# A Parametric Thoracic Spine Model Accounting for Geometric Variations by Age, Sex, Stature, and Body Mass Index

Lihan Lian, Michelle Baek, Sunwoo Ma, Monica Jones, and Jingwen Hu

## Introduction

Crash statistics have shown that vertebral fractures in motor-vehicle crashes are on the rise. As automated driving technologies are realized, occupants sitting in more reclined postures are likely to experience higher spinal injury risks. Moreover, female, older, and obese occupants have been reported to incur higher risks of spinal injuries compared to midsize young males. Therefore, a parametric model of Tspine that can account for the morphological variations of a diverse population is needed to achieve improved safety equity.

## Objective

The objective of this study is to develop a parametric thoracic spine (T-spine) model that can account for the morphological variations among the adult population.

## Methodology

In this study, CT scans from 101 subjects were collected. CT segmentation, landmarking, and mesh morphing were applied to map a mesh template onto the T-spine vertebral geometry for each subject. Generalized Procrustes Analysis (GPA), Principal Component Analysis (PCA), and regression analysis were performed to develop a 3D parametric geometry model of each T-spine vertebra and spinal curvature. The 12 vertebral models and the spinal curvature model were combined to predict the complete T-spine geometry for a given set of subject covariates; specifically, age, sex, stature, and body mass index (BMI).

## Results and Conclusion

The statistical T-spine geometry model based on the 101 subjects will be presented. All subjects are without skeletal pathology and are evenly distributed between men and women with ages of 17-93 years, stature of 150-200cm, and BMI values of 17-55 kg/m2.

Significant morphological variations exist in the T-spine across the sampled subjects. Dimensional trends showed that both vertebral height and depth increased consistently from T1 to T12, while vertebral width decreased from T1 to T3 and then increased from T4to T12, indicating a necking effect around T3/T4. A wedging ratio, the ratio of the anterior to posterior height of the vertebral bodies, was observed to range from 0.9 to 0.95 for T1-T12. Statistical analyses found a significant effect of age on the T-spine curvature and vertebral body wedging ratio, as older subjects tend to have more kyphotic curvatures. Stature had a significant effect, especially on the vertical height, which also had a profound impact on the geometric differences between women and men. A leave-one-out Root Mean Square error (RMSE) analysis was conducted for each node of the mesh predicted by the statistical model for every T-spine vertebra. Most of the RMSEs were less than 2 mm across the 12 vertebral levels, indicating good accuracy. Model accuracy decreased slightly for the tip of the spinal process and facet capsules, which is likely due to difficulty associated with segmenting and landmarking these sub-regions. The presented parametric T-spine model can serve as a geometry basis for parametric human modeling or future crash test dummy designs to better assess T-spine injuries accounting for human diversity.