GEOMETRIC SCALING FACTORS FOR THE PEDIATRIC BRAINSTEM

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Introduction

Injuries caused by motor vehicle crashes (MVCs) are the leading cause of death for children in the United States [1] as well as the leading cause of head injury. Head trauma also results in significant morbidity in the pediatric population and contributes to approximately 300,000 hospitalizations a year[2]. The focus of this study is the improvement of geometric scaling factors for the pediatric brainstem using a morphometric analysis. Geometric morphometrics has been used in the anthropology and comparative biology fields for some time to assess differences in fossils and across species. This knowledge can be combined with medical imaging modalities to quantify shape changes based on an individual's age.

Purpose

The purpose of this study was to improve the predictive abilities of current finite element models. These models of the brain have detailed representations of the structures within the brain but are the size and shape of an adult. Geometric scaling factors for these structures will allow for the adaptation of these models to a correct pediatric size and shape. With more accurate finite element models, the response of the pediatric skull and brain can be better predicted for improved countermeasure evaluation and design.

Methods

The Magnetic Resonance (MR) imaging modality, instead of the more common Computed Tomography (CT) modality, was selected for this study because it better displays soft tissue, such as the structures of the brain. The scans used in this study were selected from a medical center's radiological database and were conducted on the patients due to a medical necessity. Since these scans were collected over several years and not specifically for this study, there was no standardized protocol followed other than the existing medical center protocols for patient scanning. All scans were completed using a Signa Excite or a Genesis Signa MR machine with a 256 by 256 or 512 by 512 pixel image. The size of the pixels ranged from 0.3125 to 0.8594. A trained radiologist assisted in the collection and identification of the scans to ensure all subjects were grossly normal in their brain and skull anatomy. The data set consisted of 59 individuals, both male and female, from the following age groups: newborn, three months, six months, one year, three years, six years, ten years, fifteen years, and twenty one years.

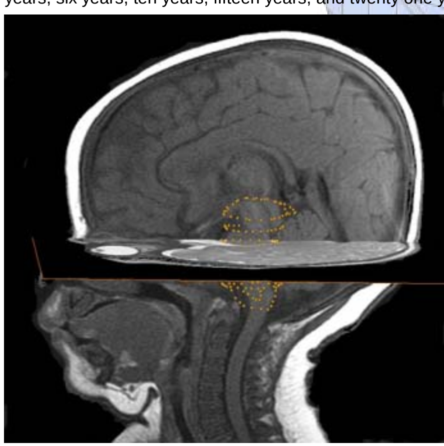


Figure 1. Brainstem data point collection using Amira software and coregistered transverse and sagittal MR scans.

Methods, Continued

Slice et al(1996) [3] described a method to compare homologous points across individuals to assess shape differences. This method relies on identifiable landmarks on all individuals, such as points on bony structures, as the basis of comparison. The problem encountered with these "true" landmarks for the brainstem was that while they could be used to determine basic relationships and general sizing of the structure, they failed to accurately describe the curvature. Therefore, true landmarks were supplemented with the sliding landmark method described by Bookstein(1997)[4] and Gunz(2005)[5]. Each individual had data collected, then a landmark dataset created with 290 landmark points.

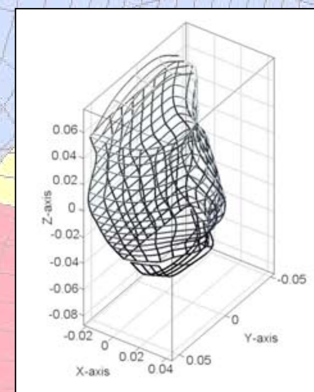
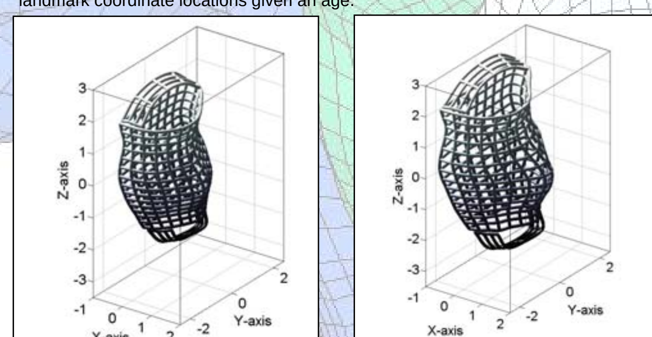


Figure 2. Resulting landmark coordinate set for the brainstem (points are connected by lines for visualization purposes)

A general Procrustes analysis and bending energy analysis was conducted on this dataset. The resulting landmark coordinate locations of the general Procrustes mean configuration were regressed as a function of age. This regression model outputs landmark coordinate locations given an age.



3 year old **21 year old**

Figure 3. Pediatric male brainstems in the correct size and shape for a 3 month old (left) and a 21 year old (right)

Results

The general Procrustes analysis was completed for this dataset. From the regressions calculated from the Procrustes mean configuration, age described 83% of the shape change using a linear regression and 87% of the shape using a quadratic regression. These values were obtained by conducting permutation tests with 100,000 iterations to assess statistical significance. The resulting p-values of were 0.17177 for a linear regression and 0.13467 for a quadratic regression. From the landmark coordinate sets, geometric shape scaling factors were calculated.

Age	Width (x)	Length (y)	Height (z)
21 YO	1.0000	1.0000	1.0000
15 YO	0.9603	0.9795	0.9724
10 YO	0.9272	0.9626	0.9495
6 YO	0.9009	0.9491	0.9311
3 YO	0.8811	0.9391	0.9174
1 YO	0.8679	0.9324	0.9082
6 MO	0.8647	0.9308	0.9059
3 MO	0.8630	0.9300	0.9048
Newborn	0.8614	0.9291	0.9037

Table 1: Scaling factors along the principal axis as illustrated in Figure 2, isolating shape changes with age

Discussion

The results indicate there is some variation in shape of the brainstem as an individual ages. This study is the first in a series investigating the various changes in shape of the various structures in the brain. In a qualitative assessment, there seems to be less variation in a structure such as the brainstem versus a structure more influenced by the shape of the head, such as the cerebral hemispheres. The difference in the shape of a toddler's skull versus an adult skull is more pronounced; therefore, future studies may show a stronger correlation between the shape of the structure and the age of the individual.

This study demonstrates a method of quantifying the shape change of the brainstem as a function of age. Based on predicted shape changes derived from a sliding landmark method of general Procrustes analysis, initial scaling factors for the height, length and width of the pediatric brainstem were calculated. This technique will facilitate the development of more accurate finite elements models to better predict the response of pediatric occupants.

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