

Original
Article

Conventional Multi-Planar Reconstruction Imaging Is Insufficient to Determine the Indication for Segmentectomy

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Purpose: The diagnostic potential of conventional multi-planar reconstruction (MPR) images, which consist of horizontal, frontal, and sagittal section, in approximating the anatomical distance between tumors and intersegmental planes remains unclear. The aim of the present study was to clarify the validity of decision-making for segmentectomy based on MPR imaging and identify a specific tumor location that is likely to result in the overestimation of the anatomical margin on MPR images.

Methods: The study population included 33 patients who were considered eligible for segmentectomy based on the observation of MPR images, and verified using a commercially available image-analysis software whether the decision-making based on MPR images was indeed correct or not.

Results: MPR image-based assessment resulted in the overestimation of the anatomical margin in as many as 8 (24%) of the 33 patients. Overestimation predominantly occurred in cases involving patients with tumors at certain segments (right S1, right S2, right S3, left S3, and left S4) that had a complex and oblique intersegmental plane.

Conclusion: Conventional MPR image-based assessment frequently resulted in the overestimation of the anatomical margin. We recommend using software-based assessment preoperatively in patients with tumors in the risky segments, particularly in cases involving indistinct tumors.

Keywords: lung cancer, segmentectomy, surgical margin, computer simulation

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Introduction

Lobectomy has been the standard radical operative procedure for primary lung cancer since Cahan reported on radical lobectomy in 1960.¹ However, the use of low-dose computed tomography (CT) in lung cancer detection has led to a remarkable increase in the detection of early lung cancer.² Despite a lack of evidence to support lung segmentectomy for primary lung cancer, segmentectomy is widely performed for patients who seem to have less aggressive diseases, such as minimally invasive adenocarcinoma.^{3,4} Segmentectomy is also an important

option for small metastatic lung tumors. However, it is well known that an insufficient surgical margin is likely to result in positive stump cytology, leading to local recurrence.⁵⁾ Thus, during tumor excision using an endostapler, securing a surgical margin of at least 2 cm is recommended for tumors of >2 cm in size. Otherwise, the surgical margin that is secured should be greater than the corresponding tumor diameter.^{3,4)} Unfortunately, it is often difficult to certify the surgical margin during thoracoscopic operations for tumors located deeply, particularly if tumors that possess a lepidic growth pattern. Thus, preoperative confirmation of the anatomical margin (the length between the tumor and the intersegmental plane on preoperative CT) is mandatory to determine the indication for segmentectomy. The indication for segmentectomy has been evaluated by conventional multi-planar reconstruction (MPR) images, which consist of horizontal, frontal, and sagittal sections. However, the length between the tumor and intersegmental plane cannot always be measured on MPR images because the intersegmental plane in these images is often located at an oblique angle. To solve this issue, we used a commercially available imaging analysis software program that enables the almost automatic measurement of the distance between the tumor and the intersegmental plane. In the present study, we subjected patients who were considered eligible for segmentectomy based on the observation of MPR images, and verified whether or not decisions made based on the observation of MPR images were correct. The aim of the present study was to clarify the validity of decision-making for segmentectomy based on the observation of MPR images and to identify specific tumor locations in which decision-making based on MPR images would likely result in the overestimation of the anatomical margin.

Patients and methods

Patients

This was a retrospective study involving 33 patients who were considered eligible for anatomical segmentectomy based on preoperative CT. These patients were recruited between April 2012 and February 2014. This study was approved by our institutional review board. The anatomical eligibility criteria for segmentectomy in our institute were as follows: (1) patients with T1aN0M0 primary lung cancer, a ground-glass component of <20 mm, and tumor center located in the outer one-third of the lung field, (2) patients with metastatic lung tumors for

which wedge resection was considered difficult, and (3) patients with an anatomical margin of at least 2 cm between the tumor and the intersegmental plane for cases involving tumors of >2 cm in size, or an anatomical margin wider than the tumor diameter. Eligibility was independently evaluated on horizontal, frontal, and sagittal section images by two general thoracic surgeons, then the software-based simulation results were obtained. In the event of inter-observer discord, the two surgeons discussed the findings until consensus was achieved.

CT

Helical CT scans were obtained using 64-detector (Somatom Definition or Sensation 64; Siemens Erlangen, Germany) row CT scanners. With the patient in the supine position, we obtained 1-mm high-resolution CT images of the entire lungs during a deep inspiratory breath hold. We used a 512 × 512 matrix, 2-mm collimation, and a scan time of 1.0 s, at 120–130 kVp and 220–230 mA. Contrast media was used to enhance pulmonary vasculature. Three-dimensional (3D) volume rendering images of the bronchus, pulmonary vein, and artery were created using a commercially available simulation software program (Fuji, SYNAPSE VINCENT, Tokyo, Japan). With this software, the distance between a tumor and any intended segmental plane can be readily obtained. However, because the intersegmental plane is determined by the distribution of the pulmonary artery, vein, and bronchus, we must verify whether the segmental artery, vein, and bronchus are correctly recognized by the software program. Incorrectly recognized bronchovascular branches must be revised manually.

Verification of MPR-based evaluation

The helical CT data of the eligible patients were then analyzed by the imaging reconstruction software program, as mentioned above. After ensuring the branching pattern of the pulmonary bronchovascularity, we determined whether or not the obtained anatomical margin met our predefined criteria. We calculated the overall incidence of overestimation of the anatomical margin on MPR imaging. We also investigated the types of segmentectomy that were likely to result in overestimation.

Statistical analysis

The incidence of overestimation by the MPR-based analysis was compared between the groups using a chi-squared test. P values of <0.05 were considered to indicate statistical significance.

Table 1 Patient characteristics (n = 33)

Variables		
Age (year)	Mean (range)	63.8 (17–84)
Gender	Male/female	13/20
Tumor size (mm)	Mean (range)	15.8 (7–28)
Histology	Primary lung cancer	29
	Metastatic lung tumor	4
	Colonic cancer	1
	Rectal cancer	1
	Rhabdomyosarcoma	1
	Osteoclastoma	1
Tumor location	Right upper lobe	9
	Right lower lobe	9
	Left upper lobe	12
	Left lower lobe	3

Table 2 Proposed operation and the incidence of insufficient anatomical margin

Proposed operation		N	Insufficient margin (%)	MPR-based margin (cm)→Software-based margin (cm), Final surgical procedure	
Right	S1	4	2 (50%)	1.5→1.3, Wide wedge resection 1.7→1.1, Upper lobectomy	
	S2	3	1 (33%)	1.7→1.0, S2+S1a resection	
	S3	3	1 (33%)	1.6→1.1, Wide wedge resection	
	S6	1	0 (0%)		
	S7	0	0 (0%)		
	S8	3	1 (33%)	1.3→0.9, S6b+S8a+S9a resection	
	S9	3	0 (0%)		
	S10	2	0 (0%)		
	Left	S1+2	4	0 (0%)	
		S3	4	2 (50%)	1.8→1.0, S3+S1+2 resection 2.0→1.2, upper lobectomy*
S4		3	1 (33%)	1.6→1.0, S3ab+S4+S5 resection	
S5		0	0 (0%)		
S6		1	0 (0%)		
S8		1	0 (0%)		
S9		1	0 (0%)		
S10		0	0 (0%)		
Total			33	8 (24%)	

*Converted from S1+2+S3a resection to lobectomy due to insufficient surgical margin. MPR: multi-planar reconstruction

Results

Characteristic variables are shown in **Table 1**. The study population included 33 patients (female, n = 20; male, n = 13; mean age, 63.8 years (range, 17–84 years)). The mean tumor diameter on thin-section CT was 15.8 mm (range, 7–28 mm). The presumed radiologic pathology of the tumor was primary lung cancer in 29 cases and metastatic lung tumor in 4 cases.

Based on the assessment of the anatomical margin on preoperative MPR images, various segmentectomy procedures were planned in the 33 patients (**Table 2**). However,

according to the software-based assessment, eight patients (24%) appeared to have an insufficient anatomical margin that did not meet the predefined criteria (**Table 2**). When the incidence of insufficient anatomical margin was calculated in each affected lobe, the incidence was highest in the right upper lobe (4 of 10 patients, 40%), followed by the left upper lobe (3 of 11 patients, 27%), right lower lobe (1 of 9 patients, 11%), and left lower lobe (0 of 3 patients, 0%). Thus, seven of the 21 (33%) patients with right or left upper lobe lesions appeared to have an insufficient margin, while one of the 12 (8%) patients with a right or left lower lobe lesion appeared to have an insufficient margin (P = 0.107)

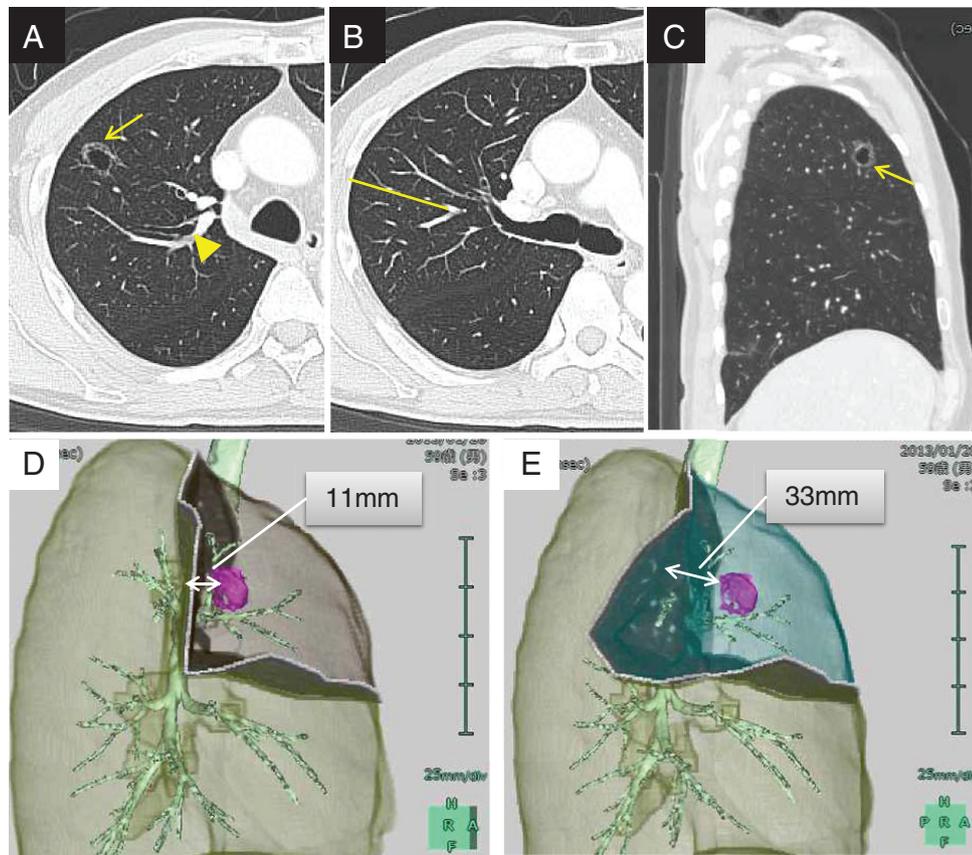


Fig. 1 representative case with minimally invasive adenocarcinoma, 1.6 cm in diameter, in the right upper lobe S3 (axial section; AB, sagittal section; C) undergoing software-based measurement of the distance between the tumor and intersegmental plane (D, E). On MPR images (A, B, C), the tumor appeared to be a barely enough distance (more than 1.6 cm) from the S2; however, the distance was found to be only 1.1 cm in the computer simulation (D). To secure a required anatomical margin, additional resection of S2b was needed (E). Arrow; primary lesion, Allow head; B2+BX1a, Solid line; V2c (intersegmental vein between S3a and S2b). MPR: multi-planar reconstruction

Table 3 Incidence of insufficient anatomical margin according to the affected lobe or the type of intersegmental plane

Group	N	Insufficient margin (%)	P*
Affected lobe			
Upper lobe	21	7 (33%)	0.0193
Lower lobe	12	1 (8%)	
Type of intersegmental plane			
Complicated	17	7 (41%)	0.107
Non-complicated	16	1 (6%)	

* χ^2 test.

(Table 3). No patients with a tumor in a segment with only one intersegmental plane (e.g., S6 and S1+2) had an insufficient margin. Figure 1 shows the representative case with

minimally invasive adenocarcinoma, 1.6 cm in diameter, in the right upper lobe S3 undergoing software-based measurement of the distance between the tumor and the intersegmental plane. Although MPR images appeared to show that the tumor in the S3 was located a barely enough distance (more than 1.6 cm) from the neighboring segment S2, the actual anatomical margin was found to be too short (1.1 cm). Additional resection of S2b was found to be sufficient to secure the necessary anatomical margin.

The comparison of MPR images to the 3D volume rendering images revealed several important findings. For instance, there were three intersegmental planes in the right upper lobe, and all the planes were located at a diagonal angle (Fig. 2A). In other words, the planes were not parallel to horizontal, coronal, or sagittal anatomic planes in the conventional MPR images, and thus, it was

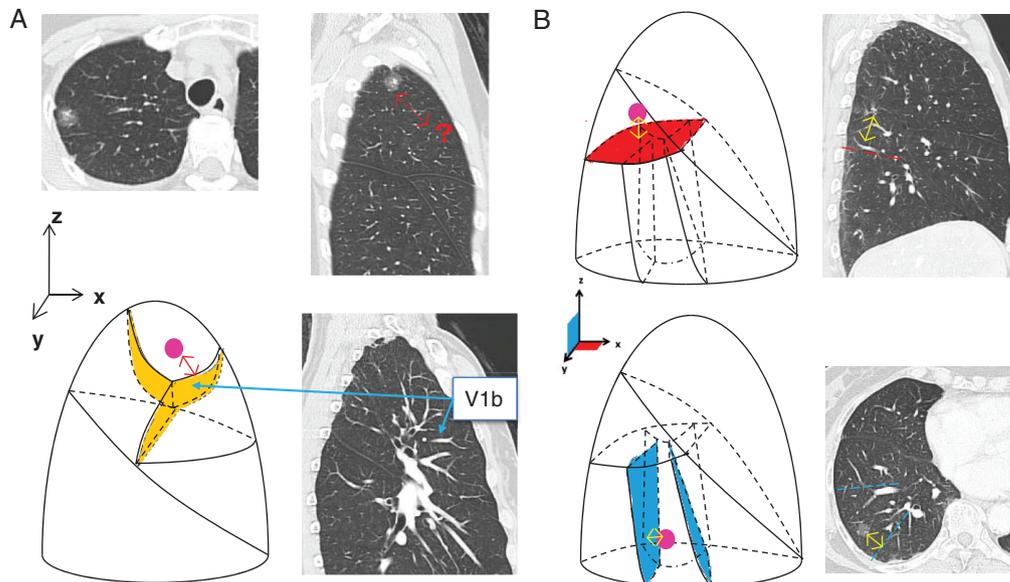


Fig. 2 The intersegmental planes in relation to the three-dimensional axis (horizontal, vertical, and longitudinal) in the right lung. The segmental planes of the upper lobe (S1/S2, S1/3, S2/3, S1+2/S3), as depicted in yellow, are all diagonal to the respective axis. They are not parallel to the horizontal, coronal, or sagittal anatomic planes in conventional MPR images; thus, it is difficult to obtain accurate images of intersegmental planes on MPR images (A). For instance, it is difficult to measure anatomical margin between right upper lobe tumor and the intersegmental plane consisting of V1b (A). In contrast, the intersegmental plane between the superior segment and the basal segment is almost parallel to the horizontal plane in both lower lobes and is feasible to image the intersegmental plane (red) on the sagittal view (B). Since the planes in other areas of segments in the basal segments spread radially and widen along the longitudinal direction, it is easy to image a single intersegmental segment on a single plane (blue) (i.e., the horizontal view on MPR images) (B). For instance, it is easy to measure anatomical margin between a tumor located at superior segment and the intersegmental plane (red), as well as that between a tumor and the intersegmental plane (blue) on the axial view. MPR: multi-planar reconstruction

difficult to obtain an accurate image and actual intersegmental planes. In contrast, the intersegmental plane between apical segment (S6) and the basal segment is almost parallel to the horizontal anatomic plane (**Fig. 2B**); thus, it is feasible to obtain an image of the intersegmental plane in the sagittal view. Since other intersegmental planes, particularly in the bilateral lower lobes, spread radially and widen in the longitudinal direction, it is feasible to obtain an image of a single intersegmental segment on a single plane (i.e., the horizontal view). Collectively, we defined segments with multiple intersegmental planes and oblique intersegmental planes as complicated segments and the remaining segments as uncomplicated segments (complicated segments: right S1, right S2, right S3, left S3, and left S4). As a result, 7 of the 17 (41%) patients with a tumor located in a complicated segment appeared to have an insufficient margin, while one of the 16 (6%) patients with a tumor in an uncomplicated segment appeared to have an insufficient margin ($P = 0.0193$) (**Table 3**).

In eight patients who were considered to have insufficient anatomical margin based on MPR imaging, additional resection of the neighboring (sub)segments was recommended in seven patients, and lobectomy was recommended in the remaining one patient by computer simulation (**Table 2**). During operation, six patients underwent the recommended operation, while two patients underwent wide wedge resection based on the intraoperative findings. The surgical margin was acceptable in all patients, with the exception of one patient who eventually required conversion from the recommended operation (S1+2+S3a resection) to left upper lobectomy due to an insufficient surgical margin (**Table 2**).

Discussion

Obtaining a safety surgical margin is one of the most important issues for successful segmentectomy. Some measures are needed to secure a sufficient surgical

margin during thoracoscopic operations, particularly in cases involving patients with deeply located small lesions or indistinct ground-glass lesions. One of the most rational methods is to identify the anatomical boundary between the tumor and the intersegmental plane on preoperative CT. If the anatomical margin is sufficient, the resection line can be determined by referring to demarcation, as shown by selective ventilation or a fluorescent material-based demarcation line, even if patients have palpable tumors. In the clinical setting, most surgeons determine the surgical indication for segmentectomy on MPR images. However, the diagnostic potential of MPR imaging in approximating the anatomical margin remains unclear. We performed software-based validation of the anatomical boundary after MPR imaging-based assessment in a prospective manner in consecutive patients who were considered to be eligible for segmentectomy. Unfortunately, MPR imaging-based assessment resulted in the overestimation of the anatomical margin in as many as 24% of the patients. Overestimation was predominantly found in patients with tumors at certain segments (right S1, right S2, right S3, left S3, and left S4) that had a complex and oblique intersegmental plane. We recommend using software-based assessment preoperatively in patients with tumors in such segments, particularly in patients with indistinct tumors.

We found that in cases in which the intersegmental plane was located at a diagonal angle on conventional MPR images (intersegmental plane between right S1 and S3, right S1 and S2, right S2 and S3, left S1+2 and S3, and left S4 and S5), the anatomical margin was frequently misdiagnosed: seven of the eight cases in which the anatomical margin was overestimated involved either of the oblique intersegmental planes. For instance, the anatomical margin was overestimated in two of the four patients with tumors located in the left S3, and overestimation was derived from the oblique intersegmental plane in both cases (between left S1+2 and S3). We hypothesize that the bilateral upper lobe would be associated with a significantly higher rate of misdiagnosis in comparison to the bilateral lower lobe, if we evaluated more patients, because all intersegmental planes in the bilateral upper lobe are located at an oblique angle, with the exception of the intersegmental plane between the left S3 and S4. Notably, the issue derived from overestimation in the left upper lobe may be resolved if we plan more extended resection, such as upper division segmentectomy (left S1+2 and S3) or lingula segmentectomy (left S4 and S5). However, it remains unknown whether

such an operation would indeed be beneficial for patients with regard to functional preservation. This may be revealed after the publication of the outcomes of an ongoing phase III study conducted by the Japan Clinical Oncology Group.⁶⁾

It is well known that anatomical variation in the bronchial and vascular branching pattern is frequently observed in the right upper lobe.⁷⁾ Image reconstruction software programs can be applied in cases involving anatomical variation. However, the false estimation of the anatomical margin can also be derived from the misdiagnosis of the bronchial and vascular branching patterns in patients with some anatomical variation or patients with thin vascular branches, particularly intersegmental veins after assessment of 3D volume rendering images alone. Thus, we believe that combined assessment with MPR images and 3D images is indispensable to avoid misdiagnosis of thin vascular branches. Interestingly, Nishio et al. reported, based on a study of 164 patients who underwent segmentectomy and 73 patients who underwent lobectomy, that segmentectomy of the right upper lobe was associated with a higher rate of recurrence; however, the reason for this remains unclear and may be multifactorial.⁸⁾ Based on their data, together with the current results, we should not necessarily promote segmentectomy for right upper lobe tumors.

Rapid development of CT technologies has been accompanied by remarkable advances in image reconstruction algorithms. With user-friendly image reconstruction software programs, we can easily simulate the resection of any intended segments or even subsegments.^{9,10)} Preoperative simulation may contribute to preventing the misdiagnosis of pulmonary vessels that should be resected or preserved. Although expert radiologists and thoracic surgeons can accurately deduce 3D structure from 2D images, it is still difficult to measure the anatomical margin between the tumor and intersegmental plane on conventional MPR images. Nonetheless, reconstruction of oblique section images by advanced MPR reconstruction may be helpful for approximating the length of the anatomical margin, although this technique involves additional work by the surgeon.

The current study is associated with some limitations. First, the analysis was performed in a retrospective manner. However, MPR-based evaluation and 3D reconstruction software-based evaluation were prospectively performed (in this order) for all patients who were scheduled to undergo any type of segmentectomy (single

segmentectomy, bisegmentectomy, or some other complex segmentectomy) during the study period in our institute. Second, the inclusion criteria were determined based on the assessment of MPR images alone, which could lead to a selection bias: tumors not considered to have an insufficient margin for segmentectomy on MPR images were not included in this study. However, we did not perform any segmentectomy procedures during the study period for patients who were not included in this study, suggesting that there were no cases in which the anatomical margin was underestimated on MPR imaging. Third, regardless of the present study results, it still remains unclear whether the software-based assessment contribute to reducing the risk of insufficient surgical margin, leading to reducing the risk of postoperative local recurrence, as compared with MPR image-based assessment. In addition, further experiences are needed to determine the best procedure (extended segmentectomy vs. combined resection of neighboring subsegments) to secure surgical margin in patients with insufficient anatomical margin for single segmentectomy. Finally, because it is particularly difficult to quantify the distance between tumors and oblique intersegmental planes on MPR images, we could not show discrepancies in the actual length of the anatomical margin between the MPR image and the reconstructed image.

Conclusion

Conventional MPR imaging-based assessment resulted in the overestimation of the anatomical margin in as many as 24% of cases. Overestimation was predominantly found in cases involving patients with tumors located in certain segments that had complex and oblique intersegmental planes. We recommend using software-based assessment preoperatively in cases involving tumors in such segments, particularly in cases involving indistinct tumors.

Disclosure Statement

Kazuhiro Ueda and other co-authors have no conflict of interest.

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