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Original Article

A Segmentectomy of the Right Upper Lobe Has an Advantage over a Right Upper Lobectomy Regarding the Preservation of the Functional Volume of the Right Middle Lobe: Analysis by Perfusion Single-Photon Emission Computed Tomography/Computed Tomography

Kentaro Yoshimoto[1], Hiroaki Nomori[1,4], Takeshi Mori[1], Yasuomi Ohba[1], Hidekatsu Shibata[1], Kuniyuki Tashiro[2], Shinya Shiraishi[2], and Toshiaki Kobayashi[3]

Departments of [1]Thoracic Surgery and [2]Diagnostic Radiology, Graduate School of Medical Sciences, Kumamoto University, Kumamoto, Japan
[3]Department of Assistive Diagnostic Technology, National Cancer Center Hospital, Tokyo, Japan
[4]Division of General Thoracic Surgery, Department of Surgery, School of Medicine, Keio University, 35 Shinanomachi, Shinjuku-ku, Tokyo 160-8582, Japan

Abstract

Purpose. To evaluate the advantages of a segmentectomy of the right upper lobe (RUL) over a right upper (RU) lobectomy regarding the preservation of the functional volume of the right middle lobe (RML), the postoperative forced expiratory volume in one second (FEV_1) of the RML was compared between an RU lobectomy and an RUL segmentectomy, by using a co-registered perfusion single-photon emission computed tomography and computed tomography (SPECT/CT).

Methods. The pulmonary function tests and perfusion SPECT/CT were conducted before and after surgery (RU lobectomy: 7; RUL segmentectomy: 13). The FEV_1 of the RML before and after surgery was calculated from the data of the pulmonary function test and SPECT/CT.

Results. In the RU lobectomy group, the percentage change of FEV_1 was 71% ± 12%, which was significantly lower in comparison to 92% ± 9% in the RUL segmentectomy group ($P = 0.001$). In the lobectomy group, the preoperative FEV_1 of the RML was 0.17 ± 0.10l, which decreased significantly to 0.06 ± 0.06l after surgery ($P = 0.009$). In the segmentectomy group, FEV_1 of the RML before and after the surgery were 0.23 ± 0.10l and 0.20 ± 0.11l, of which the difference was not significant.

Conclusion. An RUL segmentectomy has an advantage over an RU lobectomy regarding the preservation of pulmonary function, due to a greater preservation of not only the lung tissue, but also the FEV_1 of the RML.

Key words Right middle lobe · Pulmonary function · Segmentectomy · Single-photon emission computed tomography · Perfusion scintigraphy

Introduction

It was recently reported that a segmentectomy can result in curative rates that are equivalent to those obtained after a lobectomy in patients with T1N0 non-small cell lung cancer (NSCLC).[1–7] With respect to the postoperative pulmonary function after a segmentectomy, the only randomized controlled trial of this subject, conducted by the Lung Cancer Study Group in 1995, showed minimal advantage of a segmentectomy over a lobectomy.[8] However, several authors have advocated the superiority of a segmentectomy over a lobectomy for the preservation of postoperative pulmonary function.[9,10] The advantage of a segmentectomy over a lobectomy for the preservation of postoperative pulmonary function has generally been attributed to a greater preservation of lung tissue in a segmentectomy. However, the anatomical repositioning of the remaining lobe caused by a lobectomy may also cause a greater reduction in the postoperative pulmonary function in comparison to a segmentectomy. A segmentectomy is considered to be an acceptable alternative to a lobectomy for adenocarcinomas 2 cm or less in diameter.

It is well known that the right upper (RU) lobectomy can sometimes cause a reduction in the volume of the right middle lobe (RML) due to excessive upward bending and rotation of the RML bronchus.[11] We hypothesized that a segmentectomy of the right upper lobe (RUL) would not cause such a significant anatomi-

Reprint requests to: H. Nomori (address 4)
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Table 1. Patients' characteristics

	Right upper lobectomy	Segmentectomy in the right upper lobe
Age, years	73 ± 3	65 ± 6
Male	4	8
Female	3	5
FEV_1/FVC (%)	68 ± 12	74 ± 7
%FEV_1 (%)	99 ± 16	116 ± 19
FEV_1 of the RML (L)	0.17 ± 0.10	0.23 ± 0.10
Total no. of patients	7	13

FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; RML, right middle lobe

Table 2. Site of segmentectomy

Segment of right upper lobe	No. of patients
S1	1
S2	4
S3	4
S1 + S2	1
S3 + S2a	1
S2b + S3a	2
Total	13

S, segment
Right upper lobe: S1, apical; S2, anterior; S3, posterior

cal change in the RML bronchus or the consequent volume reduction of the RML, due to the partial preservation of the RUL. The aim of the present study is to examine whether the RUL segmentectomy can preserve the pulmonary function of the RML in comparison to the RU lobectomy, by using perfusion scintigraphy with coregistered single-photon emission computed tomography (SPECT) and computed tomography (CT) imaging (SPECT/CT).

Patients and Methods

Eligibility

The study for examining perfusion scintigraphy with SPECT/CT in the patients undergoing major lung resection was approved by the Ethics Committee of Kumamoto University Hospital in April 2005. Informed consent was obtained from all the patients after discussing the costs and benefits of the study.

Patients

Between July 2005 and January 2008, 59 patients with NSCLC underwent an RU lobectomy or an RUL segmentectomy. Of the 59 patients, 18 were excluded because they had undergone additional lung resections for other lesions. Among the remaining 41 patients, pulmonary function tests and perfusion SPECT/CT were performed both before and after surgery in 20 patients, i.e., 7 patients from the RU lobectomy group and 13 patients from the RUL segmentectomy group (Table 1). None of the patients showed atelectasis of the RML after surgery. Table 2 shows the sites of the segmentectomy.

Pulmonary Function Tests

Spirometry was performed using a dry rolling-seal spirometer (Chestac-9800DN, Chest, Tokyo, Japan), with the patient in a sitting position. Spirometry was used to determine the vital capacity, forced vital capacity (FVC), and forced expiratory volume in 1 second (FEV_1), according to American Thoracic Society standards.[12]

SPECT/CT

The lung perfusion scintigraphic images were obtained by a SPECT/CT system, which was composed of a commercially available gantry-free SPECT with dual-head detectors (Skylight; ADAC Laboratories, Milpitas, CA, USA) and an 8-multidetector-row CT scanner (LightSpeed Ultra Instrument; General Electric, Milwaukee, WI, USA). The two instruments were juxtaposed such that the CT table carrying the patient could be moved directly into the SPECT scanner before the CT scanning. As a result, each patient was identically positioned for SPECT and CT imaging.

Each 185 MBq of ^{99m}Tc-macroaggregated human serum albumin (MAA: Daiichi Radioisotope Laboratories, Tokyo, Japan) was administered intravenously with the patient first in the supine and then in the prone positions, to allow the uniform distribution of MAA. The SPECT data acquisition was performed with a vertex ultra-high resolution parallel-hole (VXUR) collimator. A 360 SPECT scan was acquired and was followed by CT scanning. The reconstructive CT images were processed into Digital Imaging and Communications in Medicine (DICOM) data and then transferred to Pegasys (ADAC Laboratories), which is a workstation for SPECT processing. One lumen of a 3-way stopcock (inner diameter 4 mm, length 10 mm) containing an aqueous solution of ^{99m}Tc O_4^- and a contrast medium was used as an external fiducial marker. In order to obtain a precise record of both images, the external fiducial markers were fixed to the common platform for SPECT and CT imaging. The two scans were performed sequentially. The fusion of the transaxial, coronal, and sagittal sections of the SPECT and CT images was man-

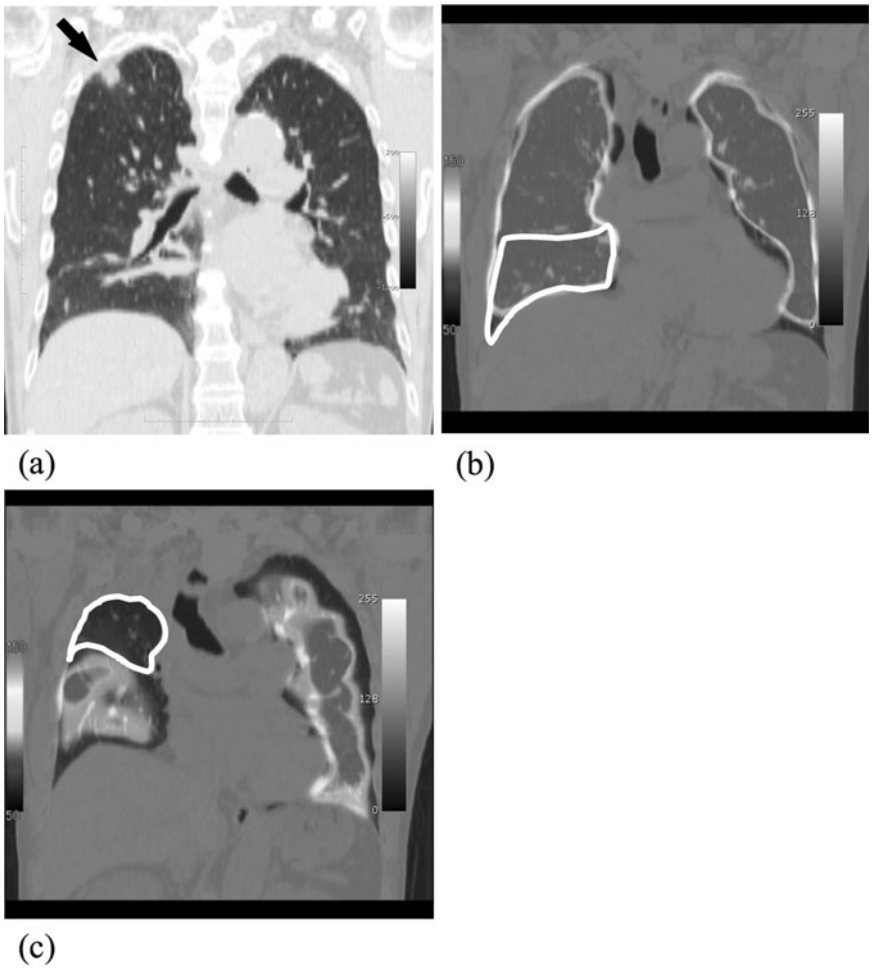

Fig. 1a–c. Lobectomy case. **a** Coronal computed tomography (CT) image before surgery, showing a tumor in the right upper lobe. **b** Perfusion single-photon emission CT (SPECT)/CT before the right upper lobectomy. The image of the right middle lobe is surrounded by a solid line. The forced expiratory volume in 1 second (FEV_1) of the right middle lobe was 0.351. **c** Perfusion SPECT/CT after the right upper lobectomy. The image of the right middle lobe is surrounded by a solid line. The FEV_1 of the right middle lobe was decreased to 0.131

ually performed by aligning the external fiducial markers of the two images on a workstation (AZE Virtual Place, AZE, Tokyo, Japan).

Preoperative SPECT/CT and the pulmonary function test were conducted within 1 month before surgery. Postoperative SPECT/CT and the pulmonary function test were conducted more than 5 months after surgery (median: 10 months; range: 5–27 months).

FEV_1 of the Right Middle Lobe

The images of the RML before and after surgery were traced on the axial CT image with the region of interest, for which radioisotope (RI) was counted on the SPECT image (Figs. 1 and 2). The FEV_1 of the RML before and after surgery was measured from the preoperative and postoperative SPECT/CT, respectively, according to the following formula:

FEV_1 of the RML before or after surgery = [Preoperative or Postoperative FEV_1] × [RI counts of the RML/RI counts of the whole lung]

Statistical Analysis

The paired *t*-test was used to compare the FEV_1 before and after surgery, using the SPSS software program (SPSS 15.0J for Windows, SPSS, Chicago, IL, USA). Fisher's exact test was used to compare the age, values of pulmonary function test, FEV_1 of the RML, and postoperative percentage reduction of the FEV_1 between the lobectomy and the segmentectomy groups. Values of $P < 0.05$ were accepted as statistically significant. All values in the text and table represent the mean ± standard deviation.

Results

Table 1 shows the characteristics of the patients in the segmentectomy and the lobectomy groups. The preoperative FEV_1/FVC (%) and % FEV_1 were not significantly different between the two groups. The values of FEV_1 of the RML, which was measured by SPECT/CT were not significantly different between the two groups.

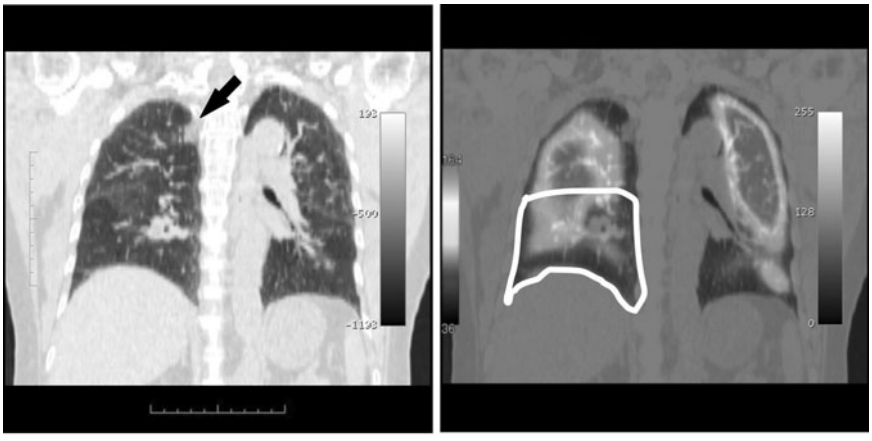

Fig. 2a–c. Segmentectomy case. **a** Coronal CT image before surgery, showing a tumor in the right upper lobe. **b** Perfusion SPECT/CT before surgery. The image of the right middle lobe is surrounded by a solid line. The FEV_1 of the right middle lobe was 0.30l. **c** Perfusion SPECT/CT after a segmentectomy of the right upper lobe. The image of the right middle lobe is surrounded by a solid line. The FEV_1 of the right middle lobe was changed to 0.24l

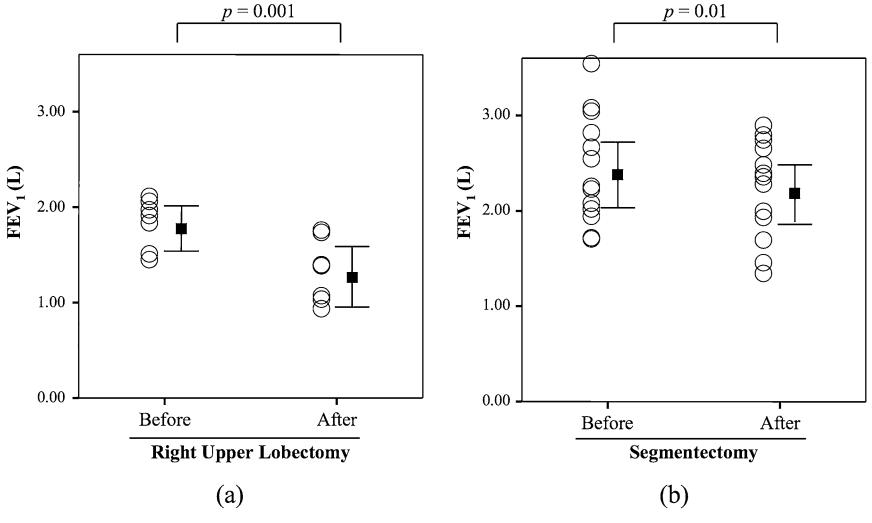

Fig. 3a,b. Forced expiratory volume in 1 second (FEV_1) before and after surgery. **a** Right upper lobectomy. **b** Segmentectomy of the right upper lobe

The preoperative and postoperative FEV_1 in the lobectomy and segmentectomy groups are presented in Fig. 3. In the lobectomy group, the mean preoperative and postoperative values of FEV_1 were 1.78 ± 0.26l and 1.28 ± 0.33l, respectively, and the difference in the values was significant (P = 0.001) (Fig. 3a). In the segmentectomy group, the mean preoperative and postoperative FEV_1 were 2.41 ± 0.57l and 2.20 ± 0.51l, respectively, and the difference in the values was significant (P = 0.01) (Fig. 3b). The percentage of postoperative/preop-

erative FEV_1 in the lobectomy group was 71% ± 12%, which was significantly lower in comparison to 92% ± 9% in the segmentectomy group ($P = 0.001$) (Fig. 4). For the patient who underwent the resection of the right $S^1 + S^2$, FEV_1 in the RML decreased from 0.301 to 0.241, and the percentage of the postoperative/preoperative FEV_1 in the RML was 80%.

The preoperative and postoperative FEV_1 of the RML calculated by SPECT/CT are presented in Fig. 5. In the lobectomy group, the mean FEV_1 of the RML was 0.17 ± 0.101 before surgery, which decreased significantly to 0.06 ± 0.061 after surgery ($P = 0.009$) (Fig. 5a).

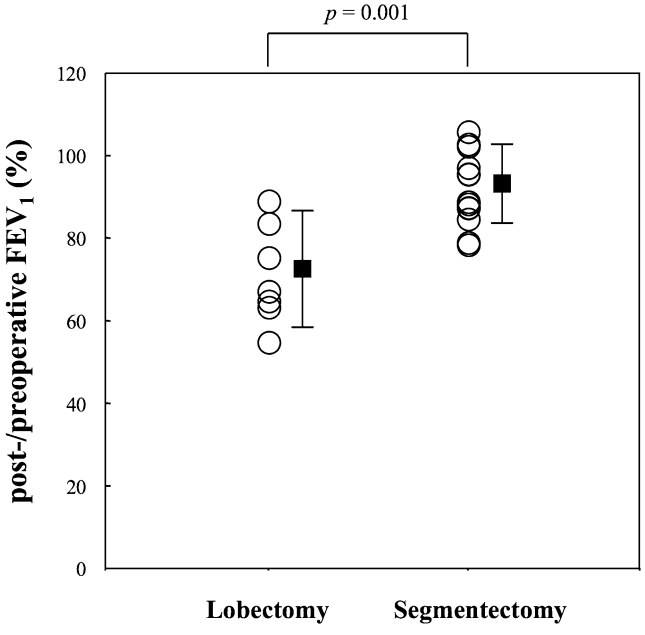

Fig. 4. Percentage of post-/preoperative forced expiratory volume in 1 second (FEV_1) in the lobectomy group and segmentectomy group

In the segmentectomy group, the mean FEV_1 values of the RML before and after segmentectomy were 0.23 ± 0.101 and 0.20 ± 0.111, respectively, and the difference in the values was not significant ($P = 0.17$) (Fig. 5b).

Discussion

The present study showed that the RU lobectomy caused a significant reduction of the FEV_1 of the RML, whereas the RUL segmentectomy did not show any such reduction. It is well known that an RU lobectomy sometimes causes volume reduction of the RML, attributed to the excessive upward bending and rotation of the RML bronchus.[11] Nonaka et al. examined the postoperative deformity of the RML bronchus and the postoperative change of the RML volume after an RU lobectomy in experiments using rabbits, and showed a significant bending of the RML bronchus upward and backward, with a significant decrease in the RML volume after an RU lobectomy.[13] The present study showed that the FEV_1 of the RML could be preserved by a RUL segmentectomy, which was most likely due to the prevention of the anatomical repositioning of the RML bronchus by the partial preservation of the RUL.

While lung perfusion scintigraphy with SPECT can show the tomographic images of scintigraphy,[14,15] this technique can hardly measure the perfusion of each lobe, because of difficulty in identifying each lobe on the SPECT images. The recent development of SPECT/CT has enabled the measurement of perfusion of each lobe on the SPECT images, by fusion with CT images. Ohno et al. showed a highly significant correlation between the actual value and the value of the pulmonary function after a lobectomy calculated by the perfusion SPECT/CT.[16] Recently, we reported that the perfusion SPECT/CT can predict the postoperative pulmonary

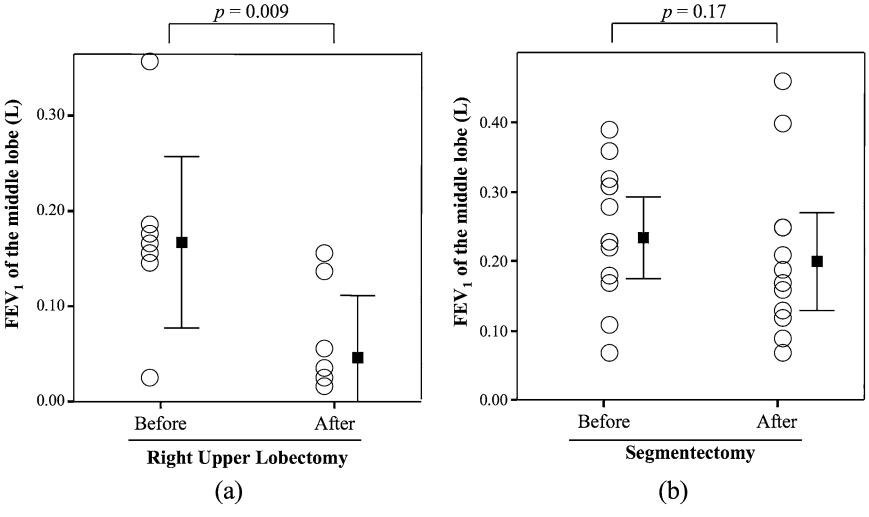

Fig. 5a,b. Forced expiratory volume in 1 second (FEV_1) of the right middle lobe before and after surgery. **a** Right upper lobectomy. **b** Segmentectomy of the right upper lobe

function within an error of 0.051.[17] Because perfusion SPECT/CT can count the radioactivity of each lobe accurately, we used it in the present study to measure the FEV_1 of the RML before and after surgery.

The greater preservation of the postoperative pulmonary function after a segmentectomy versus after a lobectomy is thought to be caused by the greater preservation of lung tissue by the former procedure.[9,10] The present data showed that the RUL segmentectomy allowed a better and more significant preservation of the pulmonary function of the RML than an RU lobectomy. We conclude that the advantage of an RUL segmentectomy over an RU lobectomy for the preservation of pulmonary function is attributable to not only the greater preservation of the lung tissue but also to the preservation of the pulmonary function of the RML, due to the avoidance of repositioning of the RML after a segmentectomy.

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References

1. Jensik RJ, Faber LP, Milloy FJ, Monson DO. Segmental resection for lung carcinoma. J Thorac Cardiovasc Surg 1973;66:563–72.
2. Tsubota N, Ayabe K, Doi O, Mori T, Namikawa S, Taki T, et al. Ongoing prospective study of segmentectomy for small lung tumors. Ann Thorac Surg 1998;66:1787–90.
3. Okada M, Yoshikawa K, Hatta T, Tsubota N. Is segmentectomy with lymph node assessment an alternative to lobectomy for non-small cell lung cancer of 2 cm or smaller? Ann Thorac Surg 2001;71:956–61.
4. Yoshikawa K, Tsubota N, Kodama K, Ayabe H, Taki T, Mori T. Prospective study of extended segmentectomy for small lung tumors: The final report. Ann Thorac Surg 2002;73:1055–9.
5. Kodama K, Doi O, Higashiyama M, Yokouchi H. Intentional limited resection for selected patients with T1N0M0 non-small cell lung cancer. J Thorac Cardiovasc Surg 1997;114:347–53.
6. Nomori H, Ikeda K, Mori T, Kobayashi H, Iwatani K, Kawanaka K, et al. Sentinel node navigation segmentectomy for clinical stage IA non-small cell lung cancer. J Thorac Cardiovasc Surg 2007; 133:780–5.
7. Yamato Y, Koike T, Yoshiya K, Shinohara H, Toyabe S. Results of surgical treatment for small (2 cm or under) adenocarcinomas of the lung. Surg Today 2008;38:109–14.
8. Lung Cancer Study Group, Ginsberg RH, Rubinstein LV. Randomized trial of lobectomy versus limited resection for T1N0 non-small cell lung cancer. Ann Thorac Surg 1995;60:615–23.
9. Harada H, Okada M, Sakamoto T, Matsuoka H, Tsubota N. Functional advantage after radical segmentectomy versus lobectomy for lung cancer. Ann Thorac Surg 2005;80:2041–5.
10. Keenan RJ, Landreneau RJ, Maley RH Jr, Singh D, Macherey R, Bartley S, et al. Segmental resection spares pulmonary function in patients with stage I lung cancer. Ann Thorac Surg 2004;78: 228–33.
11. Irani B, Miller JE, Linberg E, Attar S. Use of radiopaque markings of middle lobe (or lingual) following upper resectional surgery. Ann Thorac Surg 1968;5:1–7.
12. American Thoracic Society. Standardization of spirometry — 1987 update. Am Rev Respir Dis 1987;136:1285–98.
13. Nonaka M, Kadokura M, Tanio N, Yamamoto S, Kataoka D, Inoue K, et al. Changes in lung lobar volume and bronchial deformity after right upper lobectomy. Surg Today 1998;28:285–8.
14. Hirose Y, Imaeda T, Doi H, Kokubo M, Sakai S, Hirose H. Lung perfusion SPECT in predicting postoperative pulmonary function in lung cancer. Ann Nucl Med 1993;7:123–6.
15. Imaeda T, Kanematsu M, Asada S, Seki M, Matsui E, Doi H, et al. Prediction of pulmonary function after resection of primary lung cancer. Utility of inhalation-perfusion SPECT imaging. Clin Nucl Med 1995;20(9):792–9.
16. Ohno Y, Koyama H, Takenaka D, Nogami M, Kotani Y, Nishimura Y, et al. Coregistered ventilation and perfusion SPECT using Krypton-81m and Tc-99m-labeled macroaggregated albumin with multislice CT: Utility for prediction of postoperative lung function in non-small cell lung cancer patients. Acad Radiol 2007;14: 830–8.
17. Yoshimoto K, Nomori H, Mori T, Kobayashi H, Ohba Y, Shibata H, et al. Prediction of pulmonary function after lung lobectomy by subsegments counting, computed tomography, single photon emission computed tomography and computed tomography: a comparative study. Eur J Cardiothorac Surg 2009;35:408–13.