Prediction of pulmonary function after lung lobectomy by subsegments counting, computed tomography, single photon emission computed tomography and computed tomography: a comparative study

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Abstract

Objective: The aim of the present study was to determine the optimal method of predicting postoperative pulmonary function (PPF) after lung lobectomy. Methods: The forced expiratory volume in 1 s (FEV1) was measured in 37 patients before and after lobectomy, and the following three methods of predicting the PPF were evaluated: (1) the number of functioning subsegments to be resected were counted (subsegments counting [SC]); (2) the volume of the functioning lung was calculated using CT images (quantitative CT); and (3) perfusion scintigraphy was performed using co-registered single photon emission computed tomography and CT imaging (SPECT/CT). The FEV1 values predicted using these three methods were then compared with the measured postoperative FEV1, and the correlations and differences were analyzed. Results: While a paired t-test showed the SPECT/CT method to have the smallest difference between the measured and the predicted FEV1 values (0.05 l, p = 0.33), followed by the quantitative CT method (0.07 l, p = 0.07), and finally the SC method (0.15 l, p < 0.001), the difference between the two values was not significantly different between the quantitative CT and the SPECT/CT method (p = 0.22). Conclusions: While the SC method is inferior to both the quantitative CT and the SPECT/CT methods for predicting the PPF after lobectomy, the latter two methods are almost equally accurate.

Keywords: Computed tomography; Single photon emission computed tomography; Pulmonary function; Surgery; Lung cancer

1. Introduction

Pulmonary function is an important factor for determining the indications for lung surgery. To predict the postoperative pulmonary function (PPF), calculating the number of lung subsegments to be resected is one of the simplest methods available, and this method has been reported to predict the PPF with an accuracy equal to that of scintigraphy [1–3]. A more detailed method consists of calculating the number of functioning subsegments to be resected, distinguishing between subsegments that are occluded and those that are unoccluded by the lesions [4]. However, in patients with chronic obstructive pulmonary disease (COPD) or interstitial pneumonia, these subsegment counting (SC) methods cannot predict PPF reliably, because emphysema and interstitial pneumonia are often not distributed uniformly.

While perfusion scintigraphy can be used to image the functioning lung, the SC method has been reported to predict PPF as accurately as perfusion scintigraphy [2–6]. However, the scintigraphy data in these reports were obtained from planar images, which cannot identify the boundaries between the lobes. Recent advances in single photon emission computed tomography (SPECT) have enabled images that are more precise than planar images to be obtained [7,8]. However, even in these new SPECT images, identifying the pulmonary lobes remains difficult, because the boundaries between the lobes are almost unrecognizable. To show the anatomy of the lung on SPECT images more accurately, a fused image of SPECT and multidetector CT images (SPECT/CT) has been used recently [9]; these images allow the boundaries between the lobes to be precisely identified.

On the other hand, the volume of the functioning lung can also be calculated from CT images with a CT number in the range of −910 to −500 Hounsfield Units (HU), i.e., the quantitative CT method. Because this range of CT numbers can be used to assess the extent of emphysema, this method...
is strongly correlated with pulmonary function [10—12]. Wu et al. reported that the quantitative CT method could predict the PPF as accurately as perfusion scintigraphy [13]. However, they compared the quantitative CT method with planar scintigraphic images, and not with SPECT or SPECT/CT.

In the present study, we evaluated the optimal method for predicting PPF in patients undergoing lobectomy by comparing the SC, quantitative CT and SPECT/CT methods.

2. Materials and methods

2.1. Eligibility

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

2.2. Patients

Between June 2005 and October 2007, 79 patients underwent lobectomy for lung cancer in Kumamoto University Hospital. Of the 79 patients, 37 patients had SPECT/CT performed before surgery and the pulmonary function test before and after surgery (Table 1). The patients who underwent pneumonectomy were excluded in this study because planar image of perfusion scintigraphy is enough and SPECT/CT is not necessary for prediction of pulmonary function after pneumonectomy. None of the patients had underlying pulmonary diseases, such as interstitial lung disease, severe chronic obstructive lung disease, and infectious disease.

2.3. Pulmonary function test

Vital capacity (VC), forced vital capacity (FVC) and forced expiratory volume in 1 s (FEV1) were measured with a dry rolling-seal spirometer (CHESTAC-9800DN, CHEST Inc., Tokyo, Japan) in the seated position using a dry rolling-seal spirometer (CHESTAC-9800DN, CHEST Inc., Tokyo, Japan) within one month prior to surgery, and the PPF was measured later than 6 months after the surgery (median: 6 months; range: 6—17 months).

2.4. Subsegments counting

The PPF was predicted based on the number of functioning SC, quantitative CT and SPECT/CT methods.

2.5. Quantitative CT

CT was performed at the end of full inspiration using 4 multidetector CT scanners (LightSpeed QX/i, GE Medical Systems, Milwaukee, Wis). The scanning parameters were as follows: detector collimation 4 × 1.25 mm; helical pitch, 0.75; section thickness, 1.25 mm; section interval, 1.25 mm; rotation time, 0.8 s; tube voltage, 120 kVp; tube current, 160—200 mA. To measure the volume of functioning lung, the lung regions with a CT number in the range of —910 to —500 HU were extracted on the workstation, according to the method proposed by Wu et al. [13]. After the lobe to be resected was traced on transaxial CT images within the region of interest (ROI), the functioning lung of CT image after lobectomy was shown on the workstation (AZE Virtual Place, AZE Co. Ltd, Tokyo, Japan) (Fig. 1). Prediction of the PPF by quantitative CT was then conducted according to the following formula:

Predictive postoperative FEV1 = \[\frac{1}{2}\left(1 - \frac{n}{42 - a}\right)\times\text{preoperative FEV1}\]

where \[n\] is the total number of subsegments in the resected lobe, which is assumed to be 6, 4 and 12 for the right upper, middle and lower lobe, respectively, and 10 each for the left upper and lower lobes, and \[a\] is the number of subsegments obstructed by tumors.

2.6. SPECT/CT

Lung perfusion scintigraphy images were obtained by SPECT/CT which was composed of a commercially available gantry-free SPECT with dual-head detectors (Skylight; ADAC Laboratories, Milpitas, Calif) and an 8-multidetector-row CT scanner (Light-Speed Ultra Instrument; General Electric, Milwaukee, Wis). The two instruments were juxtaposed so 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 the SPECT and CT imaging.

99mTc-Macroaggregated human serum albumin (MAA: Daiichi Radioisotope Laboratories, Ltd, Tokyo, Japan) was administered intravenously at the dose of 185 MBq, half of the dose administered with the patient in the supine and the remaining half with the patient in the prone position, to allow uniform distribution of the radionuclide.

SPECT data acquisition was performed with a vertex ultra-high resolution parallel-hole (VXUR) collimator. A 360-degree SPECT scan was acquired, and was followed by CT.
Reconstructive CT images were processed into digital imaging and communications in medicine (DICOM) data and then transferred to a workstation of SPECT/CT (Pegasys: ADAC Laboratories, Milpitas, Calif). One lumen of a three-way stopcock (inner diameter 4 mm, length 10 mm) containing an aqueous solution of $^{99m}$Tc $\text{O}_4$ and a contrast medium was used as the external fiducial marker. To obtain precise records of both images, the external fiducial markers were fixed to the common platform for the SPECT and CT imaging. The two scans were performed sequentially. Fusion of the SPECT images with the CT images was performed manually by aligning the external fiducial markers of the two images on the workstation. Transaxial, coronal, and sagittal sections of SPECT and CT were manually fused to obtain the best matching images on the workstation (AZE Virtual Place, AZE Co. Ltd, Tokyo, Japan). Preoperative SPECT/CT had been conducted within one month prior to the surgery.

After the lobe to be resected was traced on a CT image within the ROI, the SPECT image after lobectomy was shown on the workstation (Fig. 2). The PPF was predicted according to the following formula:

$$\text{Predictive postoperative FEV}_1 = \text{preoperative FEV}_1 \times (1 - \text{RI count of the target lobe/RI count in the entire lung before surgery})$$

### 2.7. Statistical analysis

Correlations between the measured postoperative FEV$_1$ and the predicted value by the SC, quantitative CT and SPECT/CT were assessed by Pearson’s correlations and a regression analysis. The difference between the measured postoperative FEV$_1$ and the predicted value was analyzed with the paired $t$-test. To evaluate the effect size of the paired $t$-test, effect size $r$ was calculated using the $t$ value and the degrees of freedom. The differences between the measured and the predicted values were also compared by the paired $t$-test between the SC and quantitative CT, between the SC and SPECT/CT, and the quantitative CT and SPECT/CT. To evaluate the variation of the values, testing of the limits of agreement was performed by Bland–Altman analysis [15]. Values of $p < 0.05$ were accepted as being significant. All values in the text and table represent the mean ± standard deviation (SD).

### 3. Results

The mean postoperative measured FEV$_1$ value was 1.93 l, while the mean predicted FEV$_1$ values were 1.78, 1.86, and 1.89 l using the SC, CT, and SPECT/CT methods, respectively. Significant correlations between the measured and predicted FEV$_1$ values were seen for all three methods (SC; $r = 0.86$, $p < 0.001$, CT; $r = 0.90$, $p < 0.001$, SPECT/CT; $r = 0.86$, $p < 0.001$).

The mean difference between the measured postoperative FEV$_1$ and the predicted value was the largest with the SC method (0.15 ± 0.28 l), followed by the CT method (0.07 ± 0.24 l) and the SPECT/CT method (0.05 ± 0.28 l) (Table 2). With the paired $t$-test, SPECT/CT and CT methods showed no difference between the predicted and measured FEV$_1$ values ($p = 0.33, 0.07$, respectively), but SC showed the significant difference between the predicted and measured
FEV₁ value \( (p < 0.001) \). The effect size was the smallest with the SPECT/CT \( (r = 0.16) \), followed by the quantitative CT \( (r = 0.30) \) and the SC method \( (r = 0.49) \).

With the paired \( t \)-test, the differences between the measured postoperative FEV₁ and the predicted value with the SC method were significantly higher than those with the CT method \( (p = 0.01) \) and the SPECT/CT \( (p < 0.001) \) (Table 3). However, there was no significant difference of the value between the CT and SPECT/CT \( (p = 0.22) \).

The range of limits of agreement with the Bland—Altman analysis, i.e., the range of two standard deviations (2 SDs) from the mean difference between the predicted and measured values, was the smallest with the quantitative CT method (from 0.55 to 0.40), followed by the SPECT/CT method (from 0.61 to 0.52) and the SC method (from 0.71 to 0.41) (Fig. 3).

Table 2

<table>
<thead>
<tr>
<th>Method</th>
<th>Difference between the predicted and measured FEV₁ ( l )</th>
<th>Paired ( t )-test ( p )-value</th>
<th>Effect size ( r )</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPECT/CT</td>
<td>0.05 ± 0.28</td>
<td>0.33</td>
<td>0.16</td>
</tr>
<tr>
<td>CT</td>
<td>0.07 ± 0.24</td>
<td>0.07</td>
<td>0.30</td>
</tr>
<tr>
<td>SC</td>
<td>0.15 ± 0.28</td>
<td>&lt;0.001</td>
<td>0.49</td>
</tr>
</tbody>
</table>

FEV₁: forced expiratory volume in 1 s; SC: subsegments counting; CT: quantitative CT.

Table 3

<table>
<thead>
<tr>
<th>Method</th>
<th>( p )-value with paired ( t )-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC vs CT</td>
<td>0.01</td>
</tr>
<tr>
<td>SC vs SPECT/CT</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>CT vs SPECT/CT</td>
<td>0.22</td>
</tr>
</tbody>
</table>

FEV₁: forced expiratory volume in 1 s; SC: subsegments counting; CT: quantitative CT.

4. Discussion

The present study confirmed the following two points: (1) the SC method is inferior to both the SPECT/CT and the quantitative CT methods for predicting the PPF after lobectomy; and (2) the SPECT/CT and the quantitative CT methods are almost equally accurate for predicting the PPF. The inaccuracy of the SC method is reasonable, because diseases like COPD or interstitial pneumonia are generally not distributed uniformly in lung tissues. On the other hand, because both the SPECT/CT and the quantitative CT methods assess regional pulmonary function [16—22], these two methods can reasonably predict the PPF more accurately than the SC method, probably even in patients with COPD or interstitial pneumonia. While the range of limits of agreement with the Bland—Altman analysis, i.e., the range of 2 SDs, was smaller in CT method than in SPECT/CT, this analysis just...
evaluated the variation of the values, which could not rank these methods.

The quantitative CT measurement of lung attenuation has been used to assess the extent of emphysema, and this method has shown a strong correlation with the results of pulmonary function tests [10—12]. Recently, quantitative CT has been applied to the assessment of pulmonary function before lung volume reduction surgery [19—21]. A threshold of $910$ HU can exclude emphysema [10,12], while a threshold of $500$ HU can exclude areas of air-space loss resulting from tumors or non-tumor-related lesions, such as fibrosis [19,22]. Therefore, the surgical removal of lung areas with a CT number outside of the range of $910$ to $500$ HU is not expected to cause a loss of lung function. Wu et al. assessed functioning lung tissue with a CT number between $910$ and $500$ HU and compared the predicted postoperative FEV1 between perfusion scintigraphy and quantitative CT, showing similar correlations for these two methods with the measured postoperative FEV1 [13]. However, their perfusion scintigraphy data was based on planar imaging, which does not enable an accurate delineation of the lobe to be resected. Moreover, 28 of the 44 patients (64%) in their study underwent a pneumonectomy, for which the PPF can be easily predicted, even using planar imaging of scintigraphy. The present study showed that while quantitative CT was superior to SC for predicting the PPF after lobectomy, its accuracy was inferior to that of SPECT/CT.

Recently, Ohno et al. reported that perfusion SPECT/CT allowed a more accurate prediction of the PPF after lobectomy than SPECT [9]. While our results were consistent with those of Ohno et al., our study differed from theirs with respect to the SPECT/CT procedure, as follows: (1) they conducted CT imaging at the end of full inspiration, while we conducted it during the phase of stable expiration to decrease the gap in the images between SPECT and CT; (2) they used commercially available software to fuse the SPECT and CT images, while we fused the two images manually; and (3) they injected the tracer in a single bolus with the patient in a supine position, while we injected half of the dose with the patient in a supine position and the remaining half with the patient in a prone position.

While the present study showed the superiority of both of the CT and SPECT/CT methods to the SC method, there was no significant difference between the former two. The CT method has several advantages over SPECT/CT as the followings: (1) the quantitative CT method is available with the preoperative routine CT examination; (2) less expensive (US $132 vs $431 in Japan); (3) lower radiation exposure; and (4) less time required for the examination (5 min vs 30 min). Therefore, the quantitative CT method could be used in place of the perfusion SPECT/CT method for the prediction of PPF after lung lobectomy.

References


