Development of 3D Models to Represent Thoracic Morphology Variation and Assist in Surgical Rib Fixation for Chest Trauma Patients

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Introduction/Objective

Blunt chest trauma accounts for 15% of all U.S. trauma admissions, with up to 85% of these cases involving rib fracture. Rib fractures can impair normal inspiration, requiring prolonged mechanical ventilation and leading to poorer patient outcomes. Surgical rib fixation has proven effective in decreasing ventilation time and overall mortality rate as a result of chest trauma. However, the diversity of thoracic morphology presents a challenge as rib fixation plates are generally contoured to the patient during an operation, prolonging surgery and requiring a more invasive procedure. Recent studies have shown that utilizing subject-specific 3D models of the rib cage to pre-operatively contour plates and inform surgical maneuvers can considerably reduce surgical time and improve patient outcomes. Nonetheless, patient-specific models are not economically feasible or time-efficient in emergent cases. This study investigated thoracic dimensional variability with age and sex and defined representative morphological subgroups to inform the development of three dimensional (3D) rib cage models.

Methodology

The rib cage was segmented from normal patient computed tomography (CT) scans using semi-automated and manual methods. Custom MATLAB code was used to adjust segmentation point clouds about the y- and z-axes to ensure uniform orientation of the rib cages prior to measurement collection. A bounding box created from each point cloud matrix was used to measure individual chest height, width, depth, and volume. Subject measurements were defined as small, medium, or large based on tertiles. Six morphological subgroups were generated focusing on individuals with small or large chest dimensions since they represented the extreme cases within this dataset. From each subgroup, a representative subject was chosen for the development of full 3D thoracic models, including all bone, soft tissue, and costal cartilage. A patient fit calculator was designed utilizing correlation coefficients to aid clinicians in determining which subgroup model developed would be the closest match for use in pre-operative planning for a given patient.

Results/Conclusions

Subjects ranging in age from 10-80 were analyzed (74 females, 67 males; ~20 subjects/age decade). Chest volume as a representation of total chest dimensions tended to increase with age (**Figure 1**), and average values differed between ages 10-30 vs. 50-80 (mean±SD: 15,852±3,851 vs. 21,852±5,581 cm^3; $p<0.001$). Within each age decade, chest volume varied substantially (SD: ±5,988 cm^3) likely due to thoracic size differences between males and females. Average chest volume for females (15,968±3,029 cm^3) was approximately 37% less than males (21,918±5,029 cm^3).

The full thoracic 3D models developed consisted of 3 males (ages 16, 24, 44) and 3 females (ages 19, 50, 53) (**Figure 2**). By focusing on subgroups with small or large chest dimensions, these models cover a broad range of thoracic morphologies and can serve as a basis for device design testing, computational modeling applications, as well as preoperatively planning. Compared to subject-specific models, these representative models serve as a cost- and timeefficient alternative for implementation in thoracic trauma cases where rapid decision-making, acute anatomical knowledge, and prompt intervention are necessary for success.

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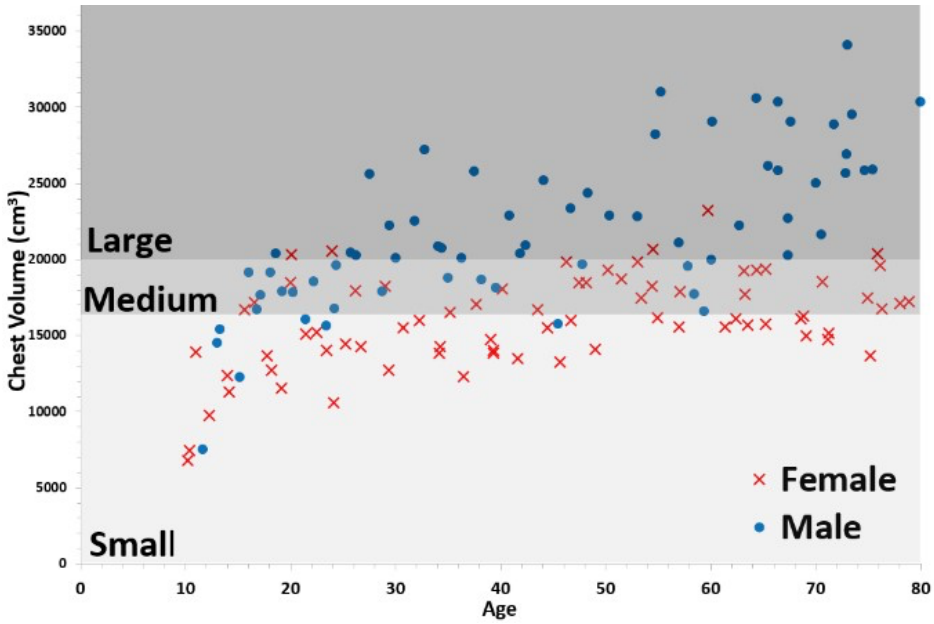
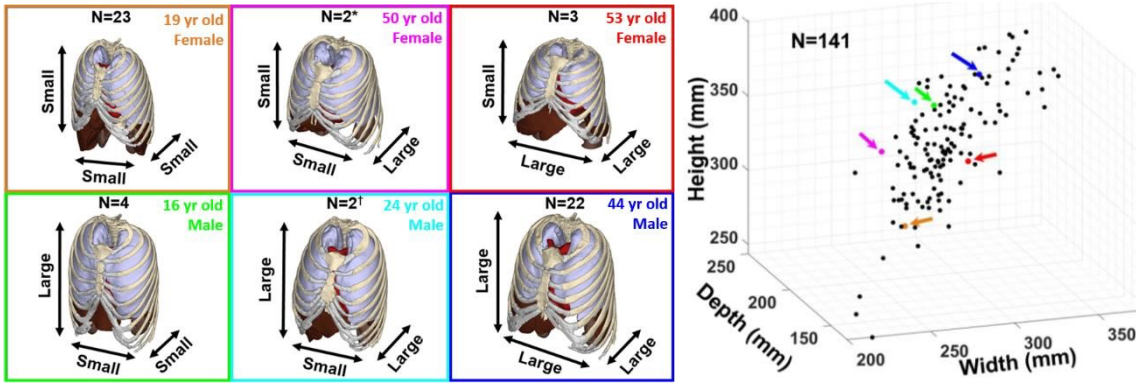


Figure 2. Chest volume for all 141 subjects aged 10-80 years old grouped by male (n=67) and female (n=74).



a) **b)**

Figure 1. a) 6 morphology subgroups, *also includes small height with large width/small depth, † also includes large height with large width/small depth. **b)** Chest measurements for all 141 subjects with models selected for 3D development