How to identify intersegmental planes in performing sublobar anatomical resections

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Abstract: Pulmonary segmentectomy is a common surgical procedure in thoracic surgery nowadays. Though this technique helps preventing postoperative pulmonary function loss, potential challenges are the management of air leaks and the difficulty of palpating ground-glass components during surgery, as well as how to deal with the intersegmental planes. Several techniques have been proposed for the identification and treatment of the intersegmental planes during sublobar anatomical resections: this review focuses on preoperative planning and workup and intraoperative strategies. Three-dimensional computed tomography bronchography and angiography (3D-CTBA), virtual-assisted mapping (VAL-MAP) using bronchoscopy multi-spot dye marking and three-dimensional computed tomography (3D-CT) are preoperative tools that may facilitate the planning of operation. Inflation-deflation techniques, infrared-fluorescence-enhanced method combined with bronchial and intravenous injection of indocyanine green (ICG) and near-infrared fluorescence (NIF) mapping with ICG have been described as intraoperative strategies to identify the intersegmental plane. The treatment and section of the intersegmental planes is mainly accomplished by stapler and electrocautery or energy devices. The use of staplers reduces postoperative air leaks, bleeding risks and operative time but seems to reduce preserved lung volume, compromising adjacent lung expansion; in addition, higher costs and sometimes non-adequate oncological margins, being a non-anatomical technique have been described. The electrocautery and energy devices allow for a more anatomical and precise dissection maintaining safe oncological margins, with a better lung expansion and so an increased postoperative lung function. Time consuming procedure and frequent requirement of aero-haemostatic tools to treat air and blood leaks are the main drawbacks. In conclusion, there are several methods to identify and treat the intersegmental planes but there are no significant differences between the different tools, therefore the use of one technique rather than another depends overall on surgeon's preference and the location of the segment.

Keywords: Pulmonary segmentectomy; intersegmental planes; lung cancer; identification and treatment

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Introduction

Pulmonary segmentectomy has become a common surgical procedure in thoracic surgery nowadays. Some studies comparing lung segmentectomies and lobectomies for treatment of stage IA non-small cell lung cancer (NSCLC) have showed similar outcomes, especially for small tumour nodules located in the central area of a segment (1). Segmentectomy can achieve an adequate surgical margin for a cT1N0M0 NSCLC located at the central area of the pulmonary segment, including ground-glass nodules (GGNs), nevertheless the major challenge is to identify targeted segmental bronchus, intrasegmental and intersegmental veins and artery, in order to guarantee an adequate anatomical resection. Moreover, although the intersegmental plane near the hilum is regulated by intersegmental veins, it would be impossible to detect and follow these veins in the distal lung parenchyma; therefore, it is mandatory to identify the intersegmental plane before dividing the lung parenchyma.

In the years several techniques have been proposed for the identification and treatment of the intersegmental planes during sublobar anatomical resections, but why the precise identification and dissection of intersegmental plane is so important?

(I) To obtain the best oncological results accomplishing a real anatomical resection: the study of Ginsberg *et al.* (2) has demonstrated that a higher loco regional recurrence rate is associated with non-anatomical resection with limited disease-free margins;

(II) To preserve pulmonary function: reducing the resected lung volume has several advantages such as reducing the postoperative risks of mortality and complications in high-risk patients and enhancing the possibility of further resections in the case of a second primary lung cancer. Compared to lobectomy, the mean decrease in forced expiratory volume in 1 s (FEV1) is low, ranging from –9% to –24% of the initial value within 2 months and from –3% to 13% 12 months after segmentectomy (3);

(III) To avoid complications such as air leakage, residual pneumothorax or pulmonary atelectasis.

The aim of this review article is to focus on the preoperative planning and workup and on the intraoperative strategies used to accomplish anatomical segmentectomy.

How to identify the intersegmental plane?

Preoperative workup and planning

Some studies have suggested the use of three-dimensional computed tomography bronchography and angiography (3D-CTBA), to guide the preoperative anatomical identification of the lung structures (4). This simulation allows the precise dissection of the segment under unilateral ventilation.

Wang and colleagues reported a new technique for tailoring complex demarcation. They used a preoperative 3D-CTBA to target the nodule, and then they performed a sharp-blunt combined dissection that included three steps: excavating the "work-plane" by grasping and lifting stumps, opening the "gate" by firing two shots with staples and finally tailoring the residual border under the guidance of the intersegmental vein (5).

Another interesting technique is the virtual-assisted mapping (VAL-MAP) (6). This new procedure allows, using bronchoscopy multi-spot dye marking, to obtain "geometric information" on the lung surface that is processed by three-dimensional computed tomography (3D-CT). Creating a map of the lung surface helps surgeons to follow a pre-marked ideal resection line, minimizing the resected parenchyma; besides, it enables surgeons to perform an appropriate stapling technique avoiding complications such as air leakage, especially during the most challenging segmentectomies. This procedure is theoretically safer than others that have been proposed in the past years, because the use of bronchoscope to place a marking, such as microcoil or dye, it may limit complications, including pneumothorax, air embolism, and the displacement of hook wires; moreover, it is not limited by the anatomy of the lung, because location of percutaneous marking in the apex, interlobar fissure and areas facing the diaphragm and mediastinum are treacherous.

VAL-MAP is a procedure composed by several steps: (I) design the lung map and determine multiple target bronchi, using virtual bronchoscopy based on CT images (enhanced CT to visualize hilar vessels, but plain CT is sufficient for VAL-MAP); (II) insertion of a bronchoscope after sedation, using the virtual images acquired; (III) insertion of metal-tips catheters in each target bronchus; (IV) injection of dye, confirming the location under fluoroscopy.

Intraoperative management

The most common way to intraoperatively identify the intersegmental plane uses a conventional ventilation method (inflation/deflation technique): the targeted segment may be isolated from the rest of the lobe by selectively inflating the residual segments leaving the target segment atelectatic or, on the contrary may be selectively inflated leaving the rest of the lobe atelectatic.

In the first case, the bronchus resected by stapler or clamped, during the recruitment remains collapsed while the preserved parenchyma is inflated, in this manner the division plane can be easily followed and dissected. One potential limitation is the limited space of manoeuvre in case of video-assisted surgery in small chest cavities where the vision may be difficult due to the inflated lung. Furthermore, if the collateral ventilation via the pores of Kohn, the canals of Lambert and the direct airways anastomosis is present, a complete atelectasis of the segment is more difficult to obtain. Finally, this method to visualize the inflation-deflation line may leave short distance between the tumour and the intersegmental plane potentially reducing the disease-free margin (7).

The resected segments inflation (RSI) method provides the bronchus isolation and encirclement with a non-absorbable suture (slip knot technique). The slip knot is not initially tightened and the lung is ventilated; when the segment is inflated properly the slip knot is tightened, the rest of the lobe is progressively deflated (in about 8 minutes) and then the bronchus is ligated, in this manner the segment remains inflated and the intersegmental plane may be followed and dissected by using electrocautery or stapler (6,7) (*Video 1*).

Alternatively, a continuous inflation of the target segment may be applied to allow intersegmental plane dissection; for that several methods have been reported to selectively inflate the segment, including the ventilation through a butterfly needle directly inserted into the segmental bronchus and jet ventilation. The first technique was suggested by Soultanis *et al.* (8), and the main advantage is the avoidance of collateral ventilation with the result of a good demarcation. Trough the insertion in the affected segment bronchus of a central venous catheter connected with a 60-mL luer-slip syringe, they inflate air until the demarcation between the segments is visible.

Jet ventilation is another excellent option, because it is selectively applied to the target bronchus to identify the anatomic plane between the segments. Bronchoscopy is required, a small bronchoscope is introduced through the double lumen endotracheal tube, and it is lead to the suitable place of the targeted bronchus by the surgeon that is able to see the light of the tip, from the surgical field. Only the affected segment is inflated, evidencing the anatomic intersegmental plane, then the bronchus is tied to keep the segment inflated (9). It is a great advantage to precisely determine the real margin distance between the tumour and the resection border provided in an inflated diseased segment. Additionally, by limiting the expansion to only the selected segment, not to the entire lobe, you may obtain an appropriate wide surgical field in this era of video-assisted thoracoscopic surgery (VATS).

Alternatively, the infrared-fluorescence-enhanced method combined with bronchial or intravenous injection of indocyanine green (ICG) has been proposed (10).

The bronchial injection is preferable to the intravenous, because the dye has a faster metabolism that is performed by the liver via the bronchial venous circulation. However, there are potential problems related to the bronchial injection, such as the possibility that the dye could flow back from the target bronchus, spreading into the bronchial tree and compromising the identification of the intersegmental plane. Besides, the injection into the infiltrated bronchus could contribute the neoplastic cell spread. On the other hand, the distribution of the ICG is not uniform in emphysematous tissues between the upper and the lower lobe, and it might be toxic, eliciting mucosal inflammation and epithelial injury. For this reason, Elkhouly and colleagues suggested a 10% dilution of ICG and no side effects were reported (10-12).

The intravenous injection implies more time to allow a uniform distribution and systemic diffusion of the dye, but it is possible to prevent this problem by tiding the segmental vein to avoid loss of ICG (11).

An innovative technique is the near-infrared fluorescence (NIF) mapping with ICG, performed by isolating the target segment with ligation of the bronchus, vein and artery and then injecting ICG into a peripheral vein, thus it perfuses all the parenchyma except for the isolated segment. This could be settled using a thoracoscope with NIF light source, providing a clear view of the intersegmental plane. This procedure is particularly used on the robotic platform, and helps to increase the oncological margin distance from the tumour to the staple line. By the way, this procedure has not been validated and objectively evaluated in a large prospective scale study yet, but the preliminary results are very encouraging (12).

How to treat and separate the intersegmental plane?

Division of the intersegmental plane is one of the most important practical issues for lung segmentectomy being responsible for the results in terms of functional lung preservation, adequate tumour margins (oncological safety and effectiveness) and prevention/avoidance of complications.

In literature are described three ways to separate the intersegmental plane: the use of staplers, electrocautery or energy devices or both of them in a combined method.

Some surgeons prefer electrocautery or energy devices for dividing the plane, while others prefer to use a stapler, however more than on personal preference it should be based on clinical characteristics of the patients, quality of the lung parenchyma (e.g., emphysematous or fibrotic lung), location of the tumour, type of segment and surgical access (open or mininvasive). All these factors are directly related with the risk of postoperative complications, amount of postoperative pulmonary function loss, local control of lung cancer and prognosis.

The use of staplers for intersegmental plane resection has some potential advantages such as the reduction of air leaks and bleeding risks and the shortening of operative time.

Potential drawbacks are: (I) difficult application for resection of some small segments like basilar segments, (II) non-anatomical technique, (III) higher costs, (IV) risk of non-adequate oncological margins and, (V) less capacity to preserve lung volume by compromising adjacent pulmonary parenchyma with a reduced lung expansion and an increased loss of postoperative lung function. As described by Sato *et al.* (4) depending on the anatomy and location, segmentectomy accomplished by stapler technique can be divided in three types: linear, the easiest one, (lingular, S6, S2, right S3), V- or U-shaped (right S1, left S3, S2b + S3a) and three dimensional, the most challenging and complex group of segmentectomies (S7, S8, S9, S10), so virtually every segment may be approached by a stapler technique.

The use of electrocautery or energy devices has, on its side, some potential advantages: it allows a more anatomical and precise dissection, with safer oncological margins, a potentially better lung expansion and increased postoperative lung function, and a good preservation of the shape of residual segments, especially in complicated-type segmentectomy.

Potential drawbacks are: (I) time-consuming technique, (II) increased air leaks and bleeding risks, (III) frequent need for aero-haemostatic tools and, (IV) more difficult application by VATS due to less space and poor bleeding control.

Matsumoto *et al.* and Liu *et al.* (13,14) found that stapling is a faster method leading to a significant surgical time savings, but according to the study of Miyasaka *et al.* (15) electrocautery showed to be faster.

Stapling technique is a fast and easy method to divide the intersegmental planes and it is superior in controlling bleeding and preventing postoperative air leaks, but it is thought to be inferior in terms of preserving lung volume and in achieving adequate tumour margin compared with precision dissection by electrocautery (7,10). Asakura *et al.* (16), in their study on *ex vivo* pig lungs, reported that the stapler method decreased the volume of the preserved segment significantly more than the scissors or combined method in large regional segmentectomy such as left upper division or basal segmentectomy. Decrease in the lung volume by the stapler method in comparison to the scissors or combined method should be due to the findings that the lung tissue including visceral pleura was caught in a stapler line, causing partial atelectasis. In this work however, a polyglycolic acid (PGA) mesh and fibrin glue was also used to prevent postoperative air leakage from the opened intersegmental plane in the non-stapler group. PGA mesh is a soft and thin (0.15 mm in thickness) absorbable material, which, together with fibrin glue, makes it possible to block air leakage from the peripheral lung tissue without significant interference with lung expansion because of excellent elasticity of both materials.

Tao *et al.* (17) however, in a recent study found that stapler use, alone, did not reduce volume and functional preservation compared to electrocautery alone or to mixed use of electrocautery and stapler. They also found that functional preservation was not correlated with preserved segmental volume but with total volume of ipsilateral lung. So, the ipsilateral unaffected lobe plays an important role in postoperative functional reserve, possibly by compensatory restoration of residual lung. To date, no clear difference was found in the majority of the studies in term of residual short- and long-term pulmonary function based on different technique to separate the intersegmental plane (15,18).

Okada and colleagues (9) strongly recommended dissection of the intersegmental plane by electrocautery, because in their opinion it offers some advantages over that by stapler: not only can the surgeon extirpate deep-seated tumours or tumours existing in locations where a stapler cannot be applied, but the surgeon can freely cut the lung parenchyma to have a sufficient margin, which does not necessarily require afterward checking for residual tumour cells on the cutting planes. When any stapler is used, the surgical margin could possibly be more reduced than expected and thus should be investigated. In addition, the application of stapling devices can often compromise adjacent pulmonary parenchyma, restricting full expansion of the residual segments and thus pulmonary function, a major goal of segmental resection. They suggested electrocautery resection in particular after jet ventilation, using fibrin sealant to prevent air leakage. However, the use of stapler may be advantageous in patients with emphysema for stringent control of air leak. Ohtsuka *et al.* (18) confirmed that pleural suture-closure of residual segments in electrocautery method may be useful to prevent delayed air leakage. Despite a slight significant number of cases with prolonged air leaks in the cautery group, they showed no difference in duration of chest tube placement, bleeding and hospital stay between the cautery and stapler groups. Interestingly, Matsumoto *et al.* (13) in a recent study, found a significant number of delayed air leaks in the electrocautery group suggesting a pleural closure of the intersegmental plane by direct suture of the pleural edges with stitches or stapler or with coverage by PGA mesh and fibrin glue as suggested by Yoshimoto *et al.* (19). Saito *et al.* (20) compared postoperative pulmonary function and complications between mesh cover and pleural suture groups. They found the use of pleural covering or suturing as the only independent factor reducing pulmonary complications such as prolonged or delayed air leaks after segmentectomy. They stated that pleural suture or mesh-cover of the intersegmental plane during pulmonary segmentectomy seems to be an effective method.

The oncological safety of the different methods for dividing the intersegmental plane has not been extensively evaluated, yet. Only one study (13) found a significant better overall survival in favour of cautery group compared with the stapler one, however this difference did not reach significance when disease-free survival was evaluated. The authors attributed the difference in survival to a selection bias with other clinical factors affecting the prognosis.

In a study published in 2011 by Horinouchi *et al.* approximately 30% of cT1N0M0 NSCLCs extends beyond one segment. In this case a simple segmentectomy cannot provide an adequate dissection and it is necessary a combined subsegmentectomy (CSS) to treat intersegmental nodules (21). This method was designed by Wei-Bing and colleagues and the inclusion criteria for CSS was a pulmonary intersegmental nodule ≤2 cm with a ≥50% ground glass opacity appearance at CT; furthermore, the procedure should achieve resection margins ≥2 cm or ≥ the size of the nodule. The intersubsegmental veins belonging to the adjacent segments were preserved to mark the border. This technique is considered preferable to wedge resection because it could guarantee anatomical and radical resection (22,23).

Conclusions

Pulmonary segmentectomy is an anatomic parenchyma-sparing resection that is recently being performed for small size lung carcinoma and constitutes a useful procedure in a thoracic surgeon's armamentarium. There are several methods to identify and treat the intersegmental planes but there are no significant differences between the different tools. The use of one technique rather than another depends overall on surgeon's preference, location of the segment and clinical characteristics of the patient.

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