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Forensic Anthropology Population Data

Differences in biomechanical properties and thickness among frontal and parietal bones in a Japanese sample

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ABSTRACT

The aim of this study was to assess the mechanical properties and thickness of adult frontal and parietal bones. The heads of 114 Japanese cadavers (78 male cadavers and 36 female cadavers) of known age and sex were used. A total of 912 cranial samples, 8 from each skull, were collected. Samples were imaged using multidetector computed tomography to measure sample thickness. The fracture load of each sample was measured using a bending test with calculation of flexural strength. Statistical analyses demonstrated no significant bilateral difference in either the mechanical properties or thickness of frontal or parietal bones. The mechanical properties and thicknesses of frontal bones were significantly greater than those of parietal bones regardless of sex. Therefore, the skull may have a great ability to resist frontal impacts compared with parietal impacts. In female samples, parietal bones were found to have a more uniform structure when compared with male samples. Male parietal bones were found to be thicker at medial sites than at lateral sites. This study also revealed parietal bones at lateral sites in female samples were thicker than in male samples. No strong association was observed between age and flexural strength of frontal or parietal bones. However, the fracture load was negatively correlated with age most likely due to the reduction of thickness.

1. Introduction

Accident statistics demonstrated that the head is one of the most frequently injured structures and the most fragile physical site during traumatic collisions, including pedestrian, motorcyclist, and side automobile impacts [1,2]. The cranium protects the brain from hemorrhage and contusion following trauma. External forces are delivered to the complex anatomy of the cranial bones in various ways [3]. Linear and depressed skull fractures are frequent consequences of head injury and are often associated with traumatic brain injury [4]. Previous studies have demonstrated that traumatic brain injury is a major cause of death worldwide [1]. For this reason, the close examination of head wounds is fundamental component of forensic analysis [5]. Adequate data regarding the mechanical properties and structure of the cranial bones are required to understand head injury mechanisms. In addition, increased knowledge of cranial bone fractures may provide mechanistic insights into skull fractures and life-threatening intracranial complications, and aid in the design of energy-absorbing head protection systems [4]. Therefore, there is a need to elucidate the biomechanical properties of human cranial bones.

Previous studies have assessed the mechanical properties of cadaveric skulls thorough a number of stress tests including compression, traction, and bending tests. However, the majority of these studies examined fetal or infant cranial bones [2,6–13]. Fetal and adult cranial bones have differing compositions; fetal cranial bones comprising a thin and non-homogeneous cortical bone layer, whereas adult cranial bones have stiff inner and outer strata comprising cortical bone separated by lightweight cancellous bone [4]. In addition, few published reports have compared the bending properties of adult cranial bones in different sites

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[2,4]. In our previous research, the biomechanical properties and structural changes of the adult human skull were investigated, by focusing on the parietal and occipital bones [14]. In the literature, however, the cranial sampling position has a significant effect on mechanical properties, with frontal impacts the most common cause of head injury in motor vehicle crashes and pedestrian accidents [4,15]. Therefore, understanding the mechanical properties of the frontal bone is of particular importance. The purpose of this study was to examine the mechanical properties and thicknesses of adult frontal and parietal bones in a Japanese forensic sample.

2. Materials and methods

The ethics committee of our university approved this research, and the requirement for approval from the relatives of studied subjects was waived.

2.1. Subjects

Cranial bones were obtained from 114 Japanese cadavers of known age and sex autopsied at the department of legal medicine at our university between January 2014 and November 2014. Subjects included 78 male cadavers (23–95 years; mean age, 54.4 ± 18.3 years) and 36 female cadavers (25–90 years; mean age, 66.6 ± 18.2 years). The estimated postmortem interval was <14 days for all subjects. Exclusion criteria were skull fracture, burning, obvious head injuries, and acquired or congenital abnormalities.

2.2. Samples

During autopsy, bone samples were taken from eight sites from each skull (Fig. 1). Left and right frontal samples (F) were tangent to the coronal suture and along the anterior extended line of the sagittal suture. Left and right parietal samples (P1) were tangent to the bregma and the sagittal suture. Left superolateral and inferolateral parietal samples (P2 and P3) were obtained from the lateral portion of the parietal bone immediately superior and inferior to the left superior temporal line, respectively. Right P2 and P3 were obtained from the lateral portion of the parietal bone immediately superior and inferior to the right superior temporal line, respectively. The length and width of each sample was fixed at 50 and 10 mm, respectively. The samples were obtained using an oscillating saw. Osseous surfaces were cleaned and washed with saline. A total of 912 samples were collected.

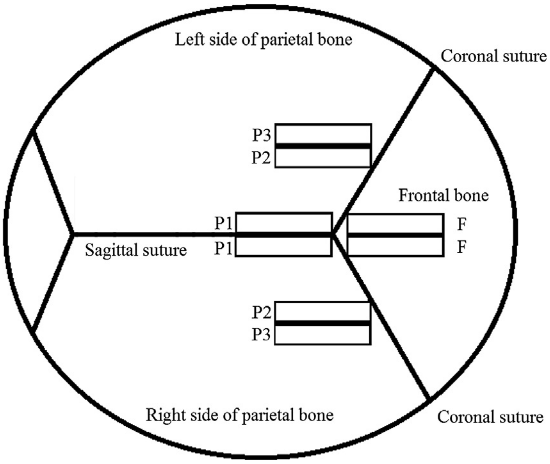

Fig. 1. Orientations of samples extracted from each cranium (superior view).

2.3. Imaging protocol and measurement

Multislice computed tomography was performed at the department of legal medicine at our university using a 16-row detector computed tomography system (Eclos; Hitachi Medical Corporation, Tokyo, Japan). The scanning protocol was as follows: collimation of 0.63 mm, reconstruction interval of 0.63 mm, tube voltage of 120 kV, tube current of 200 mA, and rotation time of 1 r/s. A hard filter was used. Image data were processed on a workstation (Synapse Vincent; Fujifilm Medical, Tokyo, Japan) to obtain orthogonal multiplanar reconstruction images and volume-rendering technique images. The sample thickness at the center of each sample (ST, mm) was measured using a reconstructed cross-sectional image, which was viewed with a window width and level of 2000 and 500 HU, respectively. Measurements were taken to the nearest 0.1 mm. The ST of each of the 20 randomly selected samples was re-measured by both the first researcher and another co-author to evaluate intra-observer and inter-observer error, respectively. The relative technical error of measurement (rTEM, %), and the coefficient of reliability (R) were calculated. The acceptance ranges of rTEM (%) using beginner anthropometrist levels for intra-observer error was <1.5% and for inter-observer error, <2.0% [16]. R values >0.95 were considered sufficiently precise [17].

2.4. Bending tests

Three point bending tests, used to investigate the mechanical properties of various beam samples including the human skull in previous studies [9,14,18–23], were conducted using a three-point-bending apparatus (JSV-H1000, JISC, Nara, Japan; Fig. 2). The testing device was composed of two lower supports and a 1000 N load cell. The distance of the two lower supports were 40 mm. The load cell applied stress at the center of the outer surface of each sample with a controlled velocity of 100 μm/s at room temperature, until the sample fractured. The apparatus was connected to a Handy force gauge (HF-100, JISC) and a computer recording the fracture load (FL, N) to the nearest 0.1 N.

2.5. Statistical analysis

The flexural strength (FS), which was measured in MPa, is a mechanical parameter used to assess the ability of materials to resist deformation under load. This parameter was calculated using the following formula:

$$\mathrm{FS} = \frac{3}{2}\frac{D}{W}\frac{\mathrm{FL}}{\mathrm{ST}^2}$$

where D represents the distance of the lower supports (40 mm), W is the sample width (10 mm).

Paired comparisons were examined using Wilcoxon signed-rank tests. Means and standard deviations of FL, ST, and FS were calculated for male and female samples. Non-parametric analysis was performed for parameters with non-normal distributions. The Mann–Whitney U test was used to compare FL, ST, and FS values between male and female samples by site. This test was also used to compare FL, ST, and FS values between F and parietal bone samples (P) as well as P1, P2, and P3 by sex. The Pearson product–moment correlation coefficient (r) was calculated, to assess the degree of correlation between age and FL, ST, and FS values as well as between FL and ST values at each site by sex. The significance level for all analyses was set as $p < 0.05$ and all statistical analyses were performed using Statistical Package for the Social Sciences (SPSS) version 21.0 (IBM Corp., Armonk, NY, USA) and Excel software (Microsoft Office 2007, Microsoft, Redmond, WA, USA).