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Quantifying the Accuracy of AirQuant Airway Measurements of to-Scale 3D Airway Models

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ABSTRACT

Purpose: To quantify the accuracy of airway measurements using AirQuant on to-scale airway models.

Methods: Six lobar airway models based on airway measurements of three patients using AirQuant were 3D-printed. The modeling pipeline generates a signed distance field of blended hollow tapered capsules based on patient anatomy with known luminal radii, luminal area, and wall thickness. In total, 123 distance airways were printed and measured. CT scans were collected of the models submerged in rice, mimicking lung parenchyma. AirQuant was then used to measure airway metrics from these scans. CT-derived metrics were then compared to the known model dimensions. For each metric, average error and standard deviation were calculated. Bland Altman analyses were run to determine mean bias.

Results: The models had a mean luminal radius of 1.87 mm (range: 0.69 mm – 5.92 mm, the AirQuant-measured CT scans of the model ("CT") had a mean of 1.98 mm (range: 0.76 mm – 7.16 mm). The average absolute error between the CT luminal radius and the model dimensions was 0.19 mm ($p = 5E-6$). The model had a mean wall thickness of 1.15 mm (range 0.80 – 2.05 mm); the CT had a mean thickness of 1.62 mm (range: 1.33 – 2.39 mm). The wall thickness average absolute error was 0.532 mm ($p = 2E-24$). The model luminal area had a mean of 13.63 mm^2 (range: 1.71 - 113.07 mm^2); the mean CT luminal area was 15.00 mm^2 (range: 2.26 - 165.74 mm^2). The luminal area average absolute error was 3.28 mm^2 ($p < 0.001$).

Conclusion: While paired t-tests indicate that AirQuant measurements are significantly different from the model dimensions, the mean error for luminal radius is smaller than a high-resolution CT slice of 0.5 mm, meaning AirQuant is accurately measuring dimensions to within one voxel. The mean error for wall thickness was similarly close to 0.5 mm. The error magnitude suggests that AirQuant can reliably quantify differences in luminal and outer radii in patient CT scans.

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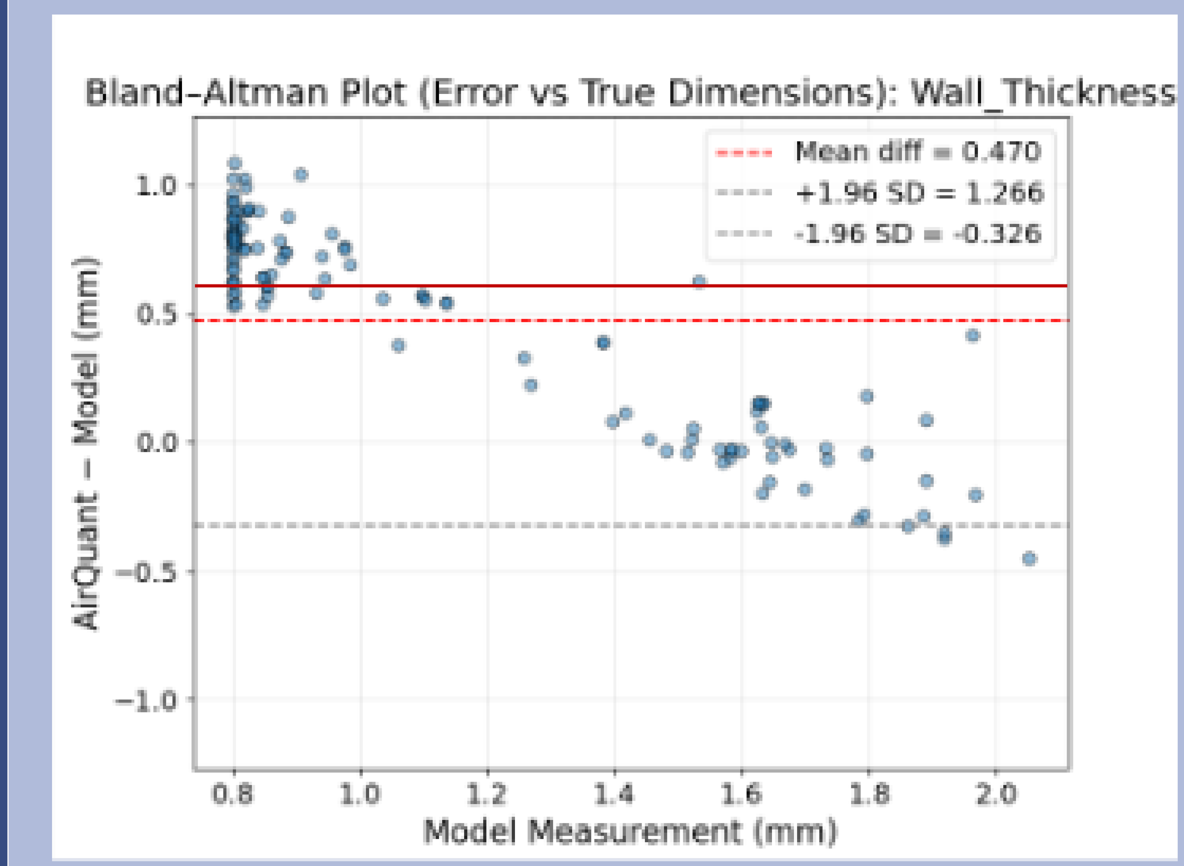
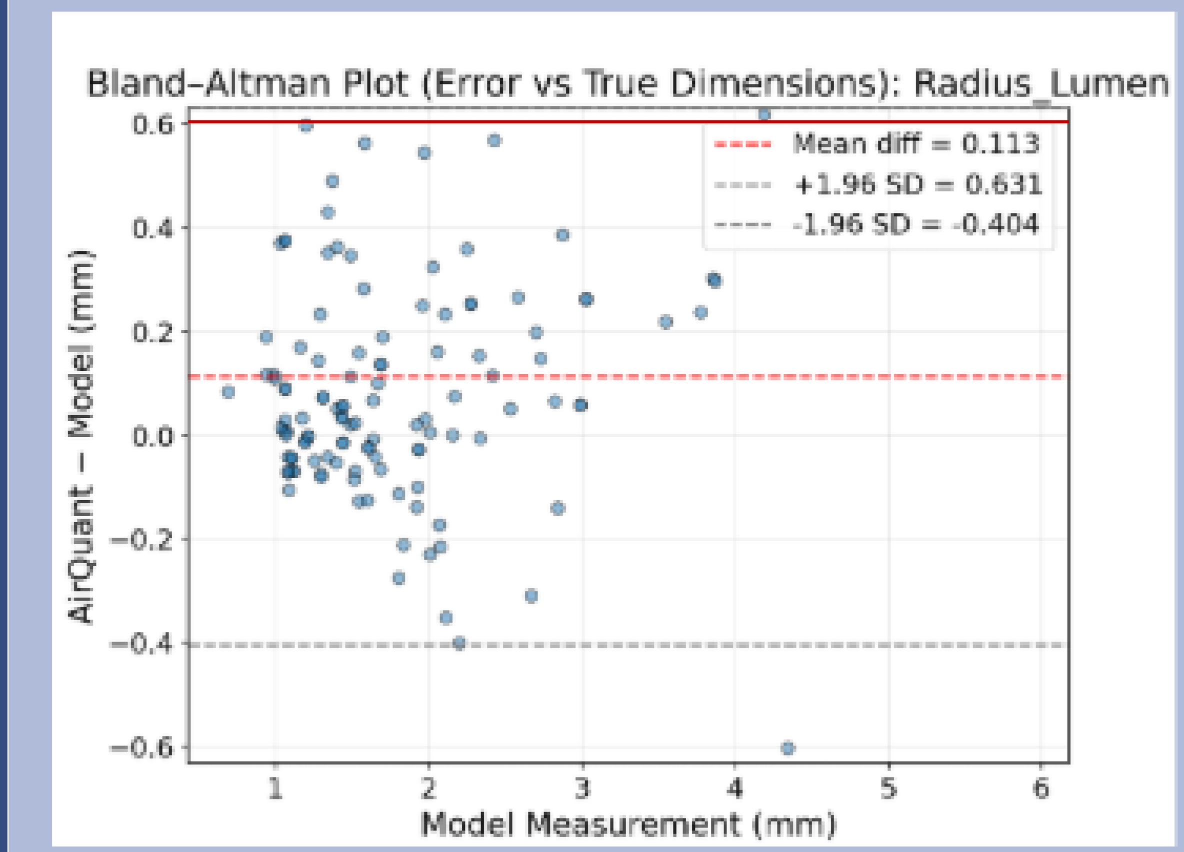
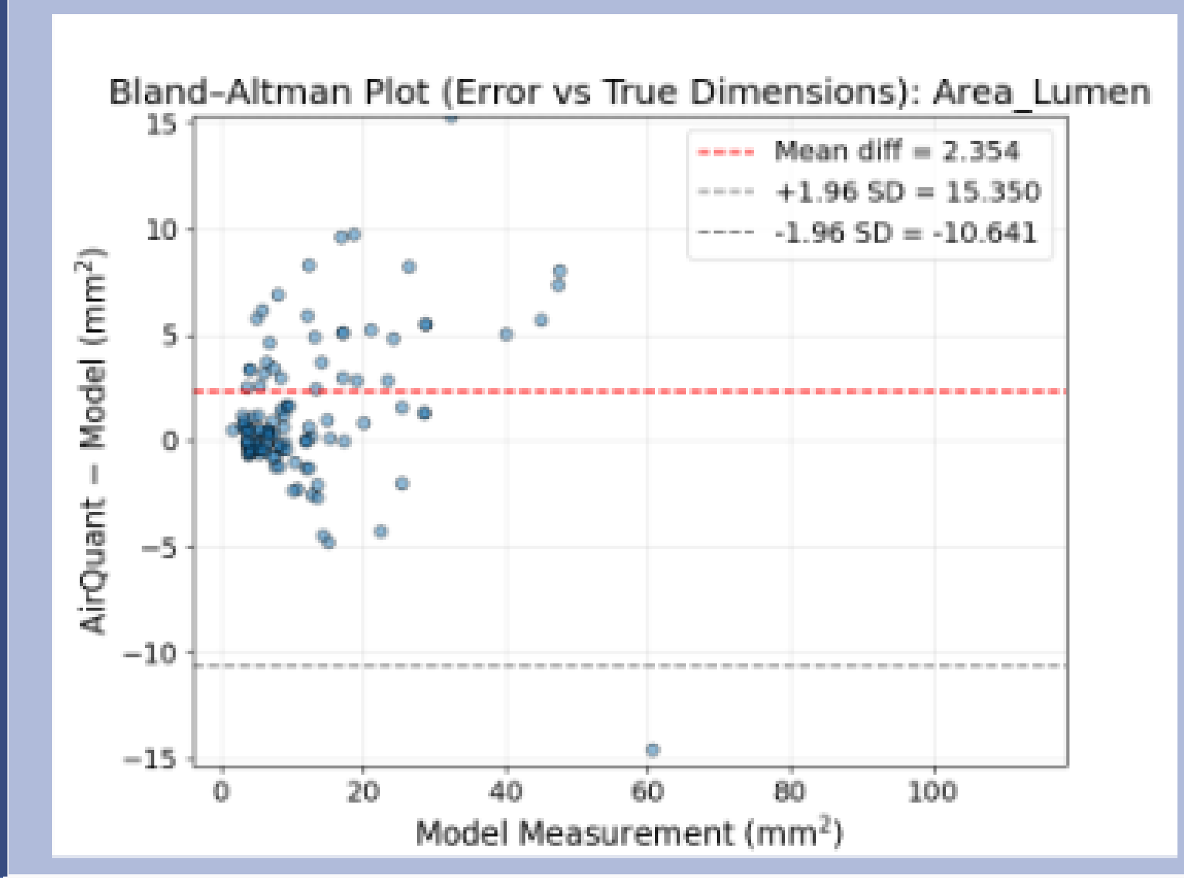
INTRODUCTION

- AirQuant[1] is a valuable, non-invasive tool for measuring patient airway metrics from CT images.
- AirQuant has been previously validated with hollow, cylindrical tubes of varying diameters, curvatures, and limited tapering, placed in rice to represent airways in lung parenchyma[2,3].
- Tubes used for validation did not represent common anatomical variations (i.e., tortuosity, diameter change, surface irregularity, and branching).
- This study employs 3D models of lobar airway trees created based on real anatomical variations in airways. in measuring luminal radius and area, and wall thickness when encountering surface irregularity, diameter change, branching, and tortuosity seen in real airways.
- The aim the study is to investigate AirQuant's accuracy

RESULTS

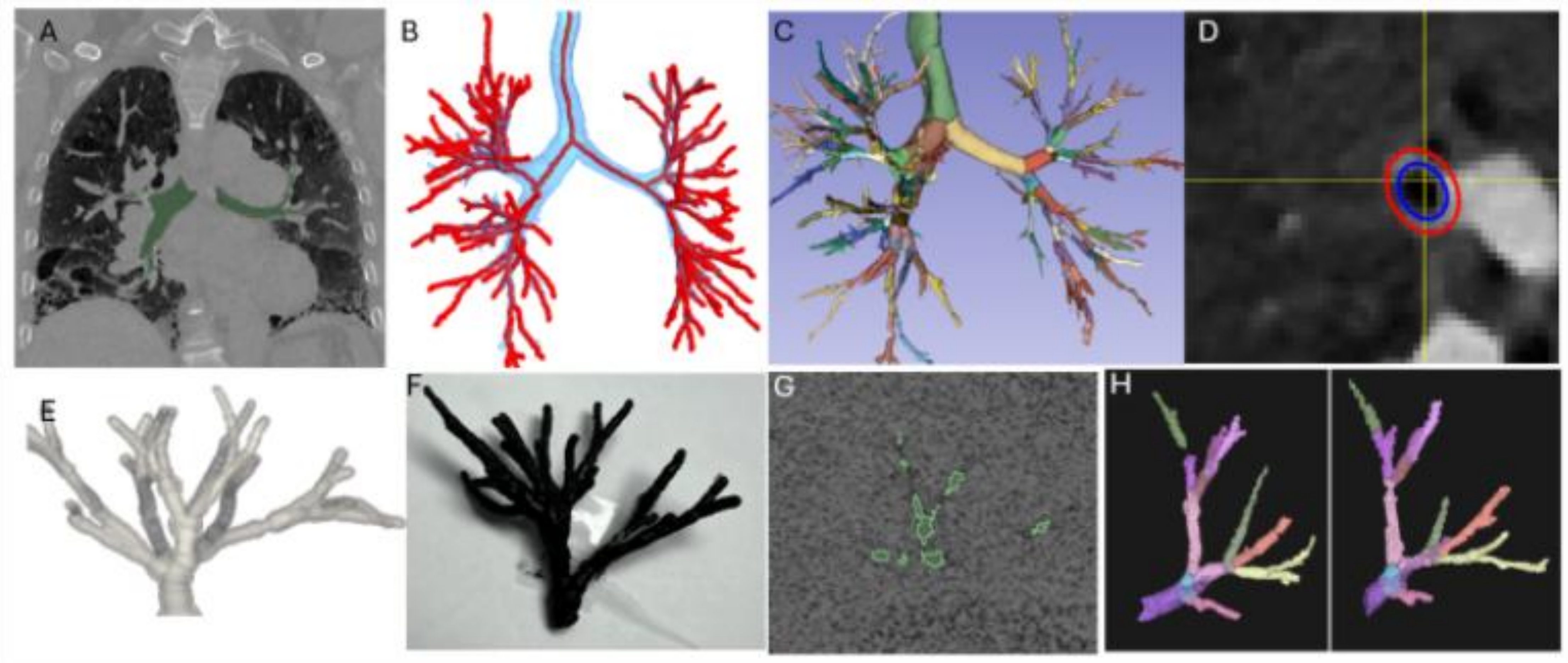






METHODS AND MATERIALS

STEP 1: Airway Model Creation and Processing



A. CT images of real patients' airways are collected and segmented → **B.** The segmentation is skeletonized to define a centerline → **C.** The centerline is parcellated into individual branches then applied to the segmentation. → **D.** Centerlines guide AirQuant in measuring radii of wall (red) and lumen (blue) in planes orthogonal to the centerline at several points.

E. Real airway measurements are used to create an anatomical model using signed distance fields with known radii and wall thickness, establishing ground truth. → **F.** The model is printed using a resin 3D printer with Uncertainty of +/- .25mm for a 10mm object. → **G.** Printed airways are scanned and segmented, then the AirQuant analysis process is repeated. → **H.** Branches from segmented model and patients segmented airways priors are matched for comparison.

STEP 2: Airway Measurement Comparison

Once each step above was completed, the AirQuant measurements for luminal radius, luminal area, and wall thickness derived from the CT of the model were compared to the model dimensions in a Python script that ran Bland-Altman Analyses and paired t-tests on the signed error to analyze how close AirQuant measurements were to ground truth.

DISCUSSION

- A high-resolution CT has slice-thickness of 0.6 mm (as indicated with the solid red line on the luminal radius and wall thickness plots), so most errors < .6 mm reported are not clinically significant.
- When compared to ground truth, the mean error for luminal radius 0.113 mm, and the luminal area is calculated using the measured radius.
- When compared to ground truth, the mean error for wall thickness was 0.47 mm.
- The error magnitudes suggest that AirQuant can reliably quantify differences in luminal and outer radii, and thus luminal area and wall thickness, from patient CT scans, to within one voxel. Thus, the AirQuant measurements are clinically reliable, even when measuring airways on the sub-mm level, with common anatomical variations.

CONCLUSIONS

- AirQuant's measurements are statistically significantly different than the expected measures from the model.
- Given that AirQuant's error magnitude is smaller than the resolution a CT slice, this difference is not *clinically* significant.
- This study suggests the reliability of AirQuant in clinical airway measurements.

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