

Optimal Minimum Number of CT Slices Required to Measure Cross Sectional Areas of Small Pulmonary Vessels

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Received 21 March 2015; accepted 2 June 2015; published 5 June 2015

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Abstract

The cross-sectional area (CSA) of small pulmonary vessels can be quantified by CT, which is a reliable method of evaluating vascular alterations in such vessels. However, the optimal number of slices required for accurate quantitation remains unknown. We evaluated relationships among all slices at 10-mm interval and all slices at 3-cm interval, 6-cm interval, and 3-slices and found the closest correlation (0.939) between all slices at 10-mm intervals and 3-cm intervals. Thus, all slices at 3-cm intervals are suitable for accurately measuring CSA.

Keywords

Computed Tomography, Cross-Sectional Area, Pulmonary Vessels, Quantitative Analysis

1. Introduction

The importance of vascular alterations in several lung diseases has been recognized. For instance, vascular alteration is a characteristic feature of chronic obstructive pulmonary disease (COPD) [1] [2] that leads to pulmonary hypertension, which is closely related to the mortality rate of this disease. Several studies recently have shown that the cross-sectional area (CSA) of small pulmonary vessels, which can be quantified measured on computed tomography (CT) images, is reliable for evaluating vascular alterations in small pulmonary vessels *in vivo* [3]-[9]. This method is relatively uncomplicated because contrast material injection is not necessary. Al-

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though this method is potentially suitable for evaluating pulmonary small vascular structures, several issues should be addressed. One of the issues is that cross-sectional areas have previously been measured in only three axial slices. However, the distribution of pulmonary vascular components is generally heterogeneous, and whether CSA measured using only three axial slices accurately reflects pulmonary vascular components throughout the whole lung has not been clarified. The present study aimed to define the minimum optimal number of CT slices required for accurate and reproducible CSA measurements.

2. Materials and Methods

2.1. Methods

Our institutional review board approved this retrospective study and waived the need for informed consent. Patients with COPD and pulmonary embolism, which are not associated with pulmonary lesions that influence CSA measurements, and patients with preoperative tumors outside the lung without clinical symptoms associated with pulmonary diseases were initially assessed. We excluded patients who had obvious abnormal lung parenchymal lesions other than pulmonary emphysema, pleural effusion or cardiomegaly suggesting cardiac failure or image noise that prevented image analyzing. None of the patients without obvious pulmonary diseases had a history of smoking. One radiologist (S.S.) reviewed CT images that were acquired between April 2012 and March 2013 and then we randomly selected 30 patients with COPD (20 male; age range, 45 - 87 years), 20 with pulmonary embolization (10 male; age range, 30 - 87 years), and 30 without pulmonary diseases (18 female; age range, 36 - 83 years).

2.2. CT Assessment

All patients were assessed using an Aquilion-64 multi-detector CT (Toshiba Medical, Tokyo, Japan) at full inspiration. None of the patients with COPD and none of those without obvious pulmonary diseases received contrast medium. Nonionic contrast material (Iopromide, FUJIFILM) was administered to patients with pulmonary embolism via an antecubital vein using an automatic power injector. Patients who weighed >50 kg or <50 kg received 150 mL and 3-mL/kg of Iohexol, DAIICHI SANKYO respectively. The first 80 mL of contrast medium was injected at a rate of 3 - 4 mL/sec and the remaining contrast medium was injected at a rate of 1.5 mL/sec. Contrast was individually optimized using bolus tracking in the main pulmonary artery. The imaging parameters were as follows: collimation, 0.5 mm; 120 kV; 80 - 300 mA; gantry rotation time, 0.5 s; beam pitch, 0.81 - 0.94. All images were reconstructed using a standard algorithm with a slice thickness of 1 mm.

2.3. Measurements of Small Pulmonary Vessels Using CT

The CSA of small pulmonary vessels was measured by CT as described elsewhere [3] [4]. In brief, the following procedures were completed using the semiautomatic Java image-processing program ImageJ Version 1.47 g (available at <http://rsb.info.nih.gov/ij/>). The lung field was initially segmented using a threshold technique with all pixels between -500 and -1024 Hounsfield Units (HU) on each image. The segmented images were converted into binary images at a window of -720 HU and then the number of vessels of a specific size and the CSA of each size range on all CT slices were determined using the "Analyze Particles" function of the ImageJ software. Simultaneously, vessels that ran obliquely or in parallel to a slice were excluded using the ImageJ software "Circularity" function and only those vessels that ran perpendicularly and closest to the CT slice based on their shape in the image were analyzed. We measured CSA at the sub-subsegmental levels defined as vessels with a cross-sectional area <5 mm² [10]. The total area of the lung in a selected slice was determined using threshold values between -500 HU and -1024 HU, and the ratios of CSA < 5 (%CSA < 5) for lung areas on each slice were calculated. The %CSA < 5 values were determined for each slice from the apex to the lung base at intervals of 1-cm, and then the mean %CSA < 5 of the whole lung was calculated. We evaluated the influence of the slice numbers by calculating mean %CSA < 5 in the four groups using all slices at 1-cm intervals (%CSA-1 cm-interval), all slices at 3-cm intervals (%CSA-3 cm-interval), 3), all slices at 6-cm intervals (%CSA-6 cm-interval) and three slices (%CSA-3slices). The upper cranial slice was taken ~ 1 cm above the upper margin of the aortic arch, the middle slice was taken ~ 1 cm below the carina and the lower caudal slice was taken ~ 1 cm below the right inferior pulmonary vein.

2.4. Statistical Analysis

Correlations between the %CSA-1 and the %CSA-3 cm-interval, %CSA-6 cm-interval and %CSA-3 slices were determined using Spearman's rank correlation coefficient (ρ values). Data are expressed as means \pm standard deviation. $p < 0.05$ was considered significant for these statistical analyses. Bland-Altman analysis was also performed to assess the systematic bias. All data were statistically analyzed using JMP[®] 8.0 (SAS Institute, Cary, NC, USA).

3. Results

Figure 1 shows correlation coefficients between the %CSA-1 cm-interval (#1) and %CSA-3 cm-interval (#2), %CSA-6 cm-interval (#3) and %CSA-3slices (#4) of 0.939 ($p < 0.001$), 0.867 ($p < 0.001$), and 0.857 ($p < 0.001$), respectively. These values were 0.941 ($p < 0.001$), 0.831 ($p < 0.001$), and 0.843 ($p < 0.001$), respectively, 0.930 ($p < 0.001$), 0.827 ($p < 0.001$), and 0.851 ($p < 0.001$), respectively and 0.926 ($p < 0.001$), 0.862 ($p < 0.001$), and 0.884 ($p < 0.001$), respectively in the patients with COPD, pulmonary embolism and in those without pulmonary diseases, respectively.

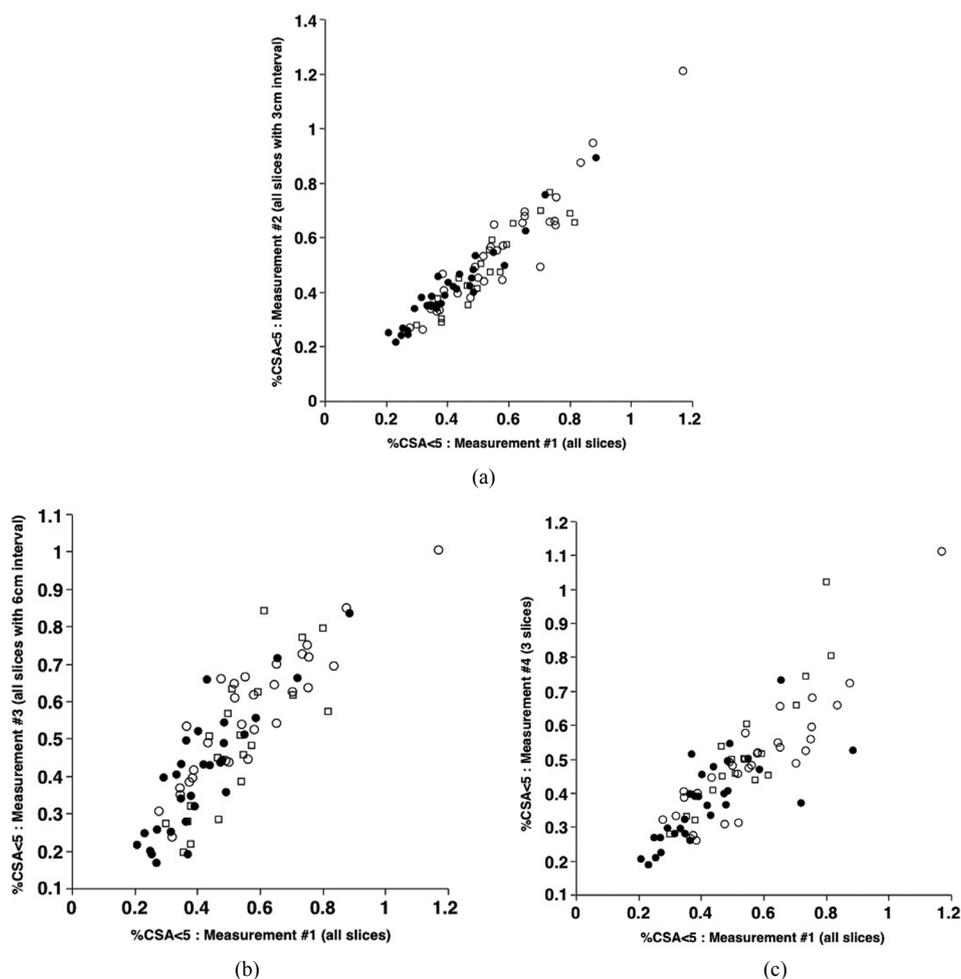


Figure 1. Relationships between %CSA-1 cm-interval (#1) and %CSA-3 cm-interval (#2), %CSA-6 cm-interval (#3) and %CSA-3 slices (#4). (a) Correlation coefficients between CSA-1 cm-interval and %CSA-3 cm- and 6 cm-intervals, and %CSA-3 slices % were 0.939, 0.930 and 0.926 in patients with COPD (●), and pulmonary embolism (□), and in those without pulmonary diseases (○), respectively. (b) Correlation coefficients between %CSA-1 cm- and 6 cm-intervals were 0.831, 0.827 and 0.862 in patients with COPD (●) and pulmonary embolism (□), and in patients without pulmonary diseases (○), respectively. (c) Correlation coefficients between %CSA-1 cm-interval and %CSA-3slices were 0.843 0.851 and 0.884 in patients with COPD (●) and pulmonary embolism (□), and in patients without pulmonary diseases (○), respectively.

Figures 2-4 and Table 1 show Bland-Altman, plots of the averages of and differences between the %CSA-1 cm-interval (#1) and %CSA-3 cm interval (#2), %CSA-6 cm-interval (#3), and %CSA-3slices (#4). The mean difference did not appreciably deviate from zero in the plot between the %CSA-1 and 3 cm-intervals, and the limits of agreement were small. In addition, measurement error was not related to the %CSA < 5 value. The limits of agreement were relatively large between the %CSA-1 cm-interval and the %CSA-6 cm interval as well as %CSA-3 slices in patients with COPD and pulmonary embolization.

4. Discussion

We found a relatively close correlation between %CSA < 5 using all slices at 1- and 3-cm intervals. The %CSA < 5 measurement of small pulmonary vessels is an alternative method of evaluating pulmonary vascular alterations

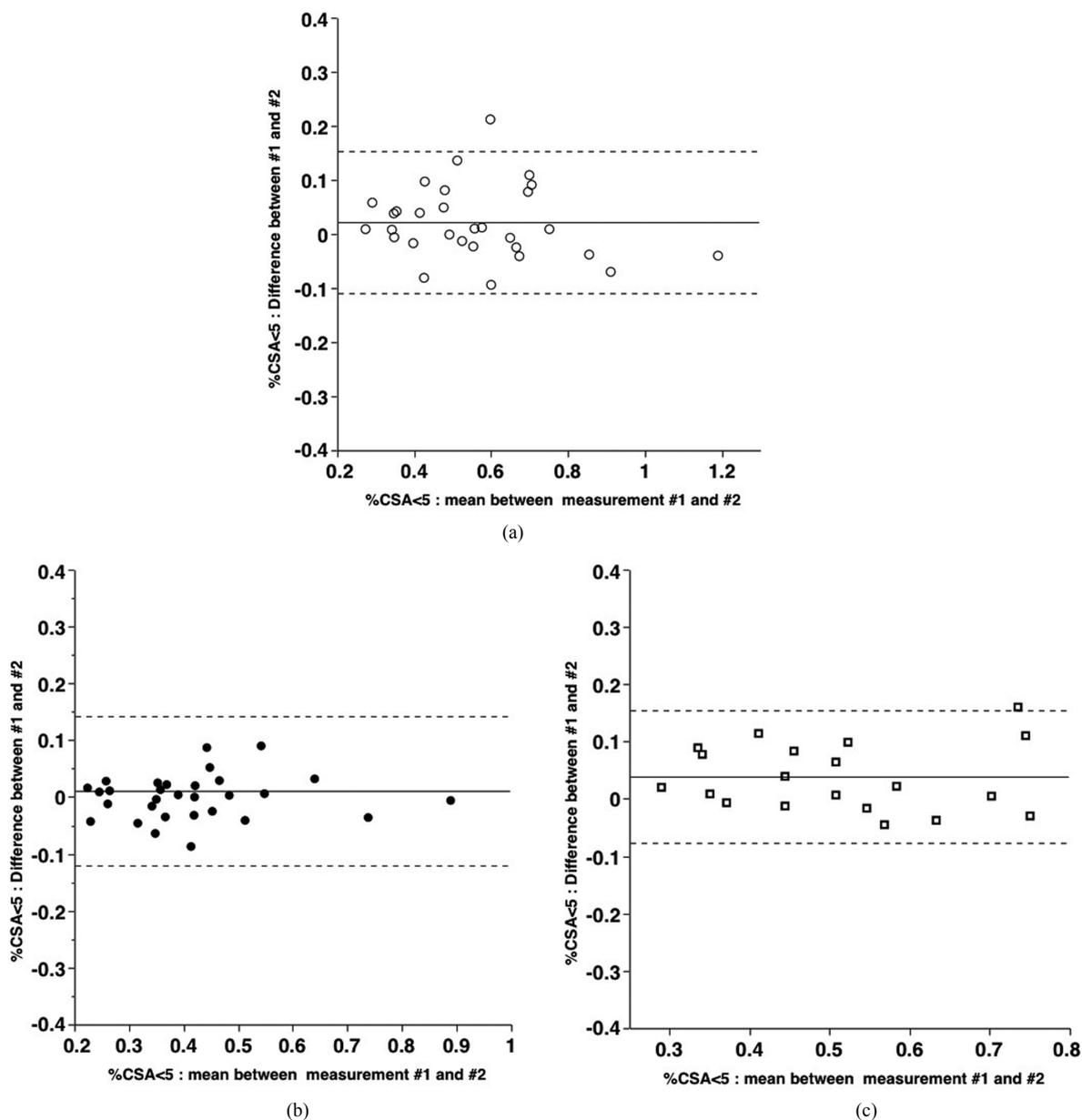


Figure 2. Bland-Altman plot of differences between %CSA-1 cm- (#1) and 3 cm-intervals (#2) against mean values, with mean absolute difference (continuous line) and 95% confidence interval of mean differences (dashed line). Patients without pulmonary diseases (a), with COPD (b) and with pulmonary embolism (c).

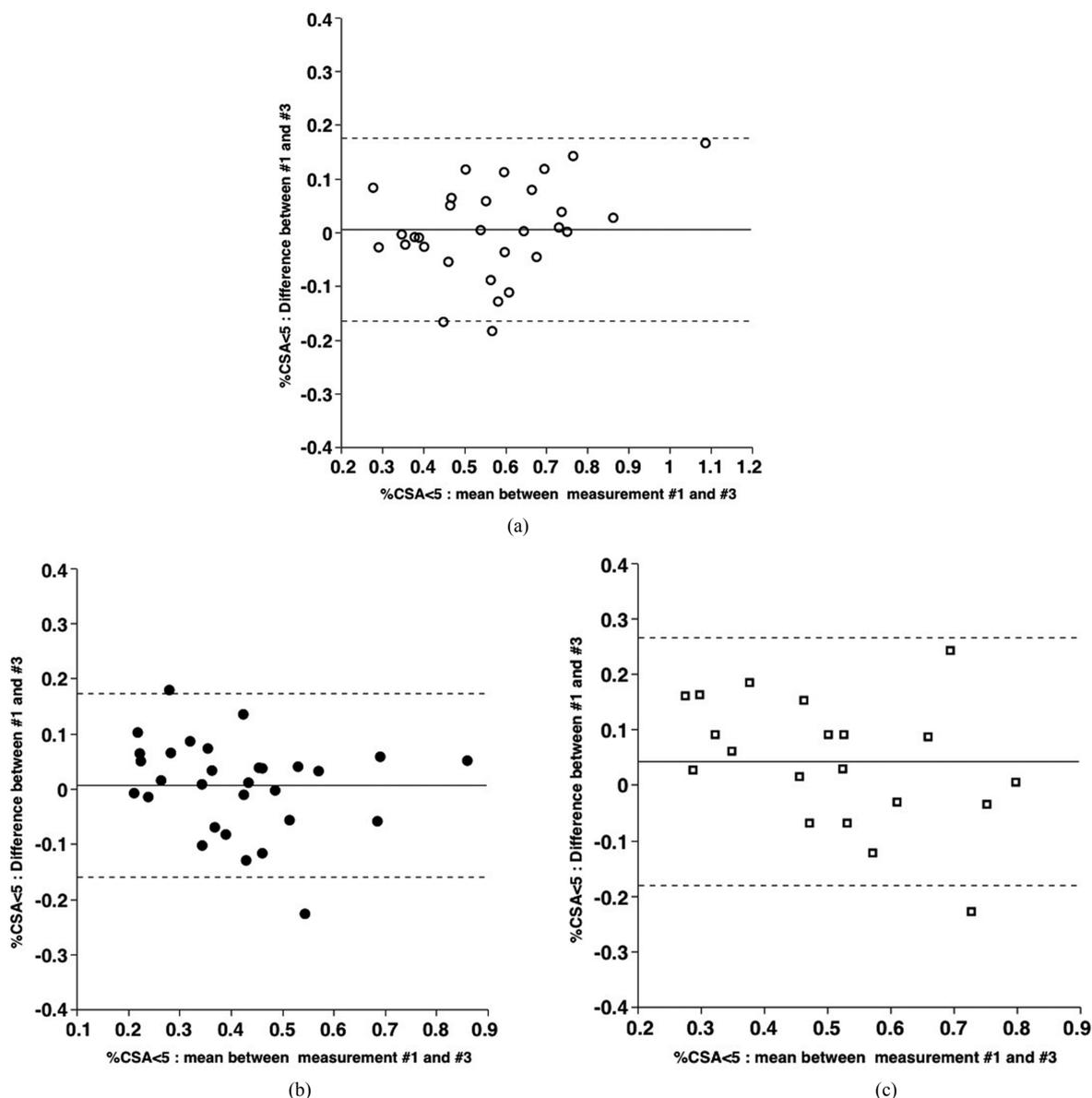


Figure 3. Bland-Altman plot of differences between %CSA-1 cm- (#1) and 6 cm-intervals (#3) against mean values, with mean absolute difference (continuous line) and 95% confidence interval of mean differences (dashed line). Patients without pulmonary diseases (a), with COPD (b) and with pulmonary embolism (c).

without a specific CT protocol or injected contrast material [3]-[5]. However, the optimal minimum number of slices has been one of several unresolved issues. The %CSA < 5 cannot be automatically or determined and thus, this procedure is time consuming if all slices are measured. The results of the Spearman's rank correlation coefficient and Bland-Altman analysis showed that the %CSA < 5 measurement using all slices at 3-cm intervals might be adequate for evaluating whole pulmonary vascular alterations.

The limits of agreements were relatively large between %CSA measured using all slices and all those at 6-cm intervals or three slices obtained from patients with COPD and pulmonary embolism that are heterogeneously distributed. This could explain the present results. However, lesions affected by pulmonary embolism widely differ among patients. Therefore, these differences might be relatively small. Ventilation-perfusion mismatches can be found in both embolic and non-embolic areas in patients with pulmonary embolism. This mechanism might contribute to the relatively small differences in the limits of agreements.

Although the %CSA < 5 method is potentially suitable for evaluating pulmonary small vascular structures [3]

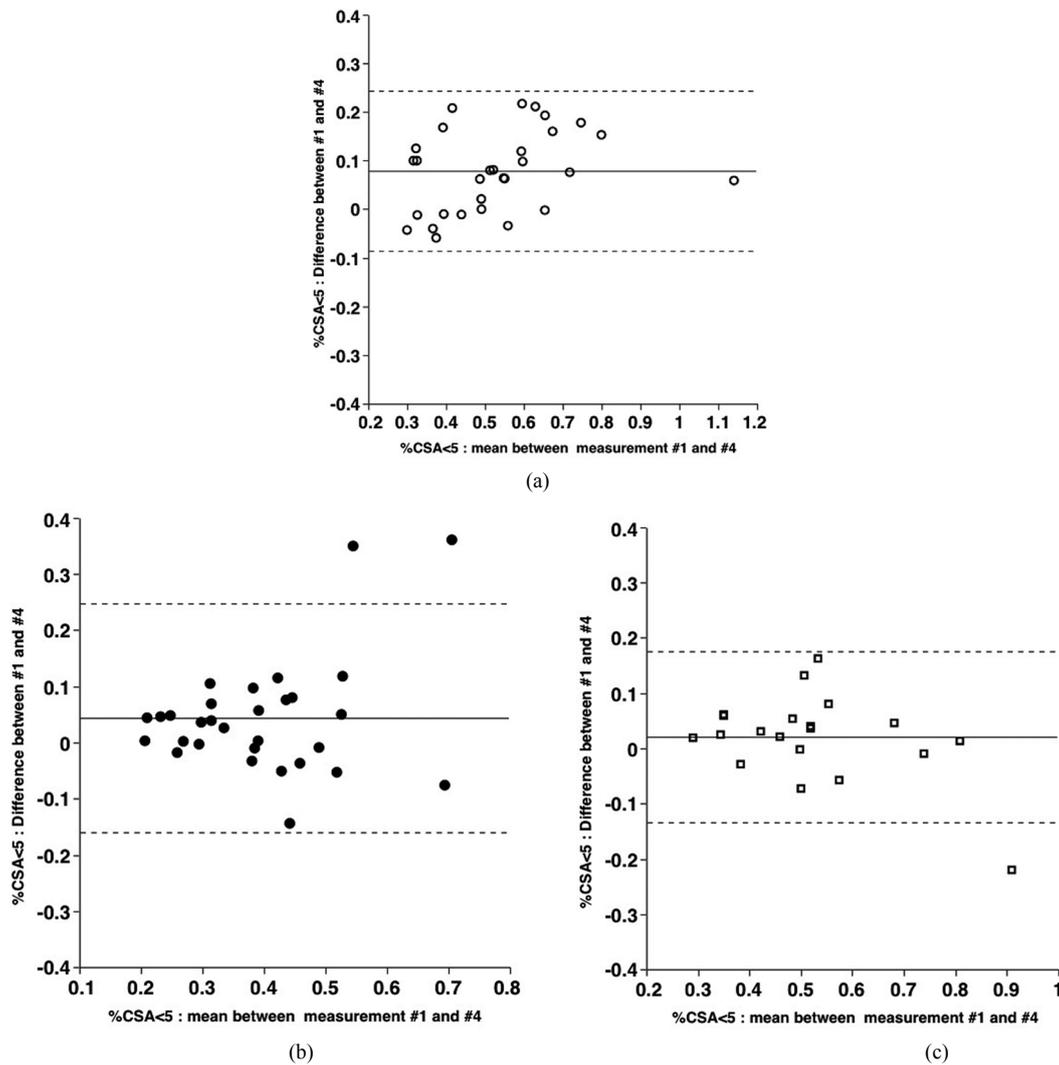


Figure 4. Bland-Altman plot of differences between %CSA-1 cm-interval (#1) and %CSA-3 slices (#4) against mean values, with mean absolute difference (continuous line) and 95% confidence interval of mean differences (dashed line). Patients without pulmonary diseases (a), with COPD (b) and with pulmonary embolism (c).

Table 1. Results of Bland-Altman analysis of all slices at 1-cm intervals.

	Mean difference ± SD	Limit of agreement
Normal		
%CSA-3 cm-interval	0.021 ± 0.067	-0.110 - 0.152
%CSA-6 cm-interval	0.005 ± 0.087	-0.165 - 0.175
%CSA-3 slices	0.078 ± 0.084	-0.087 - 0.243
COPD		
%CSA-3 cm-interval	0.010 ± 0.067	-0.121 - 0.141
%CSA-6 cm-interval	0.006 ± 0.085	-0.161 - 0.173
%CSA-3 slices	0.043 ± 0.104	-0.161 - 0.247
Pulmonary embolism		
%CSA-3 cm-interval	0.038 ± 0.059	-0.078 - 0.154
%CSA-6 cm-interval	0.042 ± 0.114	-0.181 - 0.265
%CSA-3 slices	0.020 ± 0.079	-0.135 - 0.175

[4]) and pulmonary perfusion [9], several issues should be addressed other than the optimum slice number. Firstly, we used a threshold value of -720 HU to identify vascular structures on CT images as described [3]-[9] and the optimum threshold should be determined in future studies. Secondly, the pulmonary artery and vein cannot be separately evaluated using this method. However, three-dimensional reconstruction of multi-slice CT images in conjunction with innovative image analysis software might overcome this limitation. In fact, measuring pulmonary vessel volumes $< 5 \text{ mm}^2$ has been introduced as a modification of $\% \text{CSA} < 5$ [10]. This method can evaluate whole lungs, but it does require in-house software. Multiplanar reconstruction (MPR) images might be more suitable for whole lung evaluations based on $\% \text{CSA} < 5$ values. However, both three-dimensional and MPR images require CT volume data and thus $\% \text{CSA} < 5$ measurements using axial slices might be still needed for the evaluation such as longitudinal studies in which volume data are unavailable.

This study has some limitations. Firstly, the sample size was relatively small. Secondly, we did not consider the extent of each disease, which might have affected the results. Thirdly, patients with pulmonary embolism were assessed by CT using contrast material, which might also have affected the results.

5. Conclusion

In conclusion, all slices at 3-cm intervals seemed to comprise the minimum optimum number required to measure $\% \text{CSA} < 5$.

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