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Original article

Cranial thickness in relation to age, gender and head circumference in Thai population

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Background: The skull is one of the most studied materials of the human bone. To date, several studies have investigated the range of cranial vault thickness variation in modern human.
Objective: To investigate the average thickness of cranial vaults in different positions and their relation to individual variables in the Thai population.
Methods: Cranial vaults of 118 male and 59 female cadavers aged over 20 years were eligible for the study. The measurement of the cranial vault was conducted as described: frontal cranial thickness (FCT), occipital cranial thickness (OCT), left and right lateral cranial thickness (LCT). The relationship between the cranial vault thickness and individual factors such as age, gender, height and weight, head and skull circumferences was studied.
Results: The average thickness of the female cranial vault was 7.438 mm in the FCT, 8.633 mm in the OCT, 6.355 mm in the right LCT, and 6.297 mm in the left LCT. The average thickness of the male cranial vault was 7.782 mm in the FCT, 9.354 mm in the OCT, 5.363 mm in the right LCT, and 5.459 mm in the left LCT. There was a statistically significant difference in cranial vault thickness between males and females. However, the result showed no correlation between cranial vault thickness and age as well as weight and height of the individual.
Conclusion: The cranial vault was not uniform structure and has wide variations in the thickness in different areas. The present study showed that cranial vault thickness could be used as an indicator for gendering human remains.

Keywords: Cranial vault thickness, Forensic anthropology, Thai population.

The skull is one of the most studied materials of the human bone. To date, several studies have investigated the range of cranial vault thickness variation in modern human. [1 - 10] The measurement of the human skull is a wide range of usefulness in the field of anatomy, medicine, and biomechanics. It is also useful to apply this knowledge to forensic context, e.g. personal identification and skeletal trauma analysis. [11 - 12] For example, ethnic identification from the skull provides a key to forensic investigation and the skull morphology can be used to identify the ancestry of an individual. [13] In addition, a comprehensive study focuses on cranial vault thickness is an important step toward understanding skull fracture. [11 - 14] Some weaker areas, such as the frontal bone and parieto-temporal area, are more susceptible to fracture than others. Therefore, understanding how cranial vault thickness changes in each position can aid in the prediction of skull fracture in cases of traumatic head injury.

Previous studies have demonstrated that the thickness of each part of the cranial vault is different [1 - 10], with the occipital area is the thickest and the temporal area is the thinnest. [2 , 5] It was reported that skull thickness was related to height, weight, and age in the population younger than 19 years old. [1, 15] A decrease in the skull thickness in females over 50 - 60 years old and a slight increase in males over 60 years old were also observed. [4] The previous studies have determined whether cranial vault thickness could be used as an indicator of gender and age. Nevertheless, no clear trend has been concluded. To our knowledge, there were two pieces of literature that reported on the cranial vault thickness in the Thai population. [9, 10] However, the reference points of the cranium were different between each study and there has not yet been a systematic study focusing on an

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association between skull thickness and individual variables such as age, gender, and general body build in the Thai population.

The aim of this study was twofold. First, it aimed to investigate the variation in the specific skull area thickness in the Thai population. Second, it aimed to provide an association in the relation between cranial vault thickness and age, gender, weight, height, and head and skull circumference.

Materials and methods

Data presented in this study come from 118 male and 59 female cadavers of age over 20 years, who were autopsied at the Department of Forensic Medicine, Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok, Thailand. Postmortem body weight, height, age at death, and underlying disease were retrieved from the autopsy reports. Cases with bone disease affecting the correct measurement or cases with a history of head injury with recent or healed skull fracture were excluded.

Firstly, the maximum head circumference was measured directly by a measurement tape around the widest possible circumference from the most prominent area of the forehead to the back of the head. Then, the scalp was incised and pulled anteriorly and posteriorly exposing the calvarium. The maximum skull circumference was measured by a measurement tape before the calvarium was removed. This study examined the thickness of the skull at four standard anatomical reference points: frontal cranial thickness (FCT) was measured at one centimeter inferior to the bregma; left and right lateral cranial thickness (LCT) were measured at left and right euryons, respectively; and occipital cranial thickness (OCT) was measured at one centimeter inferior to the lambda. The pieces of these landmarks and surrounding area were cut in size 2 square centrimeters from the calvarium. With individual tags, the specimens were packed without other demographic data. The preparation of each sample entailed the removal of the periosteum and related connective tissues. This preparation process was necessary for the correct measurement. Lastly, direct measurements were carried out without the knowledge of gender and age using a digital sliding caliper.

Statistical analysis

All statistical analyses were performed with the SPSS statistics program (PASW 18.0 for Windows). Of all measurements, descriptive data such as mean values and standard deviations were calculated. The Student t - test was used to determine whether there was a significant difference between the means of male and female subjects. In addition, Pearson correlation coefficients were used to analyze correlations between cranial vault thickness and age, height,weight, head and skull circumference. A P - value < 0.05 was considered statistically significant.

Results

A total of 177 cases was included, consisting of 59 females and 118 males aged between 20 - 82 years. The descriptive results of all variables of the sample population by gender are shown in Table 1. All the cranial vault thickness measurements were found to be normally distributed. When considering the thickness of the cranial vault, the OCT has the highest mean thickness value, followed by the FCT and LCT. The FCT and OCT of males were more than females. However, both LCT of males were less than females. The boxplots of the four measurements by gender are demonstrated in Figure 1.

Table 2 shows the mean difference of cranial vault thickness in the four reference positions by gender. Except for the FCT, a significant difference was observed for the OCT as well as the left and right LCT between male and female subjects.

Table 3 displays the Pearson correlation coefficients for the association between the thickness of each reference position of the cranial vault. For female subjects, there was a significant correlation between left and right LCT ($r = 0.719$, $P < 0.001$) as well as between FCT and the other sites of the cranium (r = 0.345 - 0.495, $P < 0.05$). The OCT showed an insignificant, very weak correlation with the left and right LCT (r = 0.145 - 0.164, P = 0.216 - 0.273). In the male subjects, the correlation was weakly positive at any reference point of the cranial vault (r = 0.330 - 0.447, $P < 0.001$), yet a strongly correlation was observed in the left and right LCT ($r = 0.820$, $P < 0.001$).

The intra- and inter-observer errors were evaluated. Measurements were conducted on 18 cases using all the measurements and then the results were compared with the previous results. Based on Kappa statistics, the average values of intra-class correlation coefficients were greater than 0.75 for intra-observer reliability and more than 0.9 for inter-observer reliability. Thus, this study showed good reliability for all the measurements.

Table 1. Descriptive variables according to gender.

Gender	Variables	Mean	SD	SE	Minimum	Maximum
Female	Age (years)	52.0	15.1	2.0	20.0	82.0
	Height (cm)	159.2	6.9	0.9	145.0	173.0
	Weight (Kg)	60.7	15.4	2.0	28.3	95.0
	FCT (mm)	7.4	1.3	0.2	3.8	10.3
	OCT (mm)	8.6	1.5	0.2	5.7	12.1
	Right LCT (mm)	6.3	1.3	0.2	3.4	9.6
	Left LCT (mm)	6.3	1.4	0.2	3.6	10.1
	Head circumference (cm)	53.6	1.8	0.2	49.4	58.1
	Skull circumference (cm)	49.9	1.5	0.198	46.1	54.8
Male	Age (years)	44.2	13.2	1.219	20.0	75.0
	Height (cm)	171.4	7.3	0.676	150.0	190.0
	Weight (Kg)	69.1	19.4	1.790	37.4	149.3
	FCT (mm)	7.8	1.3	0.120	4.3	12.5
	OCT (mm)	9.4	1.6	0.150	5.6	14.3
	Right LCT (mm)	5.4	1.1	0.104	3.0	8.8
	Left LCT (mm)	5.5	1.2	0.113	3.0	9.7
	Head circumference (cm)	55.8	1.9	0.175	50.9	60.5
	Skull circumference (cm)	51.7	1.6	0.148	46.5	59.3

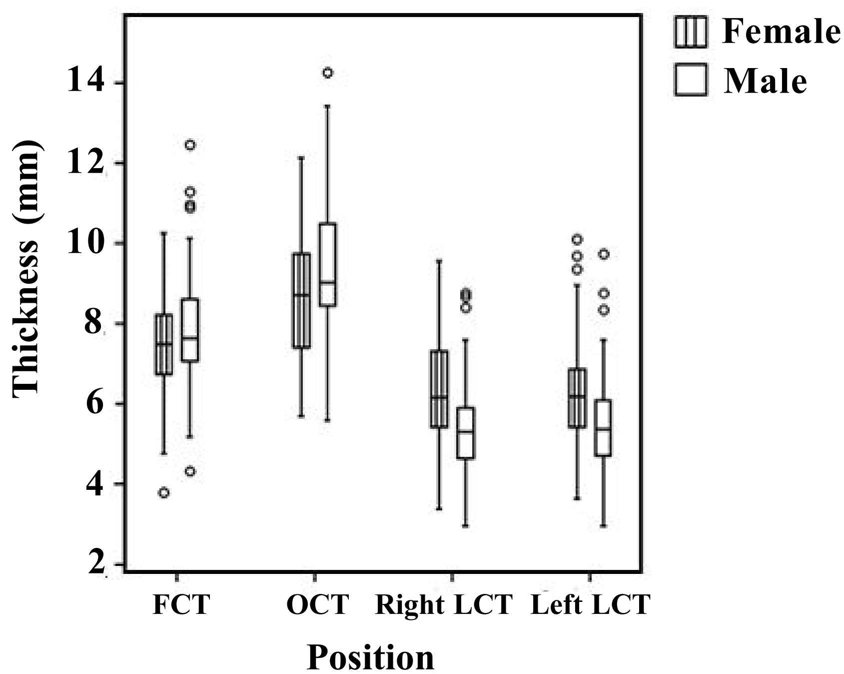

Figure 1. The boxplots showing values of skull thickness.

Table 2. Mean difference of cranial vault thickness according to gender.

	Mean difference	SE difference	Lower CI	Upper CI	*P* - value
FCT	- 0.344	0.208	- 0.755	0.067	0.100
OCT	- 0.722	0.253	- 1.221	- 0.222	0.006*
Right LCT	0.992	0.192	0.613	1.371	> 0.001*
Left LCT	0.838	0.207	0.430	1.247	> 0.001*

FCT: Frontal cranial thickness; OCT: Occipital cranial thickness; LCT: Lateral cranial thickness

Table 3. Pearson correlation for cranial vault thickness and individual variables.

Gender			Age	Height	Weight	HC	SC	FCT	OCT	Right LCT	Left LCT
Female	FCT	Pearson Correlation	0.191	0.072	- 0.044	0.058	0.242	1	0.363*	0.495*	0.345*
		Sig.	0.147	0.586	0.741	0.66	0.064		0.005	< 0.001	0.007
	OCT	Pearson Correlation	- 0.186	0.214	0.194	0.239	0.306*		1	0.164	0.145
		Sig.	0.158	0.104	0.142	0.068	0.019			0.216	0.273
	Right LCT	Pearson Correlation	0.021	0.221	- 0.002	0.114	0.247			1	0.719*
		Sig.	0.872	0.093	0.991	0.389	0.059				< 0.001
	Left LCT	Pearson Correlation	0.178	0.079	- 0.077	- 0.108	0.027				1
		Sig.	0.178	0.554	0.565	0.414	0.842				
Male	FCT	Pearson Correlation	0.169	0.103	0.071	0.262*	0.131	1	0.447*	0.365*	0.422*
		Sig.	0.068	0.266	0.445	0.004	0.157		< 0.001	< 0.001	< 0.001
	OCT	Pearson Correlation	- 0.070	0.119	0.020	0.15	0.156		1	0.330*	0.379*
		Sig.	0.453	0.2	0.829	0.105	0.091			< 0.001	< 0.001
	Right LCT	Pearson Correlation	0.116	0.055	0.017	0.206*	0.224*			1	0.820*
		Sig.	0.212	0.557	0.856	0.025	0.015				< 0.001
	Left LCT	Pearson Correlation	0.084	0.111	0.081	0.211*	0.213*				1
		Sig.	0.366	0.231	0.383	0.022	0.02				

*Statistically significant difference

Table 4. Intra-class correlation coefficient in this study.

	Intra-class Correlation coefficient			
	FCT	**OCT**	**Right LCT**	**Left LCT**
Intra-observer				
Single measure	0.785	0.836	0.939	0.986
Average measure	0.879	0.911	0.969	0.993
Inter-observer				
Single measure	0.902	0.926	0.919	0.956
Average measure	0.949	0.962	0.958	0.978

Discussion

The cranial vault thickness has been studied by several researchers because it has always risen to the challenge in anthropological research. Because the severity of skull fractures is related to cranial vault thickness, this parameter may have an implication in forensic anthropological settings, as well as in biomechanical modeling of the cranial vault. This study has investigated cranial vault thickness in relation to age, gender, weight, height as well as head and cranial circumference in a Thai forensic sample. An association would be useful in a forensic setting; for example, cranial fragments could be used in the personal identification of unidentified remains. The various techniques to measure the cranial vault thickness are conducted in the previous studies, including direct measurement and medical imaging, particularly clinical computed tomography. [3, 9, 10] A direct comparison between the results from both techniques could not be made because of variability in sample characteristics. Conceivably, the results of the direct measurement should be similar to the results obtained with medical imaging.

When considering the thickness of the cranial vault, the occipital bone has the highest mean thickness value, following by the frontal and parietal bones. It is generally accepted that activity-induced strain on bone tissues can induce localized osteoblastic activity. The occipital area where the most muscle attachments are located would show the highest cranial thickness. Therefore, the results of this study are in line with previous conclusions that muscle activity plays an important role in cranial vault thickness. [1, 16] A highly positive correlation between the left and right LCT was also observed and it led us to conclude that the symmetry of the left and right half of the human skull was evident.

In general, the measurement of cranial vault thickness has been carried out by several studies to correlate thickness with other individual variables. [1, 4, 6 - 8] Previous literature stated an association between age and cranial vault thickness in adult subjects. [6, 8] It is well known that the skull is thin in children, and its thickness increases rapidly until 17 years of age. The adult skull, however, differs on the age variation. Israel H.[17] and Adeloye H, *et al*. [8] reported that cranial thickness increases rapidly during the first two decades of life to reach a stable value in the fifth to sixth decades. In this study, the data showed no statistically significant change with age at any reference point of the cranial vault, thus, reflecting the results of many recent studies. [1, 4, 6, 7, 9,10] Thus, the present study pointed out that there is no significantly age-related difference in cranial vault thickness, which is accordance with the previous studies in Thai population. [9-10]

A statistically significant sexual dimorphism in the cranial vault thickness at the parietal and occipital regions was observed. The mean values showed that female cranial vaults were thicker than those of males at the left and right LCT in accordance with the previous studies. [1, 4, 6 - 8] Also, the OCT was greater in males. These relationships are useful in physical anthropological aspects especially gendering unidentified cranial fragments. A probable hypothesis that hormones are the primary cause of variation in cranial vault thickness is partially supported in the previous study. [16] In addition, some earlier studies reported a significant difference in FCT between male and female subjects. [1, 6] A possible cause they tried to explain was a localized and benign thickening of the inner side of the frontal bone, calling hyperostosis frontalis interna, commonly found in older women. [18] The present study selected only subjects without any bone disease affecting the correct measurement. Therefore, an insignificant difference in FCT should be expected in this study.

The available study on the correlation between head and skull circumferences and cranial vault thickness is very limited. The results in this study identified a weak association between skull circumference and both LCT in males as well as OCT in females. Therefore, these regions may play an important role in a difference in skull circumference. This study also revealed that a correlation between the cranial vault thickness and general body build was very weak. Therefore, the cranial vault thickness cannot be extrapolated from an individual weight and stature. For example, a slender man may have rather thicker cranial vault than an overweight man. At the present, nevertheless, a satisfactory explanation could not be given.

There are several limitations existed in this study. First and foremost is the small sample size of females, yet the number of female subjects in this study is greater than those in the previous studies. [4, 7] Future study should recruit more female subjects to the data set. Next, this study relies on specific locations on the cranial vault. More data covering almost all positions might be produced to evaluate complete cranial geometry. Third and last, the cranial vaults were obtained only from Thai cadavers limited to the area of Bangkok. Consequently, the results may not represent the data of the general Thai population.

Conclusion

In summary, it can be noted that a cranial vault is not a uniform plate and its thickness varies widely in different areas. The occipital bone is found to be the thickest region of the cranial vault, following by the frontal bone. This study also highlights the correlation between cranial vault thickness and gender. It is also concluded that cranial vault thickness could be used in gendering human remains. The other parameter such as age, height, and weight included in this study did not strongly correlate with cranial vault thickness. Therefore, the age-related change in cranial vault thickness is not shown in the Thai population.

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Conflict of interest

The authors, hereby, declare no conflict of interest.

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