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Clinical and Forensic Relevance of Cranial Bone Thickness Using CT Scan in Relation to Age and Gender

Zunaira, Zumirah Atiq, Saman Ali, Ayesha Sanaullah, Amna Javaid, Athar Maqbool

ABSTRACT:

Objectives: The aim of the study is to assess cranial bone thickness in relation to age and gender using computed tomography (CT) scans, and to determine the clinical and forensic relevance of any observed variations.

Study design and setting: This was a retrospective cross sectional observational analysis carried out on 128 patients head CT at Radiology department of M. Islam Teaching Hospital, Gujranwala from 1st February, 2024 to 1st December, 2024.

Methodology: Adults between the ages of 15 to 70 years were included. Data was collected by multi detector CT incisive 128 Philips using bone window. Sagittal view was selected for the measurements of unpaired frontal and occipital bones. Coronal view for the right and left paired parietal bones and axial view for the right and left paired temporal bones. Independent samples t-tests and one-way ANOVA were used to assess sex- and age-related differences, respectively. A p-value < 0.05 was considered statistically significant.

Results: Our study includes 128 participants, comprising 71 males and 57 females. The mean age of patients was 45.1 ± 18.7. The sex-based difference in cranial bone thickness was significant at upper and lower frontal, right anterior and posterior parietal, left middle and posterior parietal (p < 0.05). Based on age group the difference was statistically significant at the level of right anterior parietal only.

Conclusions: Cranial bone thickness varies significantly with gender and, to a limited extent, with age. These findings enhance our understanding of cranial anatomy relevant to surgical planning, trauma management, and forensic identification.

Keywords: CT scan, Cranial bone thickness, Gender variation, Skull anatomy, sexual dimorphism, Forensic identification.

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INTRODUCTION:

A key role of the skull is to protect the brain against mechanical trauma.[1] The human skull forms a protective cavity around brain comprising of around 22 bones. The key bones of the cranium consist of the frontal, parietal, occipital, temporal, ethmoid and sphenoid.[2] Most cranial bones are classified as flat bones, characterized by a layered architecture in which a central cancellous layer, known as the diploë, is enclosed between two outer layers of dense cortical bone.[3] Understanding how bones with a sandwich-like structure respond to external mechanical loading is essential for the design and evaluation of head protection equipment and strategies.[1] Intramembranous ossification forms most cranial bones, facial flat bones, and the clavicles, where both cortical and cancellous bone arise directly from mesenchymal connective tissue sheets.[4]

Each year, approximately 1.7 million people suffer from traumatic bone injuries, primarily caused by falls and motor vehicle collisions. Assessing changes in skull thickness with age is crucial for understanding its effect on skull deformation.[5] Around 76.5 billion dollars annual estimated cost has been attributed to TBI also termed as silent epidemic by centres for disease control. The probability of a skull fracture depends on the point of impact, as different regions of the skull vary in thickness and structural orientation.[6]

In forensic anthropology, the skull and pelvis are key structures for identifying individuals.[2] The cranium remains a key focus of research within the human skeletal system,

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valued for its structural traits related to sex, age, and heritage, making it essential for building a biological profile of unidentified individual.[7] The accuracy of sex determination in skeletal remains is influenced by the specific bones present, their preservation status, and the extent of sexual dimorphism characteristic of the population. Studies have focused on various skull features, including the cranium, mandible, glabella, mastoid process, and occipital bone to develop more accurate, reliable, and consistent methods for sex determination in anthropological analysis.[8] The cranium is the third most commonly used anatomical structure for sex estimation. Sexual dimorphism in the skull is typically evident in specific features, with males generally exhibiting larger mastoid processes, more pronounced supraorbital ridges and glabella, and a more prominent external occipital protuberance.[9]

The skull serves not only as a valuable tool for determining sex, but also supports facial reconstruction efforts, contributing significantly to the identification process. Skeletal morphology is shaped by various factors such as genetic background, environmental influences, population migration, and long-term secular trends. Consequently, population-specific standards should be developed and regularly updated.[10] The thickness of skull bone varies from young age to maturity and at various skull bone sites is required to healthcare professionals for accurate pin type selection and its location in halofixation, as well as cranial reconstruction surgeries.[11]

Studies on neurocranial thickness variation help inform mathematical models that simulate how the head responds to mechanical loading, and assess the connection between skull thickness, mechanical properties, and the likelihood of fractures from such forces.[12]

Bone thickness is thought to be influenced more by systemic and local stimuli than by genetic factors. Systemic elements such as hormonal balance, levels of physical activity, and nutritional status affect bone remodeling and growth, ultimately affecting overall skeletal robustness thus also affecting cranial bone thickness.[13]

A significant portion of the research on cranial bone thickness has been conducted on limited, potentially biased study groups. Furthermore, inconsistencies in sampling techniques and anatomical locations sampled hinder comprehensive comparisons and meta-analyses of the data. In our country knowledge gaps exist regarding skull thickness, its normal variation and potential correlations with biological and anthropological factors, due to a lack of robust evidence. With increasing immigration and population mixing, the necessity for an accurate data bank of osteometric measurements specific to different population types is acknowledged. This research primarily seeks to explain the correlation between skull thickness and age and sex.

METHODOLOGY:

A retrospective, cross sectional observational study 11 months study was carried out from 1st February, 2024 to 1st December, 2024 in the Radiology department of M. Islam Teaching Hospital, Gujranwala in Central Punjab. This research was conducted after taking approval from the Institute's Research Committee (Research Proposal No: CM/MIMDC/03/2024). The need for informed consent was waived, as it was a retrospective study. A total of 128 patients comprising of 71 males and 57 females, who came to Radiology department were selected randomly. Simple convenience sampling method was employed. Inclusion criteria: Adults between the ages of 15 to 70 years, with no history of trauma, bone lesions and concomitant skull fractures were involved in this research. Exclusion criteria: Below 15 years and above 70 years of age having localized skull bone diseases i.e. congenital or acquired deformity, infection, tumor, growth disorder or prior cranial surgery were excluded.

Data was collected by using multi detector CT incisive 128 Philips (Version 5.0.1.771, China) by using bone window. Sagittal view was selected for the measurements of unpaired frontal and occipital bones providing a side view of the skull in an anatomical position of skull. The frontal bone was segmented into three parts according to its vertical alignment; near to frontal sinus was lower third (A), middle third was at the point of the frontal tuberosity (B) and above frontal tuberosity was upper third in connection with parietal bone (C) as shown in Figure 1. The occipital bone was likewise separated into three sections; upper third close to lambdoid suture (D), in space separating lambdoid suture and occipital protuberance was middle third (E), lower third at occipital protuberance (F) as shown in Figure 1 on right side. All the views were selected while skull was in an anatomical position. Axial view was used for the paired right and left temporal bones. The thickness of temporal bone was measured on both sides, 3 cm above the zygomatic process at the right side (G) and at the left side (H) as illustrated in Figure 1 on left side. Both right and left parietal bones were measured at three points in the coronal view; anterior third towards coronal suture (I & J), middle third between the coronal and lambdoid suture (K & L) and posterior third towards lambdoid suture (M & N) as shown in Figure 2. Data analysis: Data collected from the study were analyzed using SPSS version 27.0, New York. Independent samples t-test was used to analyse variation by sex in each parameter, and the bilateral difference in the thickness of temporal and parietal bones. The correlation between cranial bone thickness and age was analysed by using one-way ANOVA test. P value of <0.05 was taken as significant. Normality of data was assessed using the Shapiro-Wilk test, confirming approximate normal distribution for each measurement variable.

RESULT:

Our study includes 128 patients, comprising 71 males (55.5%) and 57 females (44.5%) in Pakistan. The average age of patients was 45.1 ± 18.7. This study analyzed cranial bone thickness variations based on gender, age, and anatomical side using multi detector CT scan. The analysis focused on different skull regions, including the frontal, parietal, temporal, and occipital bones. Results were discussed in the following three tables, each addressing a different variable: gender (Table 1), age (Table 2), and anatomical side (Table 3). Statistical analyses were done using independent samples t-tests for gender and anatomical side and one-way ANOVA for age to identify significant differences in different skull parts.

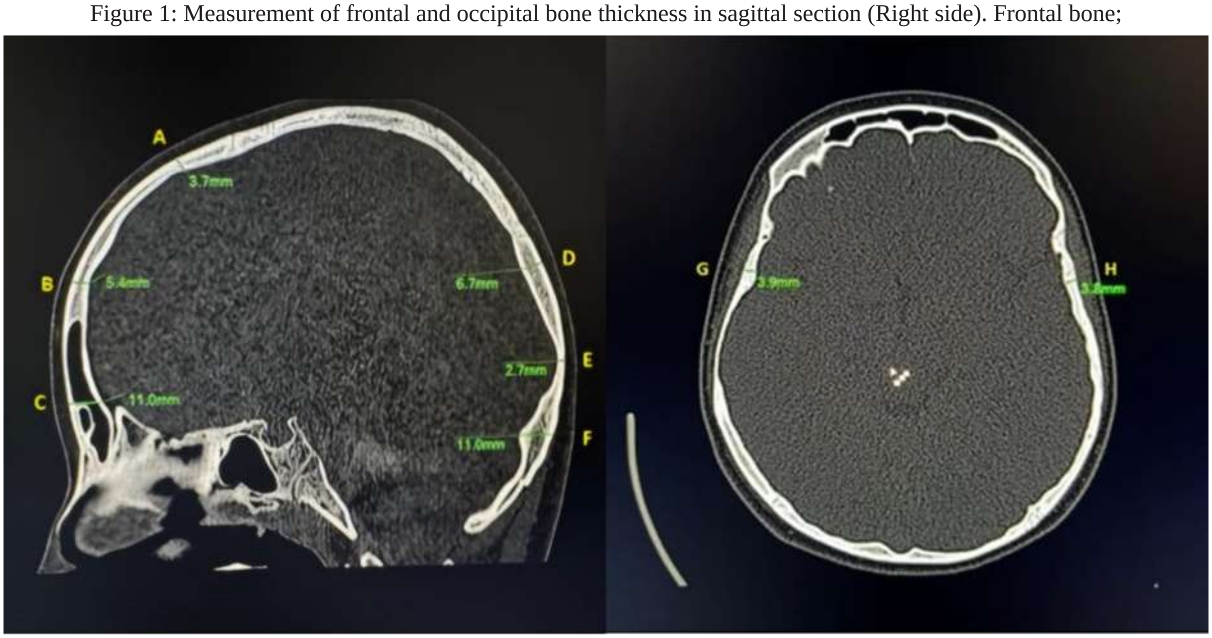
Table 1 shows Gender-Based Differences: This analysis revealed statistically significant differences in skull thickness between males and females in various regions. Particularly, in the frontal bone, both the upper and lower sections were significantly thicker in females compared to males. The upper and lower frontal thickness in females and males showed significant difference ($p < 0.001$). The right parietal bone also showed significant gender-based differences i.e. females had greater thickness in both the anterior and posterior regions. On the left side, the middle and posterior parietal areas were thicker in females when compared to males. These findings highlight significant sexual dimorphism in cranial bone thickness particularly in the frontal, right & left parietal bones.

Table 2 shows Age-Based Differences: Age-related significant variations in skull bone thickness were assessed using one-way ANOVA across the following three age groups: 15–35 years, 36–55 years, and 56–75 years. The results revealed that the most skull regions did not have statistically significant differences in thickness across these three age groups. However, a significant exception was observed in the anterior part of the right parietal bone only. Thickness increased from the youngest group to the older groups, with a significant p-value of 0.014. This suggests that specific portion of the skull i.e. right anterior parietal bone might show thickening with age. Other areas showed non-insignificant patterns. For instance, the lower frontal bone thickness increased with age, but the p-value (0.067) indicated this pattern was not statistically significant. The occipital and temporal bones also exhibited slight, insignificant increases in thickness with age. Overall, the data indicate only minimal age-related variations in skull bone thickness.

Table 3 shows Side-Based Differences: An independent samples t-test was used to compare the right and left sides of the skull. The analysis revealed no statistically significant differences in bone thickness between corresponding areas of the left and right sides of the skull. In the comparison of right and left sides of the anterior, middle and posterior regions of the parietal bone, insignificant difference was seen. Temporal bones also revealed insignificant differences on the right and the left sides. These results reveal a significant degree of symmetry between the right and left sides of the skull, indicating that lateral asymmetry is minimal in the human calvaria, at least in the regions measured.

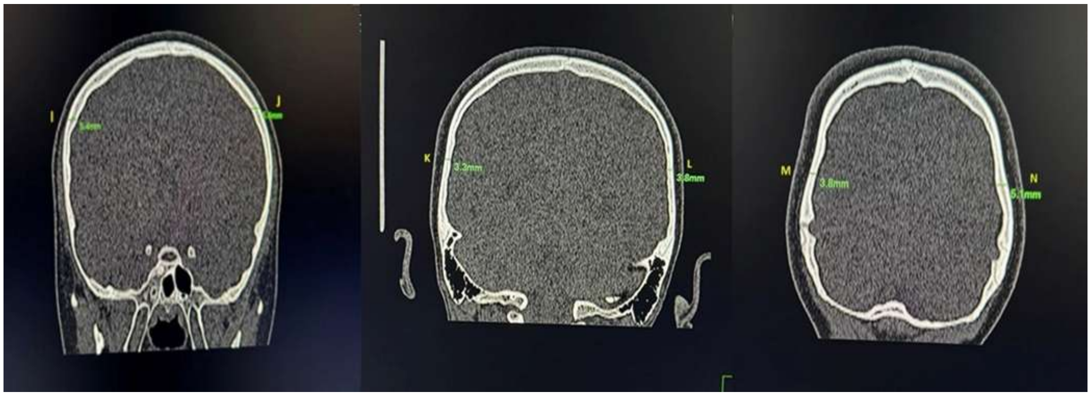
In short, the thickness variation of the frontal bone in its upper and lower sections of males and females shows significant difference with p value less than 0.05. Other regions where the difference in the skull bone thickness was

Figure 1: Measurement of frontal and occipital bone thickness in sagittal section (Right side). Frontal bone;



A: Around frontal sinus, B: At frontal tuberosity, C: Above frontal tuberosity towards parietal junction. Occipital bone; D: Towards lambdoid suture, E: Between lambdoid suture and occipital protuberance, F: At occipital protuberance. Measurement of temporal bone thickness in the axial section, 3 cm vertically above the zygomatic process(Left side). G: Right side, H: Left side.

Figure 2: Measurement of parietal bone thickness in the coronal section, towards coronal suture.



I: Right side, J: Left side. Between coronal and lambdoid suture. K: Right side, L: Left side. Towards lambdoid suture. M: Right side, N: Left side

Table 1: Comparison of CT points based on gender (using independent samples t-test)

CT scan	Region	Males	Females	p-value
Frontal	**Upper**	6.4 ± 1.7	7.5 ± 1.9	<.001*
	Lower	7.2 ± 1.8	8.5 ± 1.9	<.001*
Right parietal	**Anterior**	6.2 ± 1.3	7.5 ± 1.8	<.001*
	Posterior	7.9 ± 1.8	8.6 ± 1.8	.030*
Left parietal	**Middle**	6.4 ± 1.1	7.1 ± 1.5	.007*
	Posterior	7.9 ± 1.6	8.6 ± 1.8	.024*

*Statistically significant

Table 2: Comparison of CT points based on age groups (using one-way ANOVA)

CT scan	Region	15 – 35 yrs	36 – 55 yrs	56 – 75 yrs	p-value
Frontal	Upper	6.4 ± 1.9	6.9 ± 1.8	7.3 ± 2.0	.106
	Middle	7.1 ± 7.6	7.0 ± 1.8	7.1 ± 2.1	.995
	Lower	7.2 ± 1.6	7.9 ± 1.7	8.2 ± 2.3	.067
Right parietal	Anterior	6.2 ± 1.4	7.0 ± 1.4	7.1 ± 1.9	.014*
	Middle	8.1 ± 10.5	6.8 ± 1.3	6.8 ± 1.5	.506
	Posterior	8.3 ± 1.8	8.3 ± 1.9	8.1 ± 1.8	.907
Left parietal	Anterior	6.3 ± 1.5	9.5 ± 15.5	7.2 ± 1.7	.222
	Middle	6.6 ± 1.3	6.9 ± 1.3	6.8 ± 1.4	.572
	Posterior	8.3 ± 1.6	8.3 ± 1.8	8.1 ± 1.8	.887
Temporal	Right	5.5 ± 1.1	5.5 ± 1.2	5.5 ± 0.9	.993
	Left	5.7 ± 1.2	5.7 ± 1.1	5.7 ± 1.0	.937
Occipital	Superior	6.6 ± 1.2	6.9 ± 1.4	6.8 ± 1.3	.507
	Middle	6.3 ± 1.1	6.6 ± 1.2	6.8 ± 1.4	.210
	Inferior	8.9 ± 1.8	9.4 ± 2.5	9.8 ± 2.1	.175

*Statistically significant

Table 3: Comparison of CT points based on side (using independent samples t-test)

CT scan	Region	Right	Left	p-value
Parietal	**Anterior**	6.8 ± 1.6	7.5 ± 8.5	.319
	Middle	7.2 ± 6.2	6.7 ± 1.3	.341
	Posterior	8.2 ± 1.8	8.2 ± 1.7	.972
Temporal	-	5.5 ± 1.1	5.7 ± 1.1	.095

significant between both genders was at right anterior and posterior parietal, left middle and posterior parietal ($p < 0.05$). The comparison of CT points of skull bones based on age group showed p value less than 0.05 at the level of right anterior parietal. No statistically significant variation was seen when skull thickness of right and left sides of parietal and temporal bones were compared.

DISCUSSION:

Adult skull bones are made up of two dense layers of cortical bones separated by a central region of cancellous diploic tissue. Amongst all modern techniques available, Computed tomography (CT) offers a detailed visualization of the calvarial tables and the intervening diploic space. This capability establishes CT as a key tool for detailed cranial analysis rather than conventional radiographic techniques.[14] Our study included a sample of 128 individuals, comprising 71 males and 57 females, with a mean age of 45.1 ± 18.7 years. Previous studies by Kulathunga,[2] De Boer,[7] and Eksi[15] have documented that females have thicker frontal bones than males. This finding is consistent with our results, which revealed significantly greater thickness in females at the upper and lower regions of the frontal bone, with p-values of <0.001 for both regions. This observation could be attributed to hyperostosis frontalis interna, a condition noted to be particularly useful in distinguishing females from males in forensic analysis, as reported by May et al.[16]

The right and left parietal bones exhibited variable measurements, with the right parietal bone showing greater thickness in females than males at the anterior and posterior ends, with p-values of <0.001 and 0.030, respectively. Similarly, the left parietal bone in females demonstrated higher thickness at the middle and posterior aspects, with statistically significant p-values of 0.007 and 0.024. These findings align with Semple's[17] perspective that sex also affects the variability in calvarial thickness. This also aligns with Farzana's[18] study, which reported significant thickness in the posterior parietal region among females but found no notable differences in the anterior aspect. Contrary to

Domenech-Fernandez[11] study where skull bone thickness demonstrated an increase with age for all parameters, in our study significant age-related differences were observed only in the anterior region of the right parietal bone (p=0.014). Anzelmo[19] also stated an interesting point that along the parietal midline, a thin line is likely associated with the development of superior sagittal sinus, with thicker regions on either side but in our study only females represented this pattern while males exhibit an increasing pattern from front to back.

Quite interestingly, the right and the left temporal bones showed no change in thickness with advancing age, while almost all the rest of the studied bones exhibited an increasing pattern, although not statistically significant. This pattern of temporal bones shows contrast to Kulathungas study[2] where temporal bones thickness exhibit a positive correlation with age. Lynnerup's[20] study focussed on thickness of human cranial diploe and failed to find a remarkable correlation between age and diploic thickness of individuals. Ichalakaranji's[21] study also concluded that there cranial thickness has no relation with age. Domenech-Fernandez[11] and Kulathunga[2] also recorded that the lateral aspect of the skull vault is the thinnest amongst all and is further reinforced by our study where the temporal bone remained the one with the least value in both genders.

Anzelmo[19] mentioned that the occipital bone thickness is greatest at the lambdoid suture which is contrary to our study which shows that the occipital bones in both genders exhibit an increasing pattern towards the occipital protuberance as compared to the region closest to the lambdoid. Another CT based study conducted by Ichalakaranji[21] in India showed that in females the superior occipital bone is thicker and in males the inferior occipital bone is thicker, with the p value less than 0.05 making the difference statistically significant. However, our research showed contrast with female skull being thicker at level of inferior occipital bones than males but the difference was not statistically significant. Additionally, no significant variations were observed in the occipital and temporal bone thickness measurements between genders.

Another study by Lynnerup[22] across White and Black racial groups showed that the thickest skulls are of White women and the thinnest are of White men. Additionally, the study found that, in both racial groups, women had significantly thicker skulls than men at almost all levels which was similar to our study.

CONCLUSION:

This study investigates cranial bone thickness among a Pakistani population using computed tomography (CT) imaging, revealing sex-based variation, with females exhibiting significantly greater thickness in the frontal and parietal bones. A subtle but statistically significant age-related increase was observed at the right anterior parietal bone, suggesting localized morphological adaptation. Bilateral symmetry was evident in the parietal and temporal bones, affirming their consistency in clinical evaluation.

These findings support the integration of sex- and age-specific cranial data into neurosurgical planning, craniofacial reconstruction, and forensic anthropology. Statistical analyses confirmed robustness, with significance established at $p < 0.05$.

Future research should prioritize ethnically diverse sampling to enhance generalizability, and examine the differential morphology of inner versus outer calvarial tables. Moreover, coupling such anatomical data with advanced 3D imaging, finite element modeling, and biomechanical simulation presents promising potential for refining implant design, pre-surgical assessment, and forensic reconstruction protocols.

Authors Contribution:
Zunaira: Concept and design of study
Zumirah Atiq: Concept and design of study, drafting
Saman Ali: Drafting and reviewing criteria
Ayesha Sanaullah: Data analysis, reviewing critically
Amna Javaid: Data analysis, reviewing critically
Athar Maqbool: Final approval of version

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