Parametric Modeling of Cervical Spine Geometry Across Diverse Populations

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Introduction

Background

- According to the Freeman & Leith, there are 869,000 new cases of cervical spine injuries in the U.S. annually caused by motor vehicle accidents (MVA), with about 1,500 causing vertebrae dislocations (Freeman et. al, 2020).
- Current computational human model accounts for only three sizes and shapes of the human body (Small female, midsize male, and large male) (Hu and Jones, 2021).
- Finite element models, which simulate crash injuries and body responses, are very timely and costly to generate, so most standard models are based around the average 50th percentile male body (Hu and Jones, 2021).

Objectives

- To create parametric models of the cervical spine (c-spine) and to quantify the effects of sex, age, size, and BMI on bone geometry.
- To create diverse population of models to allow for more accurate simulations of injury as well as identify points of vulnerability in crash scenarios.

Methods

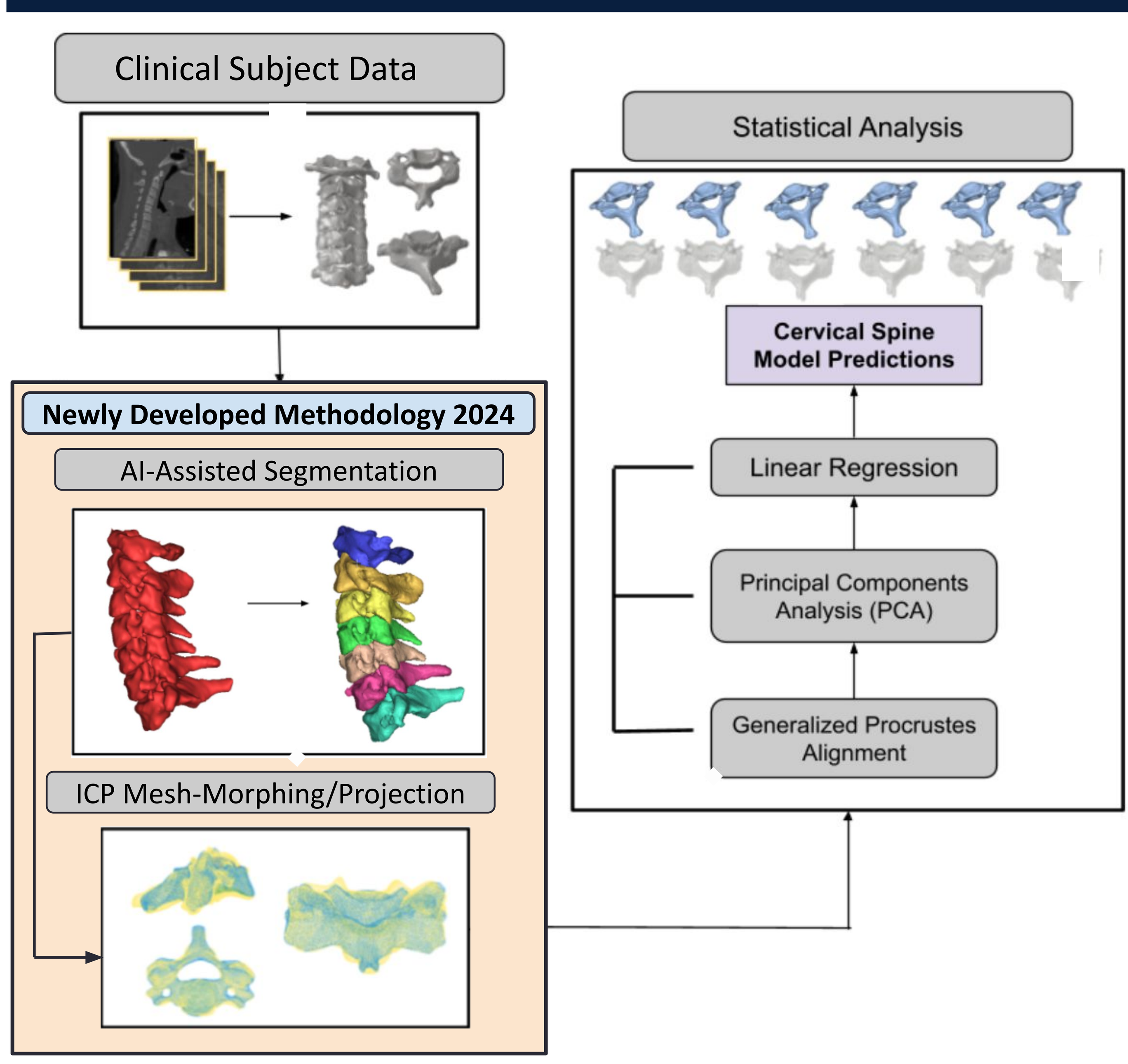


Figure 1. Graphical flow chart documenting the methodology. Notable methods that improved efficiency include an AI-based segmentation (TotalSegmentator) and a non-rigid ICP to improve for morphing.

Conclusions

- Parametric human modeling can be achieved by integrating large quantities of data with subjects with a wide range of characteristics (e.g. gender, BMI, age).
- The cervical spine sub-team developed an advanced segmentation protocol, which includes the TotalSegmentator tool and made further strides in statistical analysis, which was implemented to segment **827** additional subjects, post-process **314** subjects, and analyze **170** subjects to optimize the diversification of cervical spine modeling.
- This expansion of the dataset allows for the implementation of a vehicle safety design that protects vulnerable populations.

Acknowledgement

The completion of this undertaking could not have been possible without the guidance and the instruction from the faculty, alongside the work of the previous cervical spine team. The University of Michigan Transportation Research Institute (UMTRI) and the Multidisciplinary Design Program (MDP) have also greatly supported the progress and findings of this research.

Subject Distribution (n = 314) and Post-Processed Examples

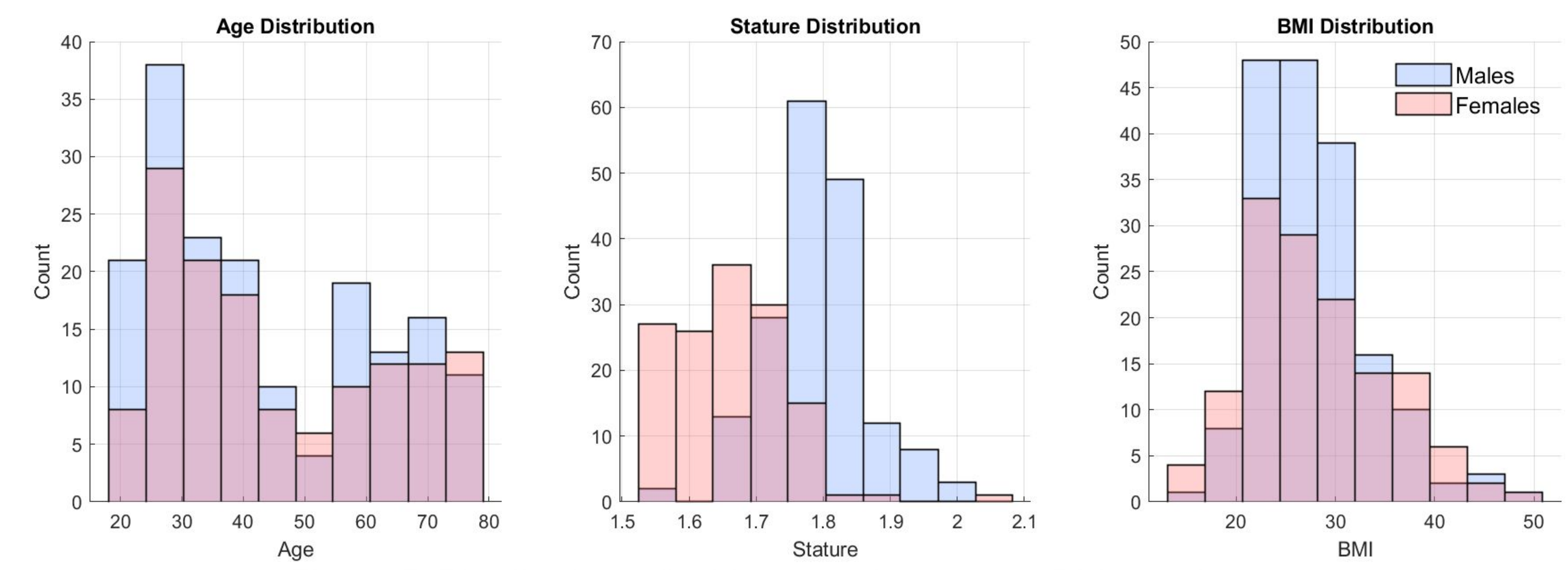


Figure 2. Distributions of subject covariates across 314 samples.

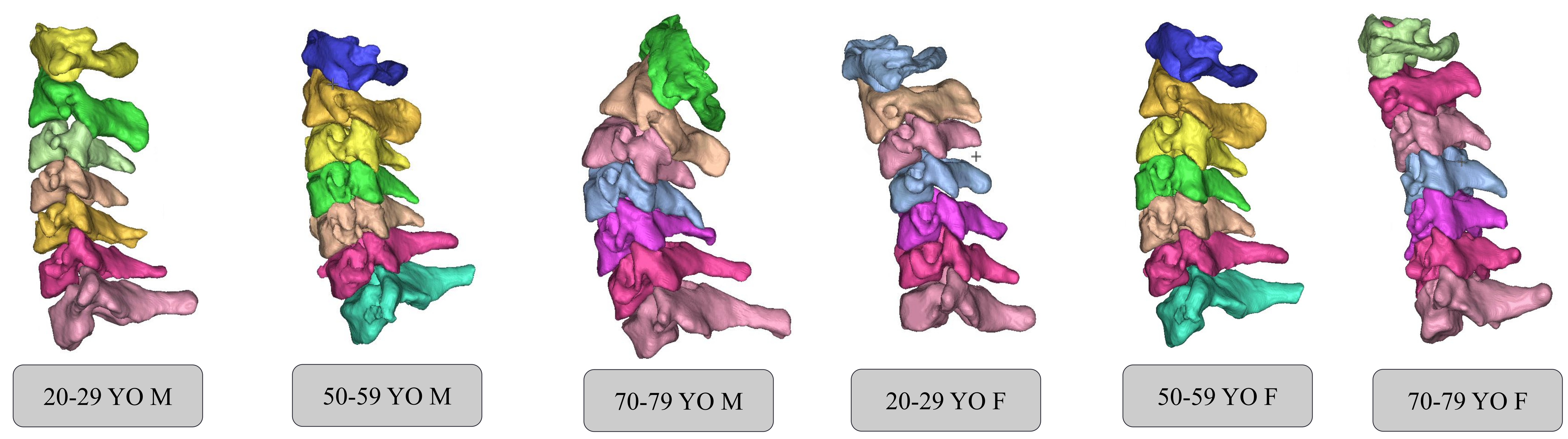


Figure 3. Examples of post-processed subjects after AI-assisted segmentation over various age ranges.

Results

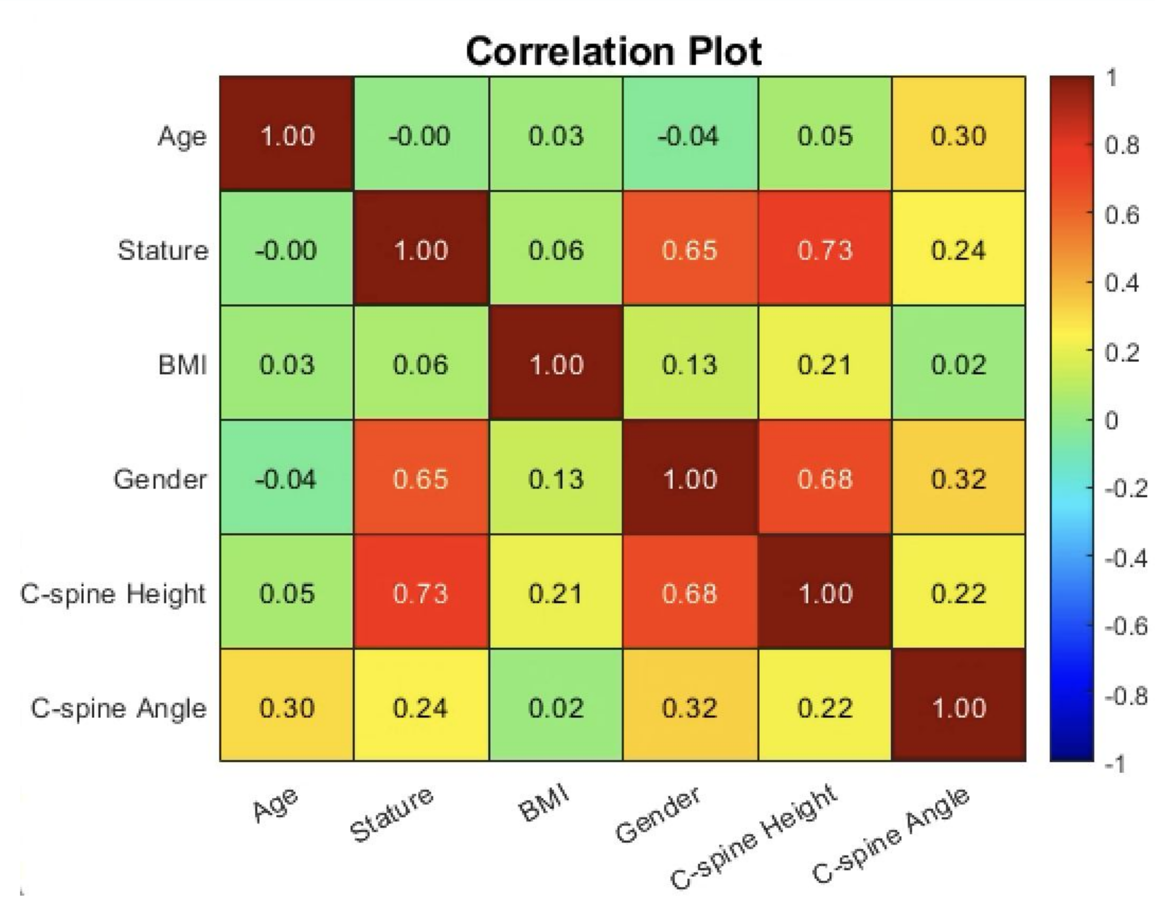


Figure 4. Correlations among the six features used as predictors in regression analysis.

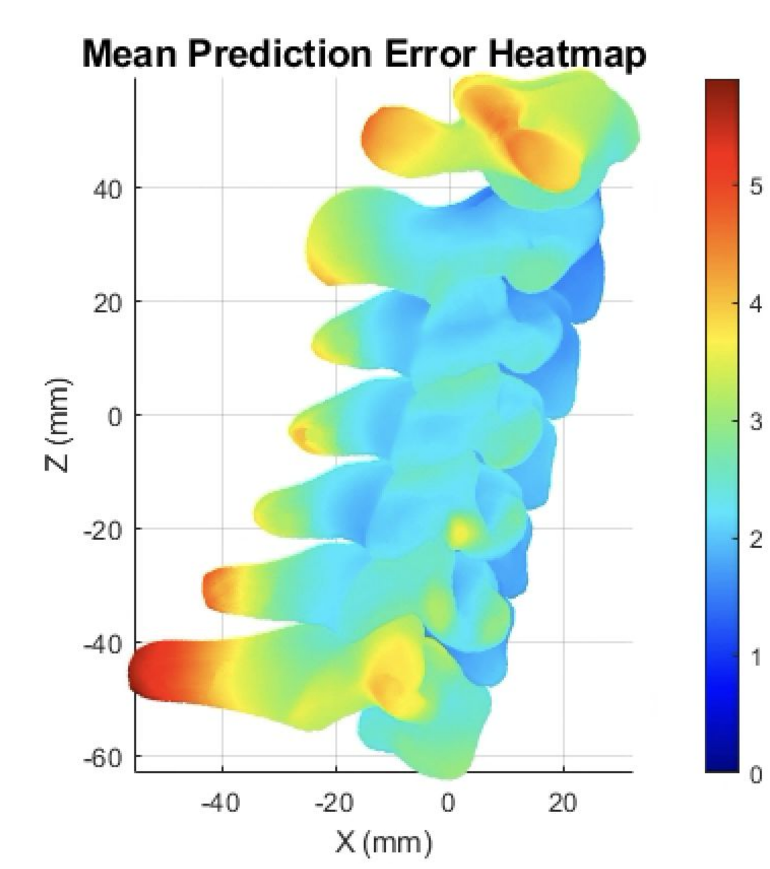
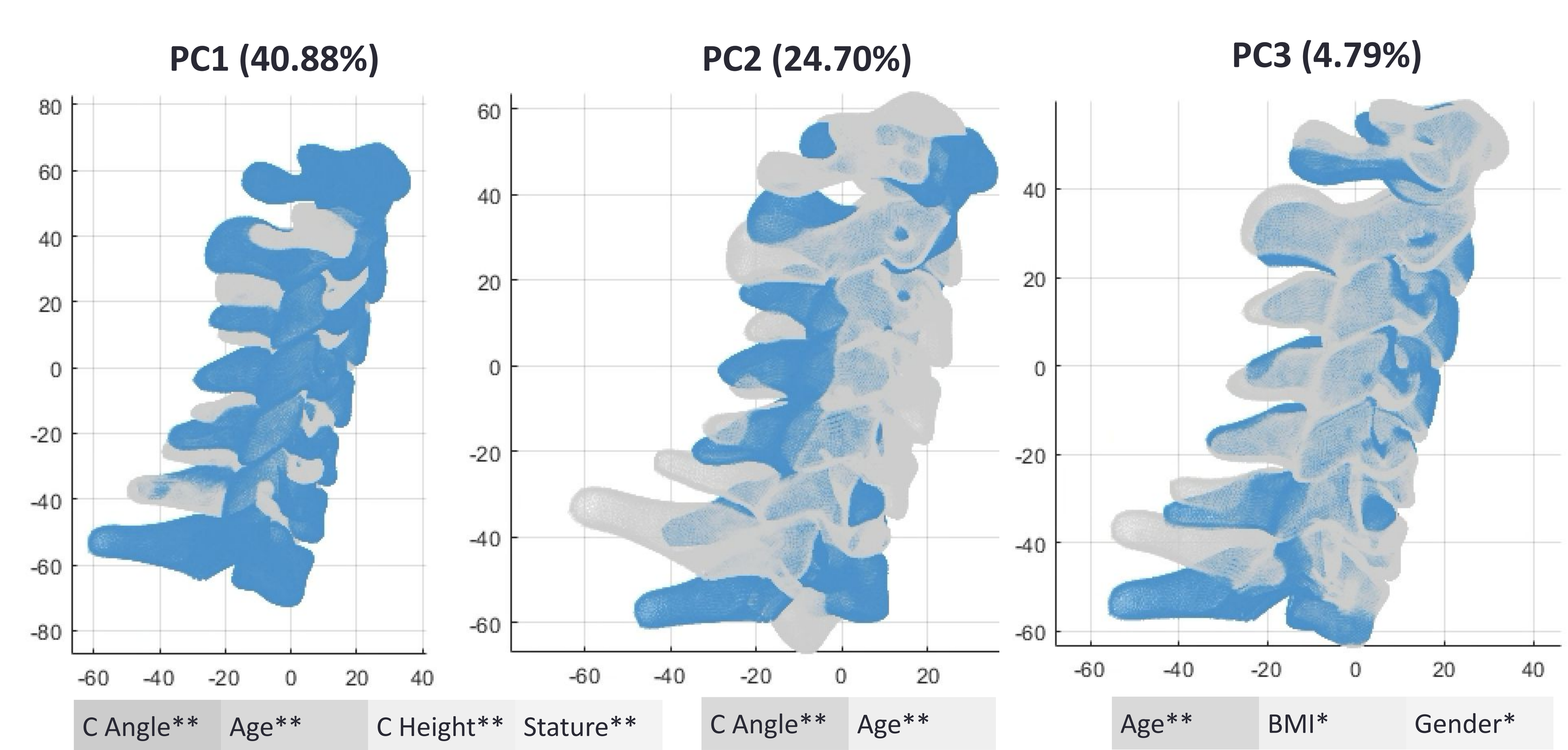


Figure 5. 3D visualization of the mean prediction error across nodal coordinates.



C Height: cervical spine height, C Angle: cervical spine angle (represents curvature)
Significance (p-value): <0.05**, <0.1*

Figure 6. PC variations with ±2 standard deviations and their corresponding statistically significant predictors. The first principal component (PC1) explains the most variance (40.88%), representing cervical spine size. The $\mathbf{R^2}$ of the final regression model is **0.6109**, using the six features as predictors.

References

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