The Thickness of Parietal Bones in a New Zealand Sample of Cadaveric Skulls in Relation to Calvarial Bone Graft

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Abstract

Objectives To evaluate the average thickness of the parietal bones in their different regions to identify the ideal site(s) for calvarial bone graft harvest.

Methods and Materials Thickness of the parietal bones of 25 wet cranial vaults of New Zealand European origin was measured in 135 different locations using an electronic caliper. Analyses to identify the ideal harvest sites were conducted so that the sites fit the features of an ideal harvest site described in the literature as: (1) 6 mm of minimum thickness and (2) 2 cm away from the midline.

Results and Conclusion The overall average thickness was 6.69 ± 0.22 mm. The average thickness at different sites within the same bone ranged from 2.85 to 6.93 mm. In keeping with previous studies, the report observed a progressive thickening of the parietal bone in medial and posterior directions. Of the 135 different locations measured, only 20% exceeded an average thickness of 6 mm as well as being 2 cm away from the sagittal midline. These locations were mainly located between 6 to 11 cm posterior to the coronal suture and 2 to 5 cm away from the sagittal suture.

Conclusion Harvesting the calvarial bone graft in the area 6 to 11 cm posterior to the coronal suture and 2 cm away from the midline is recommended based on our study using cadaveric cranial vaults of New Zealand Europeans.

Keywords

- bone graft
- reconstruction
- Calvarial graft
- graft harvest

Bone grafting in cranio- and oral and maxillofacial surgery has been used for many decades for the reconstruction of the craniofacial skeleton for congenital defects, trauma, post-tumor resection, preprosthetic augmentation of the severely resorbed alveolus secondary to tooth loss, and in dental implants.¹ Of the many types of bone grafting materials available (autogenous, allogeneic, xenogeneic, and alloplastic), the autogenous grafts are still considered as the gold

standard.² The calvarium, iliac crest, ribs, tibia, and various intraoral regions are potential donor sites.

The first use of a calvarial bone graft was reported independently by Muller and by Konig in 1890 to reconstruct cranial defects using a calvarial osteocutaneous flap.^{3,4} Since then, several different applications have been published in the literature including reconstruction of fractures involving the orbital walls and nose, midfacial reconstruction following

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tumor resection, alveolar augmentation, maxillary sinus augmentation, grafting of alveolar clefts, and in cosmetic rhinoplasty.^{5–10}

Calvarial bone grafts have several advantages over other donor sites including proximity to the recipient site, possibility of sharing a same surgical field as the recipient site, less resorption, a scar that is well hidden in the hair-bearing region, and a lower overall complication rate and morbidity.^{11,12} Despite these advantages, harvesting the calvarial bone graft can potentially cause devastating intracranial complications such as iatrogenic damage to dura matter, the cerebral cortex, and vital vascular structures (namely the superior sagittal sinus and middle meningeal artery).¹³

To prevent these complications, several studies have measured the thickness of the parietal bone to identify the safest sites for the calvarial bone graft harvest. The mean thickness ranged from 4.73 mm in its thinnest part to 7.72 mm in its thickest part in these studies.^{14–17} The studies consistently noted that there is a gradual thickening of the parietal bone as the measurements proceeded medially and posteriorly, hence the consensus was created to harvest the graft from the posteromedial aspect of the bone. Based on their thickness measurements, Hwang et al and Moreira-Gonzalez et al also proposed a thickness map as a practical guide to surgeons for choosing the ideal calvarial bone graft harvest sites.^{14,15} Although these maps are excellent at identifying thick regions of the skull, they do not reflect on the features of the ideal harvest sites described in the literature.

The current literatures describe ideal features of calvarial bone graft harvest sites as: (1) minimum total thickness of 6 mm; (2) 2 cm away from the sagittal midline; (3) and minimum thickness of 2 mm of the diploetic space.^{13,18–20} It is believed that 6 mm of bone provides sufficient thickness, and staying 2 cm away from the midline reduces the risk of encountering the superior sagittal sinus. So far, no information has been published on the thickness of the parietal bones in a New Zealand population. This report will determine the average thickness of the parietal bones in their different regions using the cadaveric cranial vaults of a New Zealand sample. Using these data, a thickness map will be developed to identify the optimal locations using anatomical landmarks. Finally, identification of the ideal calvarial harvest sites will be performed guided by a minimum thickness of 6 mm, 2 cm away from the midline.

Materials and Methods

Sample

Twenty-five wet cadaveric cranial vaults (50 parietal bones) were obtained from the Department of Anatomy at the University of Otago, Dunedin, New Zealand. These cranial vaults came from deceased New Zealand Europeans who donated their bodies to the university and were subsequently allocated for dental undergraduate teaching purpose. The samples were collected consecutively after being prepared. Twenty-five specimens were the maximum number that the department could provide from 2009 to 2010.

Data Collection

Background information such as gender, age at death, and cause of death were obtained. Some relevant and important data such as history of head trauma, neurosurgery, or bony pathology including Paget's disease or any congenital abnormalities of the bone could not be identified.

Cranial vaults were separated from the cadavers in one piece and markings were made on the skull to determine the points where measurements were to be taken. Each cranial vault was identified for its anatomical landmarks (coronal suture, sagittal suture, superior temporal line, and lambdoid suture). Several lines were drawn (►Fig. 1) following an adapted design used in Jung et al's study.¹⁶ First, lines of best fit were drawn along the sagittal (SSL) and coronal sutures (CSL). Second, multiple lines parallel to the SSL and CSL were drawn with a 1-cm gap in between. These lines were then termed as *S lines* and *C lines*. A manual caliper was used for this purpose. The *S lines* were further named as *S1*, *S2*, *S3*, and so forth progressing from the SSL toward the inferior temporal line. The *C lines* were named as *C1*, *C2*, *C3*, and so forth progressing from the CSL toward the lambdoid suture. The right and left parietal bone was done separately.

Thickness was measured at the bisecting points of the *S* and *C lines*. These individual points were labeled as *S1C1*, *S1C2*, and so on. On average, 78 points per bone were measured, giving 135 possible different locations throughout the specimens. A measuring device used for this purpose was an electronic caliper (accuracy = 0.01 mm) that was modified to fit the curvature of the cranial vaults. The

Figure 1 Schematic diagram illustrating lines and points on the cranial vault. SSL, line of best fit along the sagittal suture; CSL, line of best fit along the coronal suture; S1, line parallel and closest to SSL; S2, Second parallel line to SSL; C1, line parallel and closest to CSL; C2, Second parallel line to CSL, gap between the lines = 1 cm.

measurements were performed by one examiner and recorded on a Microsoft Excel Spreadsheet (Microsoft Corporation, Redmond, WA). The recordings were rechecked by one person (other than the examiner) for accuracy. A total number of three measurements per point were performed and the measurement with the minimum thickness was taken as a final value. No points beyond the inferior temporal lines were measured, as residual muscle attachment would create inaccuracy. Also, no measurements beyond the lambdoid suture were performed.

Statistical Analysis

Discrete data of average age at death and male-to-female ratio were reported and then further statistical analyses were performed using the software system R (R Development Core Team; Vienna, Austria).²¹

For the thickness of the parietal bone, a linear mixed model approach was used to estimate the overall average thickness, average thickness among different gender and sides, and average thickness in different locations. The linear mixed model approach was chosen to account for the multiple measurements collected from the same specimen (i.e., correlated data). Furthermore, a univariate mixed model analysis was conducted to evaluate any statistical associations between the variables (gender and side) and thickness.

To evaluate for regional variations in thickness, three main analyses were performed. First, a thickness map was produced based on the average thickness among different locations. Second, a multivariate analysis was performed to determine the difference in thickness among each location. Finally, using a linear mixed model, an average thickness for each line (S lines and C lines) was estimated to assess for any variations in a mediolateral (S1 to S9) and anteroposterior (C1 to C9) direction. This analysis was performed by fitting a linear model to different thicknesses among the different lines. A p value < 0.05 was used to evaluate statistical significance and R^2 was used to predict the accuracy of the linear relationship.

Analyses to identify the ideal sites for calvarial bone graft harvest were performed using features of 6 mm of minimum thickness and 2 cm away from the midline as a guide. First, all the locations with an average thickness greater than 6 mm were identified and calculated in proportion. Second, the first step was repeated after excluding the locations within 2 cm from the midline (i.e., excluding locations along the S1 and S2 lines).

In this study, a p value of less than 0.05 was determined as being statistically significant.

Results

Demographics

The age at death was identified in 22 of the 25 individuals who donated their cranial vaults. The average age at death was 80 years. The gender was identified in 23 specimens, of which 12 were female and 11 male (►Table 1).

Thickness

The overall average thickness of the points using a correlated data was 6.69 mm with a standard error of 0.22 mm. The

Table 1 Demographic data of study samples

Skulls	Age at death (y)	Sex	Cause of death
1	72	F	Pneumonia
2	81	M	Lung cancer
3	62	F	Carcinomatosis
4	86	F	Cervical cancer
5	76	M	COPD
6	NA	M	NA
7	93	F	Congestive heart failure
8	89	F	Cardiac arrest
9	78	M	Lung cancer
10	75	M	Pneumonia and left ventricular failure
11	75	M	Gastrointestinal bleeding
12	NA	NA	NA
13	97	M	Cerebrovascular accident
14	65	M	Metastatic gastric carcinoma
15	NA	NA	NA
16	73	F	Respiratory cardiac arrest
17	77	F	Lung cancer
18	94	F	Cardiac arrest
19	79	F	Carcinomatosis of lung and liver
20	96	F	Congestive heart failure
21	78	M	Lung cancer
22	85	M	Colon cancer
23	75	M	Metastatic prostate cancer
24	81	F	Respiratory arrest
25	83	F	Cerebrovascular accident

Abbreviations: COPD, chronic obstructive pulmonary disease; NA, not available.

average thickness among different locations ranged from 2.85 mm to 6.93 mm. The actual thickness ranged from 2.55 mm to 13.1 mm. Of the total of 3,887 points, 1,997 points (50%) had a thickness greater than 6 mm. The gender and sex variables were found not to have any statistically significant association with the thickness (►Table 2).

Regional Variations

There was a trend for a progressive declination in thickness from the S1 line toward the S9 line in a linear relationship. The expected decrease in thickness for each consecutive line was 0.2 mm. This was statistically significant with a p value of 0.0003. The linear relationship had a high goodness of fit with R^2 of 0.83 (►Fig. 2). Conversely, a progressive inclination in thickness from the C1 line (6.75 mm) toward the C16 line (7.93 mm) was observed. The expected increase in thickness was noted to be 0.07 mm for each consecutive line, which was

Table 2 Average thickness of the parietal bones

	Thickness, mm ($\pm$ SE)	p value
Overall average	6.69 ($\pm$ 0.22)	
Ranges		
Measurement	2.55–13.1	
Average of each point	2.85–6.93	
Gender variation		0.20
Male	6.41 ($\pm$ 0.30)	
Female	Male +0.54 ($\pm$ 0.42)	
Side variation		0.21
Right	6.66 ($\pm$ 0.22)	
Left	Right +0.06 ($\pm$ 0.04)	

Abbreviation: SE, standard error.

Linear mixed model was used to estimate the averages.

Univariate mixed model was used to compare sex and side variables.

p value = considered significant if less than 0.05.

statistically significant with a *p* value of 0.0005. However, as apparent in the scatter plot graph, the plots are more randomly distributed, giving it a poor goodness of fit for the linear relationship with R^2 of 0.56 ($\rightarrow$ Fig. 3).

The thickness map clearly shows a regional variation in thickness of the parietal bone demarcated well by borders and colors ($\rightarrow$ Fig. 4). The demarcation harboring the locations with an average thickness greater than 6 mm was found to be U-shaped (bottom of the *U* facing lateral direction), covering a relatively large area between S1 to S5 and C6 to C11. A smaller U-shaped outline (bottom of the *U* is narrower and faces lateral direction) harbors the area with an average thickness greater than 6.5 mm, located mainly along the S1 line in the mid to posterior part of the parietal bone.

Ideal Sites for the Bone Graft

Of all 135 different locations, 47 (34.5%) and 13 (9%) locations had an average thickness greater than 6 mm and 6.5 mm, respectively. When locations within 2 cm from the midline were excluded, it decreased to 27 (20%) and 3 (2%) locations ($\rightarrow$ Table 3).

Figure 2 Scatterplot graph and line of best fit for average thicknesses of the parietal bone against the different S lines. Thickness is in millimetres. $R^2 = 0.83$.

Discussion

Calvarial bone grafts are widely used in craniofacial reconstruction surgery. Although the complication rates are relatively low, the magnitude of the complications are potentially devastating for both patients and surgeons alike, highlighting the need for studies such as this to look at the thickness of the parietal bones to identify the safest site(s) for calvarial bone graft harvest. This report is unique from other studies in several ways in that (1) this is the first New Zealand-based cadaveric study looking specifically at calvarial bone graft sites, (2) more locations were measured per parietal bone in comparison to other studies, (3) a thickness map was constructed so that exact locations are identifiable using anatomical landmarks, and (4) the identification of the safest sites was analyzed to fit the features of ideal graft harvest sites described in the literature.

There are several limitations of this study. First and foremost is the limited number of specimens used in this study, in part due to the resources available during the study period.

Second, our study does not address any ethnic diversity nor any age variations. The skulls were obtained only from New Zealand Europeans with an average age of 80 years, creating limitations on external validity. It has to be noted, however, that the age-related change of the parietal bone is still controversial. Maves and Matt reported that the human skull reaches 75 to 80% of its thickness by the age of 5 and reaches the overall size of an adult by the age of 8.²⁰ Thereafter, slow growth further occurs until the age of 20.¹⁶ Moreira-Gonzales et al have found no significant difference in total thickness of the parietal bone according to age,¹⁴ whereas Sullivan and Smith claimed an age-related thinning of the total thickness owing to progressive thinning of the inner plate.²²

Third and last, the specimens may have come from individuals with bone-related disorders such as Paget's disease, which could have caused an overestimation of the parietal bone thickness. This information, however, was unavailable.

In this report, the overall average thickness of the parietal bone was found to be 6.69 mm with an average thickness ranging from 2.85 to 6.93 mm in different locations, which is comparable to the previous studies that reported ranges from 4.73 to 6.67 mm in Koreans by Hwang et al,¹⁵ 5.04 to 7.17 mm in another set of Koreans by Jung and colleagues,¹⁶ and 5.3 to 7.5 mm in Caucasians and African Americans by Moreira-Gonzalez et al.¹⁴ The upper range reported in the U.S.-based study relates to thicker parietal bones found in African Americans compared with those found in Caucasians. The wider range reported in our study can be related to more measurements performed covering a greater area of the parietal bone in comparison to other studies.

The gender and side variables were found not to have any statistically significant association with the thickness of the parietal bone in this report. This differs from the finding reported by Moreira-Gonzalez et al that females had a thicker parietal bone than males.¹⁴

Figure 3 Scatterplot graph and line of best fit for average thicknesses of the parietal bone against the different C lines. Thickness is in millimetres. $R^2 = 0.56$.

In terms of regional variations in thickness, this report was consistent with other studies in that there was a gradual thickening of the parietal bone in both medial and posterior directions. This is also clearly visible on the thickness map

Figure 4 Thickness map showing regional variation in thickness of the parietal bone. Borders demarcate regions with average thicknesses of more than 6.5 mm, 6 mm, 5.5 mm, 5 mm, 4.5 mm, 4 mm, and 3.5 mm. Note a large U-shaped (bottom of U facing lateral direction) outline demarcating the area with an average thickness greater than 6 mm. A smaller U-shape outline (bottom of U facing laterally and narrower) borders an area of an average thickness greater than 6.5 mm.

Table 3 Proportion of areas with an average thickness greater than 6 mm and 6.5 mm

Average thickness (mm)	Proportions
> 6 (all)	47/135 = 34.5%
> 6 (excluding S1 and S2)	27/135 = 20%
> 6.5 (all)	13/135 = 9%
> 6.5 (excluding S1 and S2)	3/135 = 2%

Note: See text for description of S lines.

with an overall appearance similar to that of Hwang et al and Moreira-Gonzalez et al.^{14,15}

In regards to the ideal harvest sites, previous studies recommended that bone grafts be harvested in the posteromedial aspect of the parietal bone.¹⁶ However, this description is very vague and subject to interpretation. Other studies have constructed a thickness map as a practical guide to surgeons for choosing the ideal sites.^{14,15} This, however, has not addressed the current recommendations of a minimum thickness of 6 mm, 2 cm away from the midline. In this study, a significant proportion (20%) of parietal bone had an average thickness greater than 6 mm and was situated more than 2 cm away from the midline. These were mainly located between 6 to 11 cm posterior to the coronal suture and 2 to 5 cm away from the sagittal suture.

Conclusion

Harvesting the calvarial bone graft in the area 6 to 11 cm posterior to the coronal suture, 2 cm away from the midline is recommended. Note that our study sample is limited to New Zealand Europeans with an average age of 80 years, limiting external validity of our study. We therefore recommend larger studies to overcome our limitations. Also, further studies in the role of preoperative imaging could also be of value.

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