thickness and insufficient safety margin. In these situations a primary anatomical segmentectomy can be a better option than a wedge resection, provided the target nodule is in the resected segment.

The three other localization errors raise more concerns. Despite the use of a preoperative modelisation of bronchovascular structures in 2 of these 3 patients, the target nodule was not found on the specimen and forced us to extend the resection to the adjacent segment. To our knowledge, this issue has not yet been reported. However surgeons experienced with TSLR are aware of this mistake (26). Even though the target nodule is localized on preoperative mapping and the anatomy is reconstructed, spatial disorientation during the procedure is possible because the lung collapse induces changes in landmarks. This is particularly valid for basilar segments in which stapling does not follow a 2-dimensional pattern but a 3-dimensional one. In these cases, determining the precise boundaries of the segments to be resected is essential. This can be achieved by the so-called virtual assisted lung mapping described by Sato *et al.* (26) where a multispot dye-marking via bronchoscopy is used for determination of the resections margins. The alternate method consists in the coloration of the whole segment(s) to be resected by intrabronchial injection of methylene blue (27) or indocyanine green (ICG) (28) or systemic injection of ICG using a near infrared imaging system (29). All these methods have their advantages and shortcomings. Finding the best compromise should be one of our priorities in the forthcoming years.

Conclusions

Even though the study of registers and ongoing trials may come to the conclusion that lobar resections have a slightly better OS than sublobar resections, the fact remains that (I) many of our patients cannot afford a lobectomy, especially those who have already undergone a lobectomy for a previous lung cancer; (II) many GGO and metastasis cannot be satisfactory treated by a mere wedge resection and require an anatomic segmentectomy. As it is now clear that

a segmentectomy has a much better outcome when done by thoracoscopy rather than by thoracotomy (4), we have to do our best make TSLR a precise, safe and oncological procedure that competes favorably with alternate and less satisfactory treatments such as SBRT or radiofrequency. This is one of the challenges of the forthcoming years that will require not only technical skills but also the use of outstanding technologies such as modelisation, preoperative planning and mapping.

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Footnote

Conflicts of Interest: One of the authors (DG) is consultant for an instrument manufacturer (Delacroix Chevalier). The other authors have no conflict of interest to declare.

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