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Determination of Average Contour of Thais Skulls for Design of Implants

Khemachit Sena and Surasith Piyasin
Department of Mechanical Engineering, Faculty of Engineering,
Khon Kaen University, 40002 Khon Kaen, Thailand

Abstract: In this study, 100 dry skulls of Thais collected at the Srinagarind Hospital in Khon Kaen, Thailand were CT scanned and served for the investigation of the geometric average contour of Thais skulls. Moreover, measurements of distances between landmark points on skulls (cranial anthropometry) were made with this set of skulls for future standardization of skull implants. Thus the main purpose of this study was to determine the average contour of Thai skulls using techniques of medical image processing, Computer Aided Design (CAD) and reverse engineering software tools. After obtaining the average contour or the skull template we were able to select a region of interest and cut it for each proper standardized implant. These standardized implants will reduce the time for surgeons in implant preparation process. With their presence there is no longer necessity for CT scanning process and therefore treatment costs for a patient decrease considerably. Therefore, the result will be a good alternative for cranioplasty compared with conventional methods.

Key words: average contour, skull implant, cranial anthropometry

INTRODUCTION

A treatment of cranial vault defects or cranioplasty was consequent to accidents, infection, tumor ablation or congenital defects. The purpose of cranioplasty is not only cosmetic repair but also cerebral decompression, protecting of underlying brain and improving the neurological status. There are two involved principal cranioplasty methods: osteoplastic reconstruction and restoration with alloplastic implants. Which method should be selected depends on size, site and shape of defect, age and health of patient. In the field of cranioplasty, alloplastic materials have been widely applied[1-5]. Reconstruction of the cranial vault is therefore performed according to those reasons and precise repair of the defect is very important for the design of human skull implants.

With the use of computers in the field of medicine today, there are several effective tools for operation planning, design of implants and other medical applications. Basic input data of these applications are data from CT-or MRI-scanning belonging to patients themselves or skeleton studies which can be reconstructed in 3D models for a study purpose[6]. Computers play an important role in medical implants design. They diminish design time and are applicable for pre-or postoperative planning. In addition to computers, modern design and manufacturing technology namely Rapid Prototyping (RP), Rapid Tooling (RT) and CNC machines are indispensable instruments in the design and manufacturing process of individual bone implants that accurately match skeletal anatomy[7-9].

Nowadays customized design for skull implants is widely used with many methods and materials. One of the most modern techniques is to design with CT scanning data through medical image processing and CAD software. A non-defected part from contra-lateral side of skull is mirrored based on the imaging technique for designing implants[10]. After the implant has been designed it must be justified for functionality by surgeon. Then STL file of the implant model is transferred to the rapid prototyping machine to fabricate a master part (implant model) for molding. A casting mold can be made of silicone rubber or dental stone from which implants of biocompatible materials such as PMMA or bone cement are fabricated[11]. If bone cement is used, silicon rubber would be an appropriate rapid tooling, while dental stone is suitable for heat curing or self-curing PMMA. For PMMA implant PMMA powder is mixed with its solvent and then pressed in the dental stone mold followed by a heating- or self-curing process. Furthermore, the implant must be finished as end work. These operations require much

Corresponding Author: Khemachit Sena, Department of Mechanical Engineering, Faculty of Engineering, Khon Kaen University, 40002 Khon Kaen, Thailand Tel: +66-43-202845 Fax: +66-43-202849

preparation time and skill both of the surgeon and technician.

This study will reduce procedure of CT scanning and design time for patients with not very large or complex defect. Design of standardized skull implants therefore will help the surgeon in implant preparation, by selecting implant that matches well with each case. This study also begins with CT scanning data but from skeletal dry skulls which were donated to Srinagarind hospital. Srinagarind Hospital is one of the biggest hospitals in Northeast Thailand with quite a great number of patients from various areas. The objective of this study is to develop a technique to determine the average contour of scanned Thais skulls in order to have a template for further design of standardized implants. The details of each step are described as follows.

MATERIALS AND METHODS

Data from CT (Computed Tomography) scanning: In the first step one hundred samples of Thai dry skulls collected from donors at the Department of Anatomy, Srinagarind Hospital, Khon Kaen University, Thailand, were obtained for 3D CT scanning. The donors were 54 males, 35 females and 11 unknown gender with the age range of 26-81 years at the time of death, the period when all had stopped growth (>18 years old). Sets of 4-6 skulls were laid in an acrylic box and scanned with SIEMENS Spiral CT scanner as shown in Fig. 1. Suitable CT parameters were: 120 kV, 0 degree gantry, 512×512 matrix, 1.5 section thickness with a reconstruction increment at 1 mm intervals. The data were then exported in DICOM format and recorded in storage media.

3D Reconstruction: The CT scanning data of each set of skulls in DICOM format were then imported into the medical image processing software(Mimics, Materialise N.V., Leuven, Belgium) in order to separate each skull by means of the thresholding technique (Hounsfield unit). In addition, the reverse engineering method was used to reconstruct a selected skull to an optimal 3D model, the suture and landmark points of which can be clearly seen by human eyes. The optimal 3D model was hereafter exported into the stereolithography (STL) format for further steps.

Cutting and separating of outer wall contour: For determination of the average contour only upper parts of skulls were considered, excluding facial parts and skull bases. Every skull was segmented following a plane that passes through the Glabella (GL), the right

Fig. 1: CT scanning of 100 dry skulls

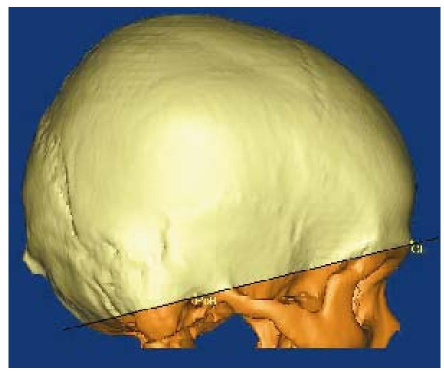

Fig. 2: Cutting for upper part

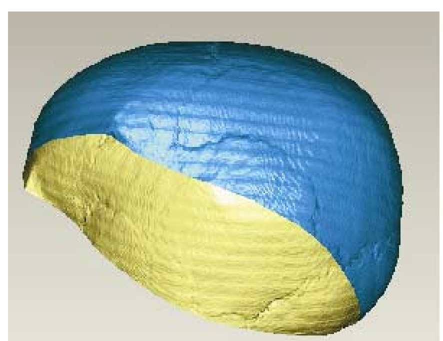

Fig. 3: Separation of outer wall contour

Porion (PoR) and the left Porion (PoL) as shown in Fig. 2. After cutting of skulls with the plane, outer wall surfaces must be extracted with the help of surface extraction and cutting techniques. This must be repeated for all 100 skulls in STL format (Fig. 3). The extracted surfaces were then placed in the same position before averaging with the alignment method. One

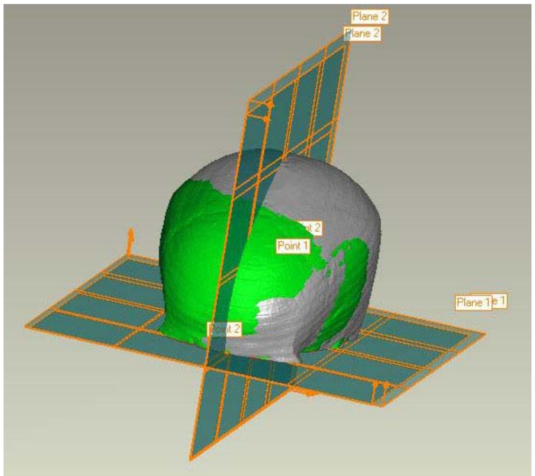

Fig. 4: Alignment to the same position

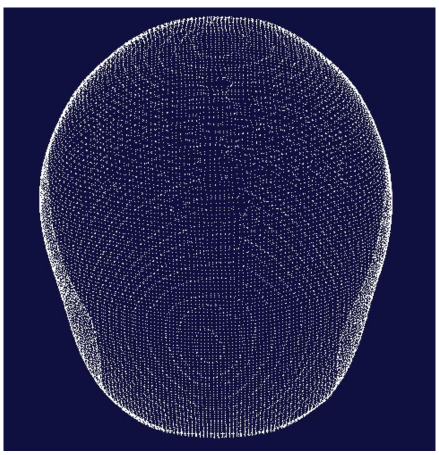

Fig. 5: Outer wall contour of a skull presented as a point cloud

reference point and two reference planes, here the Glabella (GL) and two perpendicular planes were used for alignment (Fig. 4).

Point Cloud Averaging: Before geometric averaging of the outer wall contours began, the STL files of the outer wall contours had to be first transferred into a point cloud format (Fig. 5). Then all of the 100 point clouds were averaged as shown in Fig. 6. The outcome averaged point cloud was retrogressively transferred to the surface STL file again. The above mentioned averaging and transfer processes were carried out with reverse engineering techniques. Finally we obtained the desired averaged contour of Thai skulls (Fig. 7a and b). It will be used as skull template for farther design of implants.

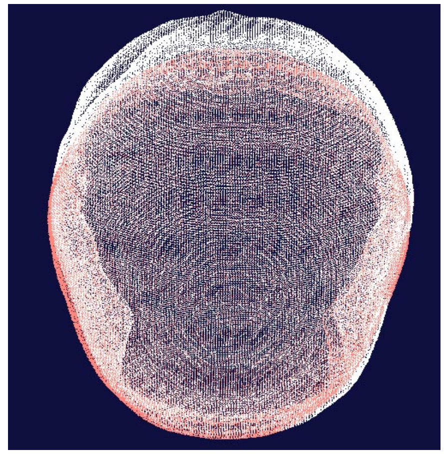

Fig. 6: Point clouds of 100 skulls

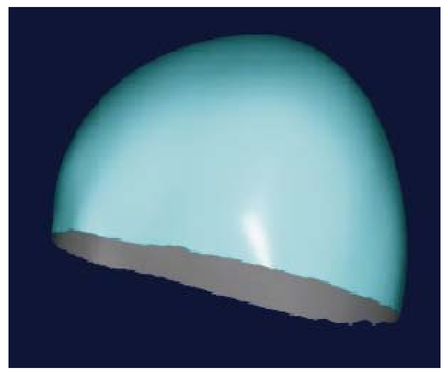

Fig. 7a: Side view of the average contour of Thai skulls

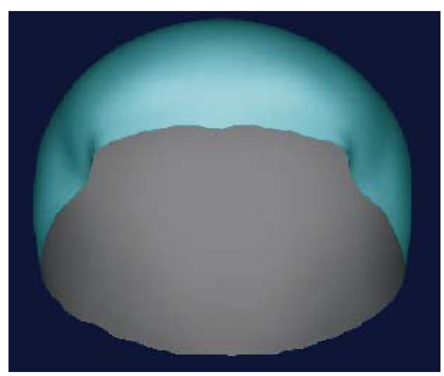

Fig. 7b: Front view of the average contour of Thai skulls

Design of Implants from Calculated Template: From the freeform averaged contour, geometries of standardized prostheses at various positions can be cut using computer aided design (Fig. 8). Figure 9 shows samples of implants with 3 sizes left and right that

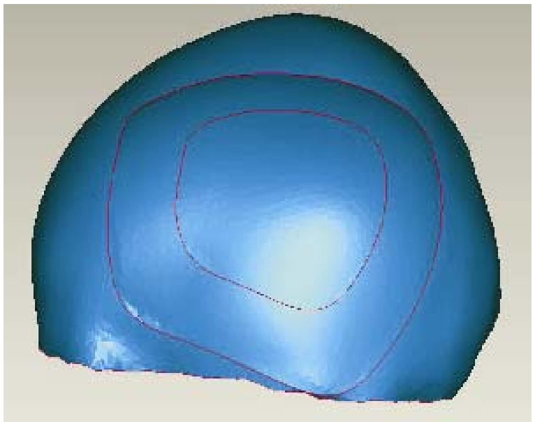

Fig.8: Cutting for implants

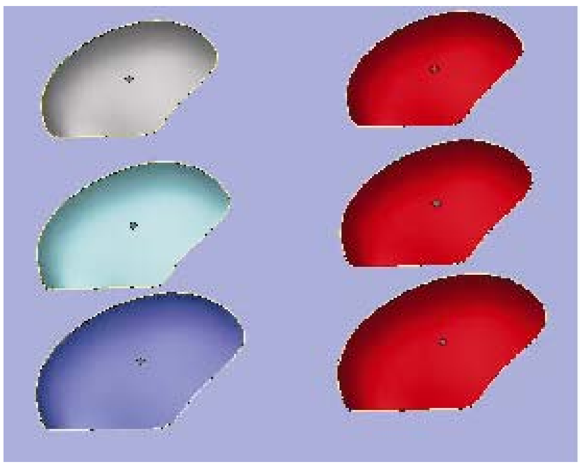

Fig. 9: Samples for implants

cover the temporal, frontal and parietal bones, which can be optionally made of Titanium sheet, PMMA , CFRP or other alloplastic biocompatible materials.

RESULTS AND DISCUSSION

With utilization of the medical image processing, CAD and reverse engineering techniques, the new method for determination of average contour of Thais skull is presented in this study. The calculated average contour of Thais skulls can be used as a template for further design of standardized implants for Thais. This is a good alternative for cranioplasty with not so complex defects. It decreases the operation time and difficulty for preparation of implants. Moreover, the cost of implants is lower, because there is no need to perform CT scanning and one fabrication mold can be used multiple times.

Table 1: Measurements of overall sizes of Thai skulls

Measurements (mm)	All samples (n = 100)					
					95% CI	
	Min	Max	Mean	σ	Lower	Upper
Max breadth	131.43	161.00	142.18	5.41	141.12	143.24
Max height	116.87	151.61	135.13	5.75	134.00	136.26
Max length	153.03	191.07	170.06	7.34	168.62	171.5

Skull measurements and reliability of samples: Besides the calculation of the average contour, measurements of overall sizes (maximum breadth, maximum height and maximum length) were carried out in MIMICS with these studied 100 dry skulls. From the statistical analysis (Table 1) it was found that the confidence intervals at 95% are narrow which means that this group of dry skulls samples can very well be the representative of Thai population. Measurement with the MIMICS program is a measurement on both 2D and 3D images by identifying landmarks points on a 3D reconstructed model or on CT-scanning images. This method is quite accurate and a comfortable method in comparison with 2D or other measurement methods in the past[12-17].

Standardized implants: Procedures for determination of average contour and design of standardized implants can be applied to other parts of bones in human body and also to other races of people if we have enough data from their CT scanning. In comparison with the personalized design suitable for large or complex skull defects and requiring precision, the standardized design is an alternative convenient way that reduces time and cost of operation.

Due to the limitation of surgeon's visibility during the operation, computer with medical image processing plays an important role in design of implants and effective surgical planning.

From statistical records of patients whose implants were designed at the National Metal and Materials Technology Center (MTEC), Thailand, the most injured area is the area between Temporal-, Parietal- and Frontal bones[18]. Hence, the preliminary design was focused to this adjacent area (Fig. 8 and 9).

Materials for implants are dependent on acceptable cost for each patient, size and site of defect. In this study we aim to use titanium mesh sheets although they are expensive because of their strength, lightness and bendable properties compared with PMMA or CFRP which are cheaper.

Finally we have to develop methods for choosing proper size of implant that best fits the patients' heads and produces best cosmetic result.

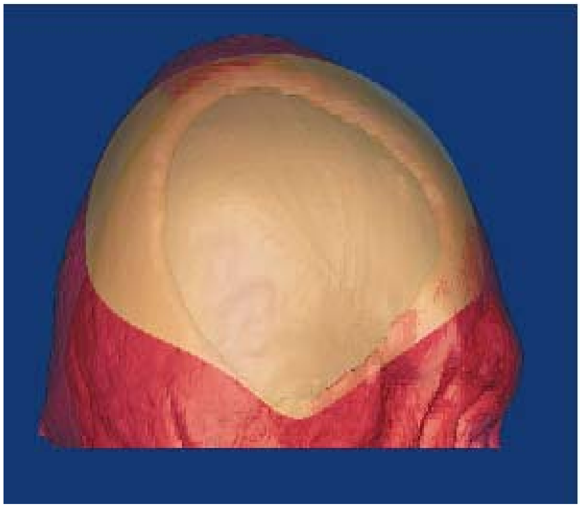

Fig. 10: Implants evaluation

Treatment and evaluation: Evaluation of the designed standardized implants must be accomplished both in computer simulation (Fig. 10) and in clinical test in aspects of aesthetic and functional result for better treatment in the future.

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REFERENCES

1. D'Urso, P.S., W.J. Earwaker, T.M. Barker, M.J. Redmond, R.G. Thompson, D.J. Effeney and F.H. Tomlinson, 2000. Custom cranioplasty using stereolithography and acrylic. Br. J. Plastic Surg., 53: 200-204. doi:10.1054/bjps.1999.3268.
2. Hieu L.C., E. Bohez, J. Vander Sloten, Phien H.N., E. Vatcharaporn, P.V. An, N.C. To, P.H. Binh and P. Oris, 2002. Design and manufacturing of personalized implants and standardized templates for cranioplasty applications. IEEE ICIT'02 Proceedings-2002 IEEE International Conference on Industrial Automations, Dec. 11-14, Bangkok, Thailand, 2: 1025-1030. http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=1189312.
3. Pompili, A., F. Caroli, L. Carpanese, M. Caterino, L. Raus, G. Sestili and E. Occhipinti, 1998. Cranioplasty performed with a new Osteoconductive, Osteoinducing Hydroxyapatite-derived material. J. Neurosurg., 89: 236-242. http://www.unboundmedicine.com/medline/ebm/record/9688118/full_citation/Cranioplasty_performed_with_a_new_osteoconductive_osteoinducing_hydroxyapatite_derived_material_
4. Eufinger, H., M. Wehmoller, E. Machtens, L. Heuser, A. Harders and D. Kruse, 1995. Reconstruction of craniofacial bone defects with individual alloplastics implants based on CAD/CAM manipulated CT-data. J. Cranio Maxillo-Facial Surg., 23: 175-181. Doi: 10.1016/S1010-5182(05)80007-1.
5. Nishiyama, T., T. Nakajima, Y. Yoshimura and Y. Nakanishi, 1994. Utilizing solid models for preoperative shaping of HAP-TCP ceramic bone substitute: Application for craniomaxillofacial surgery. Int. J. Plastic Surg., 17: 173-177. Doi: 10.1007/BF00188555.
6. Marsh, J.L. and M.V. Vannier, 1983. The third dimension in craniofacial surgery. Plastic Reconstruc. Surg., 71: 759-767. http://www.ncbi.nlm.nih.gov/pubmed/6687945.
7. Dean, D., K.J. Min and A. Bond, 2003. Computer aided design of large-format prefabricated cranial plates. J. Craniofacial Surg., 14: 819-832. http://lib.bioinfo.pl/pmid:14600623.
8. Singare, S., L. Dichen and L. Bingheng *et al*., 2004. Design and fabrication of custom mandible titanium tray based on rapid prototyping. Med. Eng. Phys., 26: 671-676. Doi: 10.1016/J.Medengphy.2004.06.001.
9. Singare, S., L. Dichen and L. Bingheng *et al*., 2005. Customized design and manufacturing of chin implant based on rapid prototyping. Rapid Prototyping J., 11: 113-118. DOI: 10.1108/13552540510589485.
10. Bruant, A.T., S.E. Don and B.S. Wiliam, 1988. Computer-designed prostheses for orbitocranial reconstruction. J. Plastic Reconstruc. Surg., 81: 315-322. http://www.ncbi.nlm.nih.gov/pubmed/3340666.
11. Tomancok, B.B., G. Wurm, J. Trenkler and Manfred, 1999. Extended cranioplasty with prefabricated carbon fiber reinforced plastic implants. Phidias Rapid Prototyping Med. 3: 7-9. http://www.emeraldinsight.com/Insight/ViewContentServlet?Filename=Published/EmeraldFullTextArticle/Pdf/1560090307_ref.html.

12. Pearson, K., 1933. The cranial coordinatograph, the standard planes of the skull and the value of cartesion geometry to the craniologist with some illustrations of the uses of the new method. Biometrika, 25: 217-253. Doi:10.1093/biomet/25.3-4.217.
13. Todd, T.W., 1923. Cranial capacity and linear dimensions in White and Negro. Am. J. Phys. Anthropol., 6: 97-194. Doi: 10.1002/ajpa.1330060202.
14. Thompson, G.W. and F. Popovich, 1974. Automated processing of cephalograms, facial photographs and dental casts. Am. J. Phys. Anthropol., 40: 97-103. http://www.ncbi.nlm.nih.gov/pubmed/4817661.
15. Benfer, R.A., 1975. Morphometric Analysis of Cartesian Coordinates of the Human Skull. Am. J. Phys. Anthropol., 42: 371-382. Doi: 10.1002/ajpa.1330420305.
16. Buranarugsa, M. and P. Houghton, 1981. Polynesian head form: an interpretation of a factor analysis of Cartesian co-ordinate data. J. Anat. 133: 333-350 http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1167605.
17. Charles, F.H., M.W. Vannier and R.H. Knapp, 1990. Validation study of skull three-dimensional computerized tomography measurements. Am. J. Phys. Anthropol., 82: 283-294. http://www.ncbi.nlm.nih.gov/pubmed/2375381.
18. Sena, K., S. Piyasin and K. Sitthiseripratip, 2006. Craniometric studies of skulls for design of implants in Thailand. Technical Meeting Med. Biol. Eng., IEE, 3: 51-54. Japan http://sciencelinks.jp/j-east/article/200703/000020070306A1021255. php.