Quantitative measurements in low-dose chest CT with hybrid iterative reconstruction technique

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Purpose

To evaluate the reliability of quantitative measurements in low-dose chest CT with hybrid iterative reconstruction technique from the perspective of applying prediction formula of PFT: pulmonary function test.

Methods and materials

Subjects

We retrospectively evaluated 3 adjusted-cohorts with normal chest CT findings in individual screening for lung cancer (Group A: n=42, Group B: n=27, and Group C: n=26). Inclusion criteria was as followings; consecutive subject of individual chest-CT screening for lung cancer, male, age ranged 35 to 75 years old, never or former tobacco smoker, and reported as no active pulmonary lesion (Table 1).

Table 1

<table>
<thead>
<tr>
<th>Group</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
<td>42</td>
<td>27</td>
<td>26</td>
</tr>
<tr>
<td>Age</td>
<td>51.5 ± 7.7</td>
<td>54.1 ± 10.2</td>
<td>53.6 ± 9.4</td>
</tr>
<tr>
<td>Body height</td>
<td>168.3 ± 4.7</td>
<td>169.2 ± 5.4</td>
<td>168.1 ± 5.5</td>
</tr>
<tr>
<td>Body weight</td>
<td>69.5 ± 8.7</td>
<td>67.9 ± 9.2</td>
<td>68.7 ± 8.6</td>
</tr>
<tr>
<td>Detector</td>
<td>16-row MDCT</td>
<td>256-row MDCT</td>
<td>256-row MDCT</td>
</tr>
<tr>
<td>Bender</td>
<td>TOSHIBA</td>
<td>Phillips</td>
<td>Phillips</td>
</tr>
<tr>
<td>Dose</td>
<td>Standard with REC</td>
<td>Low (50mAs)</td>
<td>Low (30mAs)</td>
</tr>
</tbody>
</table>
MDCT scan protocols and reconstruction algorithms

Standard-dose chest CT data for Group A were obtained using a 16-row MDCT system (Aquilion, TOSHIBA, Tokyo, Japan) with imaging parameters as follows; fixed tube current of 120 kVp, variable effective tube current time product from 100 to 300mAs with REC: real exposure control; slice-thickness, 10mm and 1mm, FOV: field-of-view, 320mm; and reconstruction algorithm, FBP: filter back projection. Low-dose chest CT studies for Group B and C were performed using a 256-section MDCT system (Brilliance iCT, Philips Healthcare, Cleveland, Ohio, USA). Imaging parameters were as follows: fixed tube voltage of 120kVp; slice-thickness, 3mm; FOV, 320 mm. Group B used 3 different reconstruction techniques (FBP/ iDose3/ iDose7) at effective tube current time product of 50mAs, and group C used modified iDose4 and 30mAs. Both CT scanner stability was routinely assessed with quality check-ups using a water cylinder phantom.

Quantitative MDCT measurements

All CT data sets were transferred to a commercially available workstation (Volume Analyzer, SYNAPSE-VINCENT, Fujifilm, Tokyo, Japan), which was equipped with an image analysis application for the lungs. Central airways including trachea and large bronchus were eliminated automatically from the volumetric MDCT data of the chest by density thresholding (Figure1);
Fig. 1: A volume rendering image for quantitative analysis of the lungs. The quantitative measurement were calculated automatically from both transparent lung fields on a workstation. Trachea and bronchial tree are excluded for the calculation with slice-thickness of 3mm and 1mm.

References: Radiology, Graduate School of Medicine, Kyushu University, Kyushu University Hospital - Fukuoka/JP

Pulmonary quantitative measurements were then automatically produced, including TLC-CT: total lung capacity of CT, MLD: mean lung density, and LAA%: percent low-attenuation area. The CT density numbers ranged in the histogram for each measurement as follows: from lowest to -250 HU: Hounsfield unit for TLC and MLD, and to -950 HU for LAA% (Table 2).

Table 2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Equation/Definition</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>TLC-CT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MLD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAA%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


TLC Cotes\(7.95\times H/100+0.003\times A-7.33\)\times 1000

\(JE\)

FVC Cotes\(7.74\times H/100-0.021\times A-7.75\)\times 1000

\(JE\)

RV Cotes\(2.16\times H/100+0.021\times A-2.84\)\times 1000

\(JE\)

FEV\(Cotes\(5.66\times H/100-0.023\times A-4.91\)\times 1000

\(JE\)

\[\text{FEV Cotes} = 10.2 + 3.1\times H/100 - 0.15\times A\]

\(1.0\%JE\)

FVC JRS2001\(20034.5\times H-0.023\times A-2.258\)\times 1000

FEV JRS2001\(20036.1\times H-0.028\times A-1.178\)\times 1000

FEV JRS2001\(20028\times H-0.19\times A\)

\(1.0\%\text{Gansler} 89.313\)

**Statistical analysis**

Results of the quantitative measurements were expressed as means ± the intermediate deviation of mean for the TLC, MLD, and LAA%. Correlation coefficient \((r)\) was evaluated between quantitative CT measurements and prediction formulas for PFT as follows; TLC-CT vs. TLC, RV: residual volume, FVC: forced vital capacity, age and BH: body height; MLD vs. FEV\(_1\): *forced expiratory volume in first second* and FEV\(_1\)%: forced expired volume as percentage of forced vital capacity; LAA% vs. FEV\(_1\) and FEV\(_1\)%.

Details of prediction formulas of PFT are shown in Table 2. Differences with \(P < 0.05\) were considered significant. And also, we performed regression analysis between TLC-CT and TLC in each group. All statistical analysis was performed using MedCalc (version 14.10.2, Ostend, Belgium).

**Images for this section:**
**Fig. 1:** A volume rendering image for quantitative analysis of the lungs. The quantitative measurement were calculated automatically from both transparent lung fields on a workstation. Trachea and bronchial tree are excluded for the calculation with slice-thickness of 3mm and 1mm.
Results

Summary of results

• TLC was a reliable measurement for chest CT in both standard and low dose settings (error range was less than 10ml).

• MLD and LAA% decreased with increasing the level of iDose factor at low-dose setting.

• LAA% distributed considerably low-value at low-dose setting, comparing to standard-dose setting with FBP.

• The predicted TLC showed statistically significant correlation to TLC-CT at both standard- and low- dose setting.

• The linear correlation of TLC-CT was decreased to RV but increased to FVC in low-dose setting.

• The slope of regression of the predicted-TLC to TLC-CT was larger with decreasing effective tube current time product.

All Results

Quantitative CT measurements for the normal lung with slice-thickness of 1mm and 10mm at standard effective tube current time product with real time exposure control (Group A: n=42) are shown in Table 3.

Table 3

<table>
<thead>
<tr>
<th>Group</th>
<th>Standard</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>FBP</td>
<td>FBP</td>
</tr>
<tr>
<td></td>
<td>10mm</td>
<td>1mm</td>
</tr>
<tr>
<td></td>
<td>10mm</td>
<td>vs. 1mm</td>
</tr>
</tbody>
</table>

| TLC-CT   | 5110.8±869.2 | 4918.9±852.3 | -191.9* |
| MLD      | -828.7±26.2  | -856.4±24.4  | -27.7*  |

(CT (ml))

MLD-828.7±26.2 vs. -856.4±24.4 (HU)
LAA 4.4±5.2±7.2*
%
(%) (°)

TLC-CT, MLD, and %LAA% are shown as mean with standard deviation. The difference of TLCs was equal to total volume of bronchial tree. The thicker the slice thickness, the more pulmonary structures are averaged to convert the voxel data, resulting in decreased MLD and LAA% at slice-thickness of 1mm. At the slice-thickness of 10mm, averaging effect and stair-step artifact were remarkable in the lung field (Figure 2-A).

Fig. 2: Typical volume rendering images for quantitative analysis of the lungs at standard dose using the data at slice-thickness of 10mm (A) and 1mm(B).

References: Radiology, Graduate School of Medicine, Kyushu University, Kyushu University Hospital - Fukuoka/JP If CT data was acquired in thin slices at 0.5 to 3mm, the large airway was automatically excluded (Figure 2-B). The slice thickness of 1cm are too thick, so that the software mistaken the large airway as the part of lung field for the quantitative calculation.
The TLC-CT ranged within 10ml (0.2%) at various reconstruction algorithms with effective tube current time product of 50mAs. The TLC-CT of 30mAs with modified iDose4 was almost 200ml larger than that of 50mAs with various reconstruction algorithms (Figure 3).

![Bar Graph of TLC-CT](image)

**Fig. 3**: Bar graph of TLC-CT. The TLC-CT ranged within 10ml (0.2%) at various reconstruction algorithms with effective tube current time product of 50mAs at slice thickness of 3mm, and at FBP with standard dose at slice thickness of 1mm. The increase of TLC-CT at slice thickness of 10mm was corresponding to the erroneous volume of bronchial tree. The considerable increase was observed in the TLC-CT at 30mAs about 200ml

**References**: Radiology, Graduate School of Medicine, Kyushu University, Kyushu University Hospital - Fukuoka/JP

The MLD of both groups showed similar CT number (Figure 4).
Fig. 4: Box and whisker plots of MLD. The MLD ranged about -850 to 800 HU at various reconstruction algorithms with effective tube current time product of 50mAs at slice thickness of 3mm. The MLD at 30mAs with modified iDose4 showed similar CT number. The thinner the slice thickness, the more the MLD was decreased at standard-dose with FBP.

References: Radiology, Graduate School of Medicine, Kyushu University, Kyushu University Hospital - Fukuoka/JP

The MLD and LAA% decreased according to the enhancement of iDose factor with effective tube current time product of 50mAs. LAA% was extremely affected in low dose setting with or without IR technique. (Table 4) (Figure 5).

Table 4

<table>
<thead>
<tr>
<th>Group</th>
<th>B&amp;B 50mAs</th>
<th>iDose4 50mAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLD</td>
<td>4897.5±904.5</td>
<td>4898.5±904.5</td>
</tr>
<tr>
<td>LAA%</td>
<td>4889.8±904.4</td>
<td>5125.2±870.0</td>
</tr>
</tbody>
</table>
TLC-CT (ml)

MLD 185±32.8 (HU)

LAA 40.0±20.2 % (%)

**Table 5:** Distribution plot of LAA%. The LAA% showed considerably narrow distribution at the low-dose, comparing to the standard-dose with FBP.

**Fig. 5:** Distribution plot of LAA%. The LAA% showed considerably narrow distribution at the low-dose, comparing to the standard-dose with FBP.

**References:** Radiology, Graduate School of Medicine, Kyushu University, Kyushu University Hospital - Fukuoka/JP

TLC-CT showed a weak, but repeatable correlation to the prediction formula of TLC (rho=0.33-0.60, p<0.05) in Table 5.
The TLC-CT and body height showed statistically significant correlation to the prediction formula of PFT at all setting. The linear correlation were decreased to RV but increased to FVC in the low-dose setting. At effective tube current time product of 30mAs with modified iDose4, FVC showed statistically significant correlation to TLC-CT.

Table 6

Linear correlation coefficient of predicted PFT values for MLD (r) is shown in Table 6. The positive correlation coefficient of FEV1% to MLD was diminished at the low-dose. No significant correlation was observed between the prediction formula of PFT and the MLD.
Linear correlation coefficient of predicted PFT values for LAA% (r) is shown in Table 7. The negative correlation coefficient of FEV1%-JRS for LAA% was decreased at low-dose setting. No significant correlation was observed between the prediction formula of PFT and the LAA%. Linear regression is shown between predicted TLC of PFT and measured TLC-CT. In the range of ±2.0 SD for the predicted TLC, the slope of regression line was larger with increasing effective tube current time product (Figure 6).
**Fig. 6:** Linear correlation coefficient of predicted PFT values for TLC-CT (r). The TLC-CT and body height showed statistically significant correlation to the prediction formula of PFT at all setting. The linear correlation were decreased to RV but increased to FVC in the low-dose setting. At effective tube current time product of 30mAs with modified iDose4, FVC showed statistically significant correlation to TLC-CT.

**References:** Radiology, Graduate School of Medicine, Kyushu University, Kyushu University Hospital - Fukuoka/JP

**Images for this section:**

![Image](image1.png)

**Fig. 1:** A volume rendering image for quantitative analysis of the lungs. The quantitative measurement were calculated automatically from both transparent lung fields on a workstation. Trachea and bronchial tree are excluded for the calculation with slice-thickness of 3mm and 1mm.
Fig. 2: Typical volume rendering images for quantitative analysis of the lungs at standard dose using the data at slice-thickness of 10mm (A) and 1mm(B).
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Fig. 4: Box and whisker plots of MLD. The MLD ranged about -850 to 800 HU at various reconstruction algorithms with effective tube current time product of 50mAs at slice thickness of 3mm. The MLD at 30mAs with modified iDose4 showed similar CT number. The thinner the slice thickness, the more the MLD was decreased at standard-dose with FBP.
Fig. 5: Distribution plot of LAA%. The LAA% showed considerably narrow distribution at the low-dose, comparing to the standard-dose with FBP.
**Fig. 6:** Linear correlation coefficient of predicted PFT values for TLC-CT (r). The TLC-CT and body height showed statistically significant correlation to the prediction formula of PFT at all setting. The linear correlation were decreased to RV but increased to FVC in the low-dose setting. At effective tube current time product of 30mAs with modified iDose4, FVC showed statistically significant correlation to TLC-CT.
Conclusion

The TLC-CT was a reliable measurement in both standard and low dose setting from the perspective of applying prediction formula for PFT. The MLD and LAA% did not show significant linear correlation in both standard and low dose setting to prediction formula for PFT. Quantitative assessments of chest CT in low-dose setting with hybrid IR should be carefully implemented in individual screening or clinical practice.

Personal information

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