A Statistical Human Head Geometry Model Considering Variations in Head Skin, Skull, and Brain among the Whole Population

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Introduction:

Annually, 7.3 million motor vehicle crashes occur in the U.S., highlighting the importance of vehicle safety design in preventing injuries and fatalities. One key aspect of improving safety is enhancing head/brain injury assessments using accurate head modeling. However, current human head/brain models have limited capabilities to represent the full range of morphological variations across the broader population (Hu et al., 2021). Expanding these models to better capture anatomical diversity is essential for improving occupant protection in crashes.

Objective:

The objective of this study is to develop a comprehensive statistical head geometry model that enhances accuracy and inclusivity. This involves incorporating size and shape variations in the head skin, skull, and brain across the adult population to better represent anatomical differences. A critical aspect is analyzing correlations between head geometry and body metrics to improve predictive accuracy. This aims to enhance head injury assessments, protective equipment design, and medical applications, improving safety and healthcare outcomes for diverse populations.

Methodology:

The methodology analyzes skull geometry using head CT scans collected from 181 individuals aged 18-80 based on a protocol approved by an Institutional Review Board (IRB) at University of Michigan. Segmentation in Mimics software extracted geometries of the skull, scalp, and brain tissues based on predefined thresholds. A semi-automated landmarking process is performed in HyperMesh identifying 102 key points, including 30 anatomical landmarks manually placed and 72 additional landmarks positioned using cubic-spline methods. Template surface meshes were morphed and projected onto the segmented geometries, leveraging landmarks for alignment. Statistical analyses, including Generalized Procrustes Analysis (GPA) and Principal Component Analysis (PCA), quantified shape variations, followed by regression models to predict geometry based on subject covariates.

Results:

The research examined the predictive relationships and variations in head geometries, including the head skin, outer skull, inner skull, and mandible, using predictors such as age, height, BMI, sex, and key head measurements like head length, width, and tragion-to-top distance. The results demonstrate strong predictive correlations, as reflected in R^2 values, which range from 0.5383 for the inner skull to 0.9274 for the head skin, indicating varying degrees of model fit across anatomical features. Principal component analysis reveals that PC1 captures the largest variance, with 28.61% for skin and over 30% for the inner skull and mandible, while PC2 and PC3 explain progressively smaller variances. Key predictors such as head length, breadth, and tragion-to-top measurements show significant contributions across components. Correlation matrices among predictors indicate strong relationships between head circumference, head breadth, and length.

Conclusions:

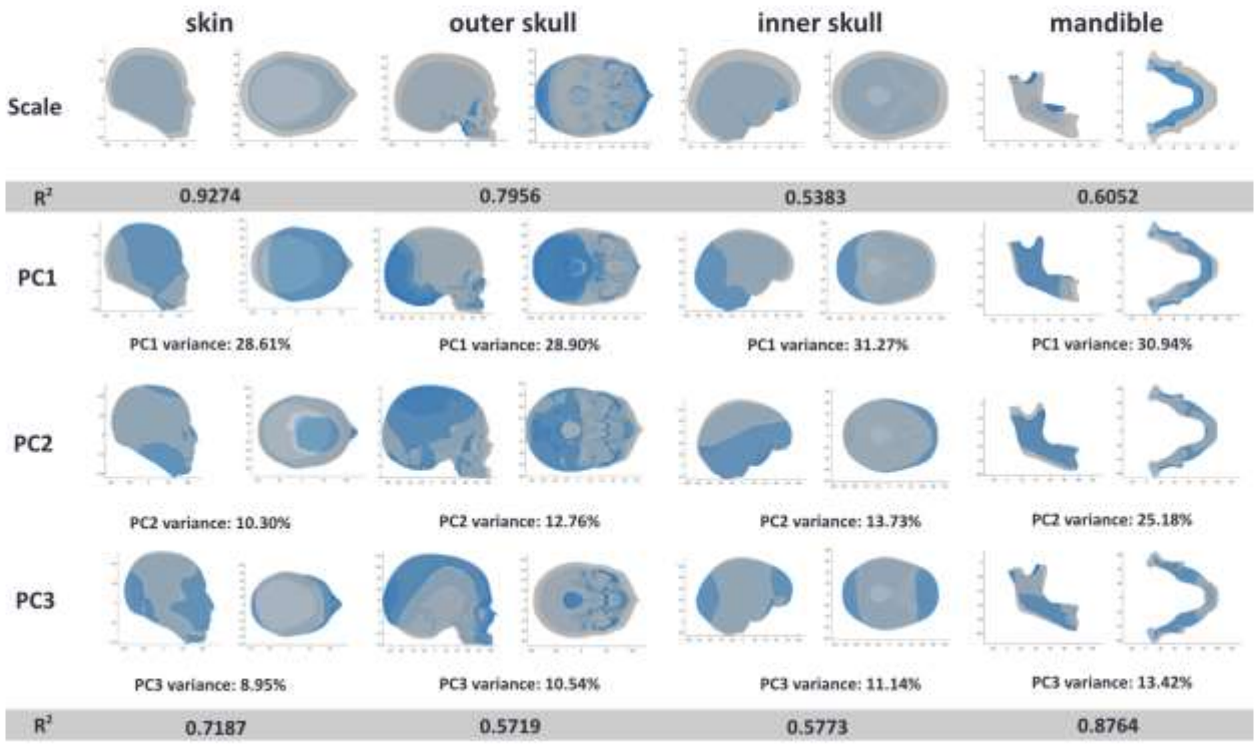
Compared with previous head geometry models, the model developed in this study includes a larger sample size encompassing a broader age range. Additionally, the mandible has been added to our statistical model, compared with the previous work (Wei at al., 2022). Our research highlights the strong influence of key predictors, including age, height, BMI, and sex on head geometry across different layers. The results emphasize the importance of these predictors in the variability and accuracy of modeling, offering valuable insights for applications in personalized and safety equipment design.

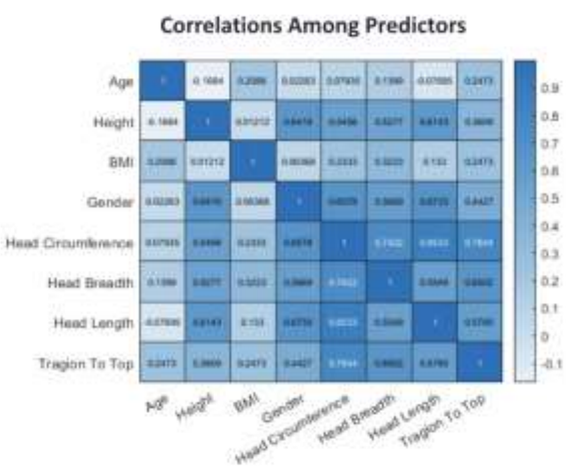
References:

Bureau of Transportation Statistics. (2021). Motor Vehicle Safety Data.

Hu, J. & Jones, M. (2021). Adaptive Design for Human Mobility.

Wei, A., Wang, J., Liu, J., Jones, M. L., & Hu, J. (2022). A parametric head geometry model accounting for variation among adolescent and young adult populations. Computer methods and programs in biomedicine, 220, 106805.


skin
outer skull
inner skull
mandible
Scale
R^2
0.9274
0.7956
0.5383
0.6052
PC1
PC1 variance: 28.61%
PC1 variance: 28.90%
PC1 variance: 31.27%
PC1 variance: 30.94%
PC2
PC2 variance: 10.30%
PC2 variance: 12.76%
PC2 variance: 13.73%
PC2 variance: 25.18%
PC3
PC3 variance: 8.95%
PC3 variance: 10.54%
PC3 variance: 11.14%
PC3 variance: 13.42%
R^2
0.7187
0.5719
0.5773
0.8764


Correlations Among Predictors
Age
Height
BMI
Gender
Head Circumference
Head Breadth
Head Length
Tragion To Top
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1