Integrated Intensity-based Quantification of Small Airway Dimensions using Computed Tomography

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INTRODUCTION

Small airway dimensions with luminal diameter less than 2mm are important biomarker for the airway obstruction disease such as asthma and chronic obstructive pulmonary disease (COPD). CT quantification is of great importance to provide insights into pathological changes in small airways for patients with COPD[1].

AIM

To validate an integrated intensity-based (IIB) method in small airway evaluation by comparing it to known dimensions and a standard full-width half-maximum (FWHM) method.

METHOD

Phantom Settings:

A 10-cm diameter cylindrical polyurethane foam mimicking lung parenchyma was fitted in an anthropomorphic QRM-Thorax phantom.

- 14 silicone tubing simulating airways: inner diameter (ID), 0.3-3.4 mm; wall thickness (WT), 0.15-1.6mm.

CT Imaging:

CT scanner (Aquilion ONE, Canon Medical)

- 320 × 0.5 mm; 350ms rotation time; 80,100 and 120 kV; 50 and 200 mA; 0 or 30° oblique angles between scan slices and the phantom;
- Filtered back projection (FBP) and adaptive iterative dose reduction (AIDR 3D) algorithms; slice thickness (0.5 mm); lung kernels (FC30, FC52, FC56).

Airway Dimension Measurement:

Semi-automated integrated-HU method (**IIB**) (**Figure 1**)

- Concept: Although the signal of each voxel is affected by the partial volume effect, the integrated HU within a region of interest is conserved.
- Three materials with known HU: air (S_o), wall material (S_w), background (S_{bg}).
- Total HU within R1: $I_1 = A_I S_o + A_W S_w + (R1 - A_I - A_W) S_{bg}$
- Total HU within R2: $I_2 = A_I S_o + (R2 - A_I) S_W$
  - If $S_{bg} \approx S_o$, wall area: $\boldsymbol{A_W = (I_1 - R_1 S_{bg})/(S_w - S_{bg})}$
  - Inner luminal area: $\boldsymbol{A_I = (I_2 - R_2 S_w)/(S_o - S_w)}$

Automated full-width half-maximum (**FWHM**) method

RESULTS

Integrated-HU based method

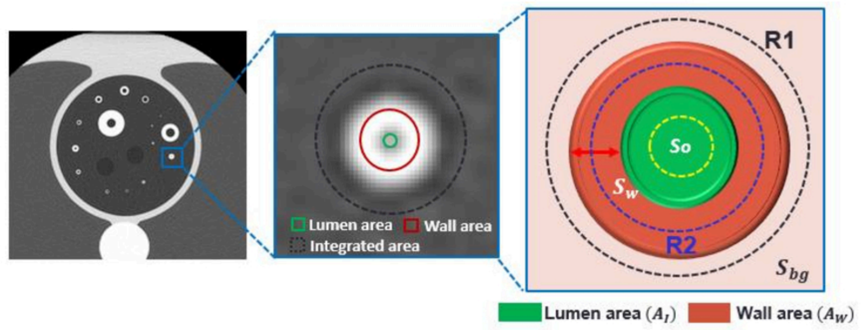

Figure 1. Representative phantom image and integrated-HU method (IIB). *An expansion of one tubing is shown for wall thickness and inner diameter measurements. S_o: pure air HU; S_W: wall material HU; S_{bg}: background HU; A_I:lumen area; A_W:wall area; regions-of-interest (R1, R2).*

Partial Volume Effect

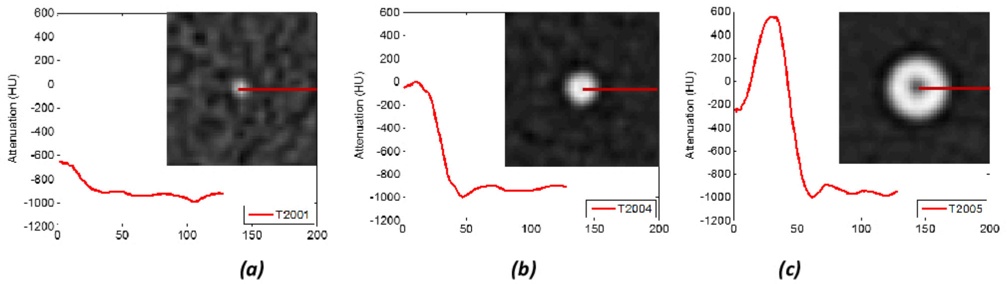

Figure 2. Profiles of representative tubing with partial volume effects. *Each profile is casted from the center of the tubing. (a)ID=0.3mm, WT=0.15mm; (b) ID=0.8mm, WT=0.45mm; (c) ID=0.8mm, WT=1.58mm.*

Mean percent error

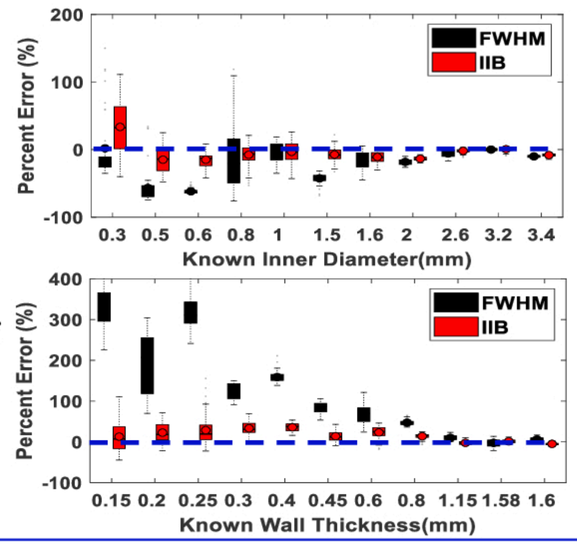

Figure 3. Box-plot of mean percent error over all measurements *using IIB and FWHM methods. Data shown in the graph were acquired and reconstructed using different CT parameters.*

$$Percent\ Error = \frac{CT\_Mesured - Reference}{Reference} \times 100\%.$$

Linear regression analysis

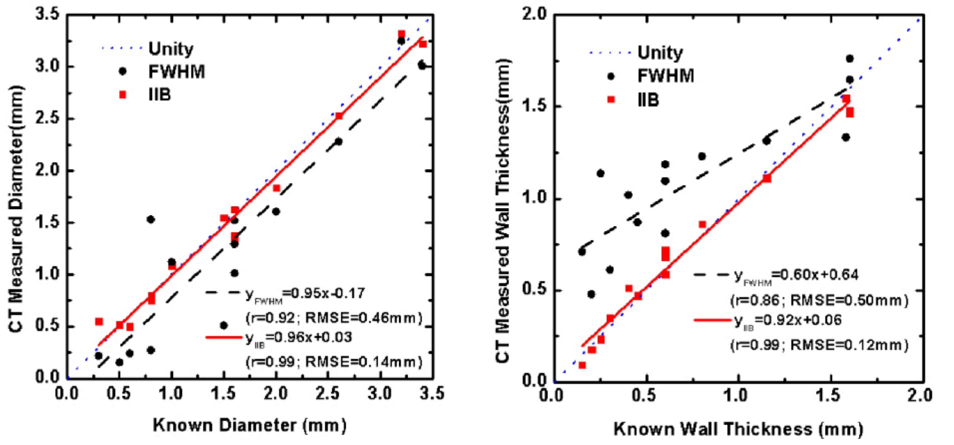

Figure 4 . Linear regression analysis of tubing dimension measurements*. RMSE: Root mean square error. Data shown in graph was acquired at 120 KV, 200 mA and reconstructed with the FBP algorithm using FC30 kernel.*

Reliability analysis

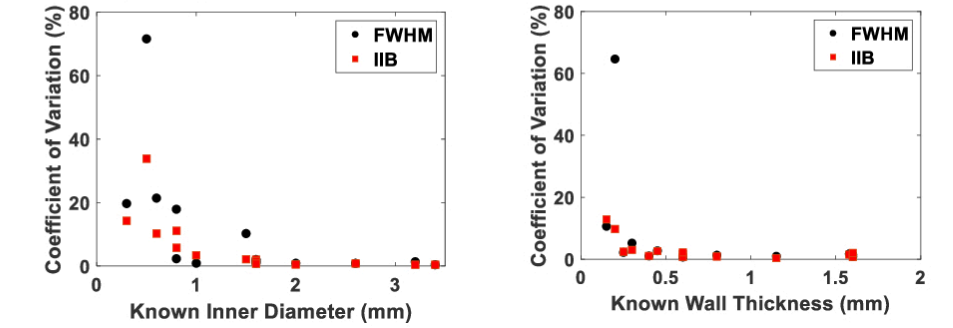

Figure 5. Reliability of tubing dimension measurements. *The coefficient of variation (CV) is calculated from independent realizations of each tubing dimension of the standard deviation (SD) and he mean. CV = SD/Mean. Data shown in graph was acquired at 120 KV, 200 mA and reconstructed with the FBP algorithm using FC30 kernel.*

Effects of CT parameters

- **Radiation dose:** As the dose decreased from 9.7 to 0.7 mGy, the mean percent errors of inner diameter and wall thickness using the IIB increased from 1.2% to 13.3% and 2.5 % to 28.9%, respectively; while using the FWHM, the mean percent errors remained consistent at approximately 21.0% and 107.8%, respectively.
- **Reconstruction :** No significant differences were found between various reconstruction algorithms and kernels using both IIB and FWHM methods.
- **Tilted angle:** No significant differences were found between 0 and 30° tilted angles using both IIB and FWHM methods.

SUMMARY

- The inner diameter can be measured within 15% error down to approximately **16th (ID~0.6 mm) and 7th (ID~2 mm)** generation airways using the IIB and standard FHWM techniques, respectively.
- The **mean error of inner diameter** using the FHWM and IIB techniques were 0.18 mm (27.7%) and 0.14 mm (13.5%), respectively.
- The **mean error of wall thickness** using the FHWM and IIB techniques were 0.37 mm (107.8%) and 0.09 mm (19.8%), respectively.
- CT dose index: 0.7-9.7mGy.

CONCLUSIONS

The new integrated intensity-based technique(IIB) enables accurate quantification of small airway dimensions, which can potentially be used for assessment of small airway disease such as asthma and COPD.

ACKNOWLEDGEMENTS

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REFERENCES

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