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Quantifying normal head form and craniofacial asymmetry of elementary school students in Taiwan

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Summary *Background:* Defining three-dimensional (3D) normal craniofacial morphology in healthy children could provide craniofacial surgeons a reference point to assess disease, plan surgical reconstruction, and evaluate treatment outcome. The purposes of this study were to report normal craniofacial form and quantify craniofacial asymmetry of healthy children in Taiwan by implementing the 3D stereophotogrammetry technique.
Methods: Healthy Taiwanese elementary school children ($n = 652$) aged 6–12 years with no known craniofacial anomaly were recruited. After the 3dMD scanning procedure, 32 landmarks were manually placed on the 3D cranial images. Thin plate spline algorithm based on landmarks and closest point matching was applied to deform a symmetric 3D template into the scale of each scanned images. Skull asymmetry and facial asymmetry were calculated using 3dMD vultus and MATLAB. Average head shape models were also presented.
Results: Overall, the mean head transverse width, height, anteroposterior length, and circumferences were 163.02, 220.79, 179.07, and 526.55 mm, respectively. On average, the skull asymmetry and facial asymmetry were 2.47 ± 1.26 mm and 0.96 ± 0.53 mm, respectively, with no significant (all $p > 0.05$) differences found when comparing males and females. In the average head shape model, certain craniofacial areas on the right side were found to be more protruded than those on the left side.

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Conclusions: This study shows that the baseline craniofacial form of the Taiwanese elementary school children is asymmetric with a tendency of more protrusion of the head on the right side.

Introduction

A symmetric craniofacial appearance is perceived as both functionally and esthetically normal. For patients with congenital craniofacial anomalies, surgical intervention and reconstruction are common solutions to restore symmetry. Therefore, it is important to understand the craniofacial morphology and symmetry in healthy children, as it provides physicians a reference point for preoperative workup (diagnostic definitions and treatment planning), postoperative evaluations of therapeutic outcomes, and longitudinal follow-up investigations (progression of untreated and treated pediatric individuals with facial asymmetry during the growing age).

Several studies have measured the craniofacial morphology and asymmetry using conventional methods such as anthropometry, cephalometry, and two-dimensional (2D) photography.[1-4] However, these methods lack the ability to identify the intricate three-dimensional (3D) curvature and the depth of craniofacial structures.[3,5-9] With the development and implementation of 3D stereophotogrammetry, a few studies have reported more precise and reliable quantification of craniofacial asymmetry in the healthy pediatric population.[10,11] These methods analyze the entire head shape to provide detailed assessment of the cranium and facial regions.[10,11]

To date, there has been no rigorous quantification of the normal craniofacial morphology in the healthy Taiwanese pediatric population. This study used previously reported analytical methods[10] with modifications to report the craniofacial form and quantify the craniofacial asymmetry in healthy elementary school children in Taiwan using 3D stereophotogrammetry.

Material and methods

With institutional review board approval, healthy children from elementary schools in Taiwan ($n = 652$) aged 6–12 years and with no known craniofacial conditions (craniofacial deformity, trauma, or operations) were recruited in this study.

A set of 3dMD (Atlanta, GA) cameras was applied to capture the 3D head images of our subjects. During image acquisition, all subjects were requested to wear a thin elastic nylon cap to minimize the influence of hair and to better reveal their true head shapes. Additionally, the subjects were instructed to sit on chairs with uniform dimensions and were asked to remain still with a neutral facial expression during image acquisition. Images were reviewed case by case afterwards to ensure they meet the satisfactory quality.

A perfectly symmetric model with known left and right point correspondences was created using custom programs written in MATLAB and was divided into head and facial parts.[10,11] In this study, the area of the face was defined by counting in points that have less Euclidean distances to the nose tip than that between the nose tip and gnathion (Figure 1).

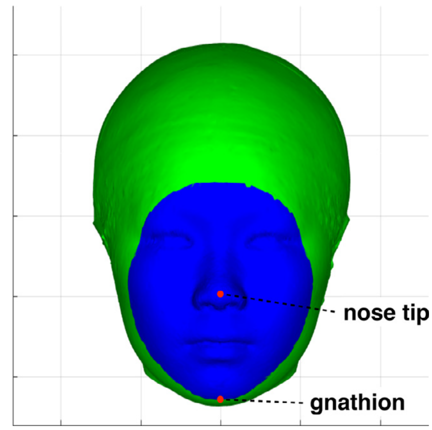

Figure 1 Defining facial area (blue area). Facial area in this study is defined as the points that have less Euclidean distances to the nose tip than that between the nose tip and gnathion.

Thirty-two landmarks of recognizable anatomical structures were manually placed on each head image using 3dMD software (Figure 2). An additional 40 landmarks were also constructed digitally and dispersed into four layers surrounding the skull apex, which is the point where the y-axis (vertical dimension) meets the skull. The layers were defined by descending 10° from the apex one after another, and each of them consisted of 10 evenly distributed landmarks (Figure 2). The origin of the coordinate system for each subject's 3D model was calculated by the nearest projection of the nose tip to the line connecting the bilateral tragus.

Several steps were taken to deform the template into each subject's 3D surface scan. At first, the template was scaled into the subject's size. Then the patients' scans were registered to match the template through rigid translation. The thin-plate spline algorithm was then applied to deform the template on the basis of the relationship between two sets of landmarks. Finally, closest-point deformation was performed to confirm the detail of points. Overall, these efforts were made to find point correspondence between the left and right sides of each subject (Figure 3).

The Euclidean distances from the origin of coordinates to each point on the 3D scan were calculated. Then the asymmetry was represented by the absolute difference between the two left and right corresponding points. Mean asymmetry was calculated for all the points. There were a total of 4912 pairs in the face area and 24,334 pairs in the head area calculated per model.

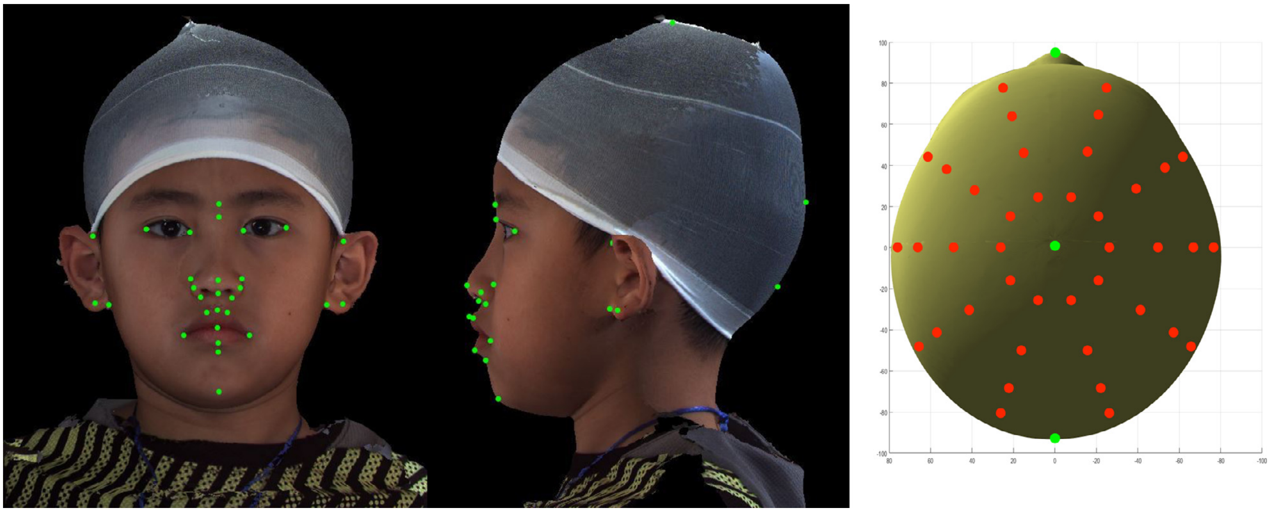

Figure 2 Placement of the landmarks. Figures on the left and center show the 32 manually placed landmarks (green) on recognizable anatomy structures. The figure on the right shows the additional 40 digitally constructed landmarks (red) from the top view.

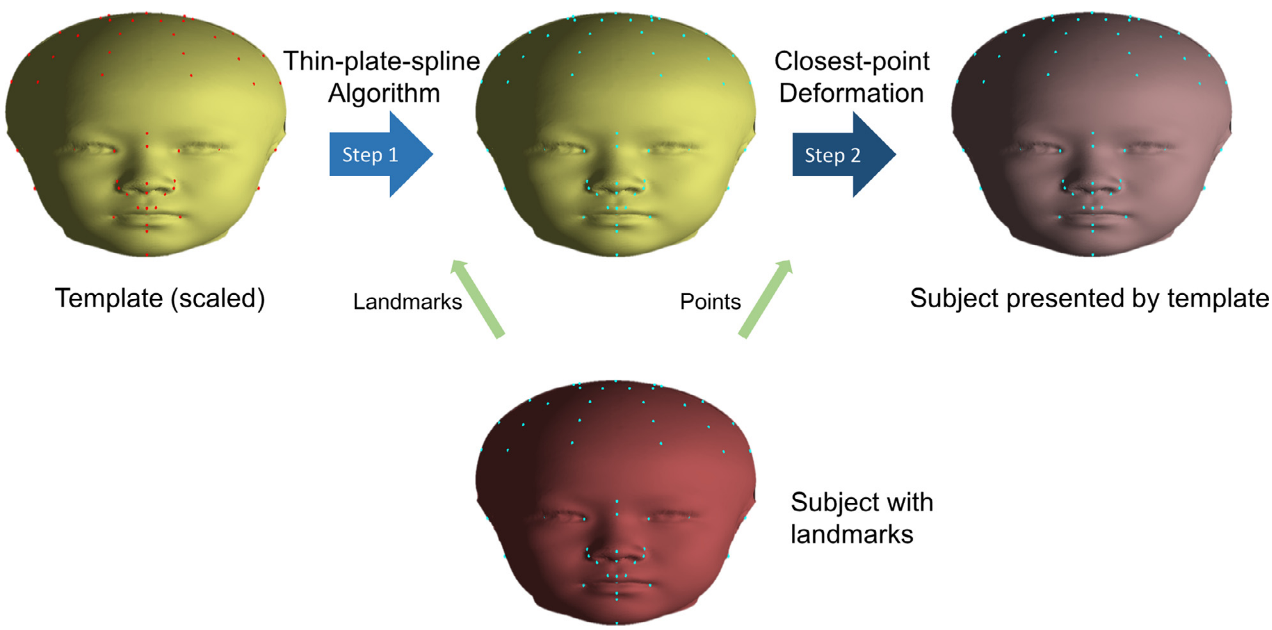

Figure 3 Transformation of template to present the subject. The thin-plate spline algorithm deforms the scaled template based on corresponding landmarks on the subject. Then, the closest-point deformation further detailed the deformed template to precisely present the subject.

Standard head measurements were also obtained. Head circumference of each subject was measured manually before taking a 3D image. On the basis of Farkas' anthropometric definitions, head transverse width (between euryons), anteroposterior length (between the glabella and the opisthocranion), and head height (between the vertex and the gnathion) were calculated.

Statistical analysis

For descriptive analysis, the mean ± standard deviation was used for metric variables, and percentages were used for categorical variables. Student's t test was adopted for statistical comparisons between male and female children, with a $p < 0.05$ considered statistically significant. All analyses were performed using SPSS version 22.0 (Chicago, IL).

Results

3D images of healthy children ($n = 676$) from elementary school in Taiwan aged 6–12 years and with no known craniofacial abnormalities were reviewed. Twenty-four images were excluded as a result of incomplete data recording or poor image quality. Among the remaining 652 subjects, 324

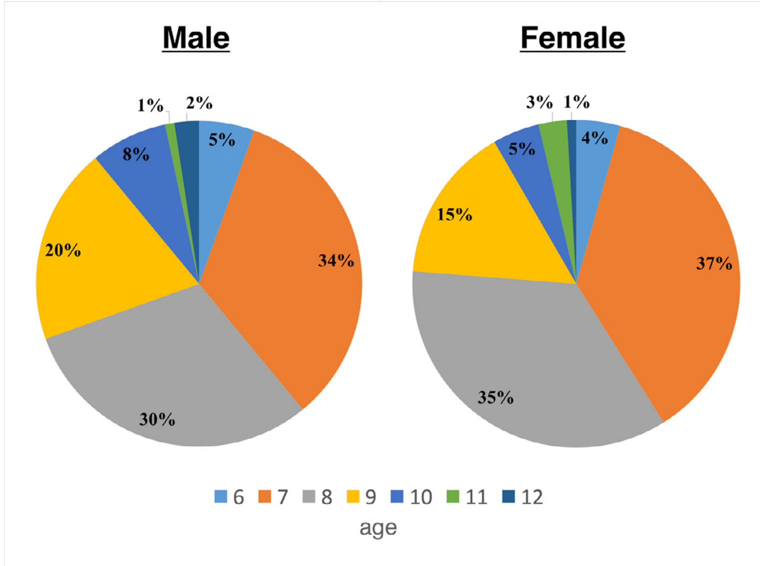

Figure 4 Proportion of male and female individuals according to age.

Table 1 Mean craniofacial norms as well as skull and facial asymmetry and laterality for healthy Taiwanese elementary school students ($n = 652$).

Parameters	All	Male	Female
Craniofacial norms			
Circumference, mm (m ± sd)	526.55 ± 16.23	528.85 ± 16.72	524.23 ± 15.40
Head height, mm (m ± sd)	220.79 ± 10.20	222.82 ± 9.75	218.74 ± 10.26
Anteroposterior length, mm (m ± sd)	179.07 ± 10.23	176.98 ± 7.48	181.19 ± 12.08
Transverse width, mm (m ± sd)	163.02 ± 11.82	165.49 ± 12.99	160.53 ± 9.93
Asymmetry parameters			
Facial asymmetry, mm (m ± sd)	0.96 ± 0.54	0.93 ± 0.50	0.98 ± 0.56
Skull asymmetry, mm (m ± sd)	2.47 ± 1.26	2.32 ± 1.12	2.62 ± 1.37
Laterality parameters			
Right face laterality (%)	69.63	74.70	64.51
Right skull laterality (%)	62.37	65.75	58.95

mm, millimeter; m, mean; sd, standard deviation;%, number of individuals.

were females (mean age, 7.91 years) and 328 were males (mean age, 8.03 years) (Figure 4).

Head measurements

Overall, the mean head transverse width, height, anteroposterior length, and circumferences were 163.02, 220.79, 179.07, and 526.55 mm, respectively (Table 1 and Figure 5).

Skull asymmetry and facial asymmetry

Overall, the mean skull asymmetry and facial asymmetry values were 2.47 (0.89-10.30) mm and 0.96 (0.31-3.65) mm, respectively, with no significant (all $p > 0.05$) differences for male versus female comparisons (Table 1).

By calculating the average value of subtracting Euclidean distances to the origin of left point from the origin of right point between all the point pairs, the percentage of subjects with a positive average value indicated an overall right laterality of the skull and face regions (Table 1).

Average head shape and its laterality

A composite head model was created by calculating the mean sets of points from all the 652 deformed templates, thereby representing the average head shape from our normal sample, with a mean head transverse width, height, anteroposterior length, and circumference of 158.11, 218.37, 179.22, and 526.55 mm, respectively (Table 2, Figure 6, and Supplementary material 1). We discovered a laterality of this average head shape model with a more protruded right cranium and face, with the most protruded part observed on the right lateral frontal area (Figure 6 and Supplementary material 1).

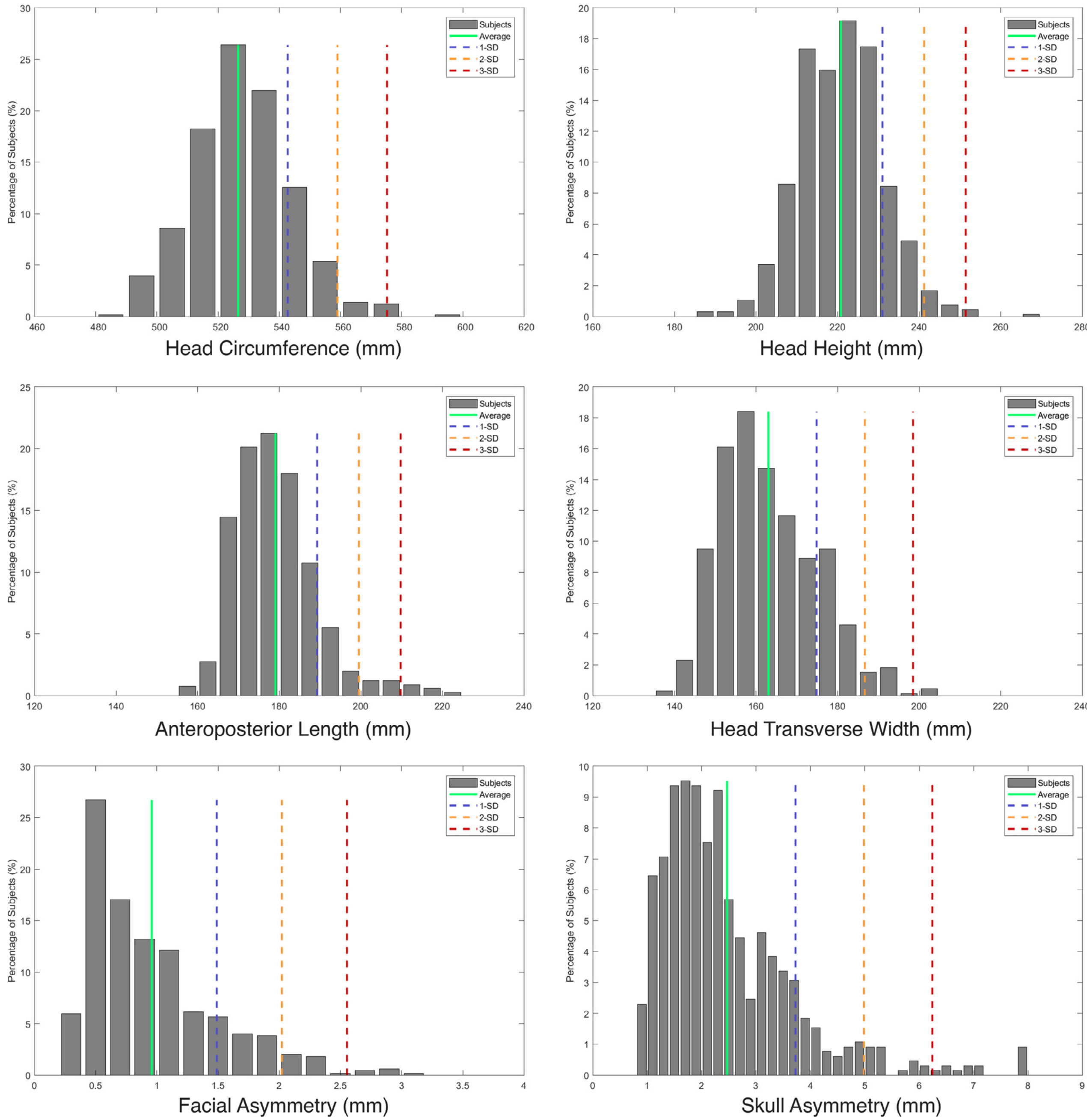

Figure 5 Overall distribution of craniofacial norms as well as facial asymmetry (bottom left) and skull asymmetry (bottom right).

Table 2 Mean craniofacial norms of the average head model created from healthy Taiwanese elementary school students ($n = 652$).

Craniofacial Norms	All	Male	Female
Head height (mm)	218.37	221.08	215.72
Anteroposterior length (mm)	179.22	176.98	181.48
Transverse width (mm)	158.11	158.83	157.24
Circumference (mm)	526.55	528.85	524.23

mm, millimeter; data presented as mean values.

Discussion

To presume there exists a perfectly symmetric human body is far from reality, and head and facial regions are of no exception. This is also endorsed by our study results, which demonstrated all the 652 participants with various degrees of head and face asymmetry. Humans are capable of detecting marked asymmetry of the face effortlessly, but how great the extent of asymmetry would be labeled as “significant” asymmetry remains as an open question in

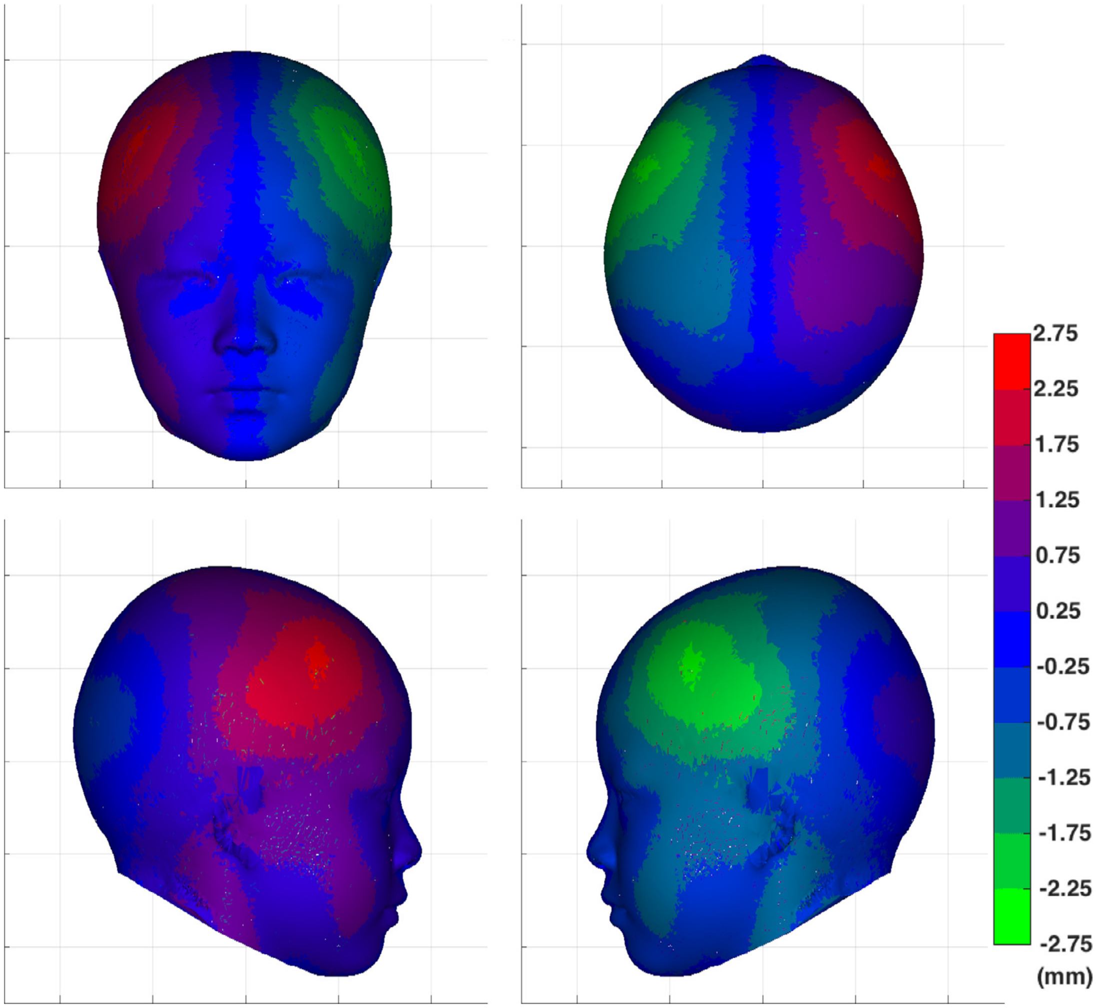

Figure 6 The average head model and its laterality. Colors with the corresponding values represent the different extent of asymmetry on this model.

literature,[12, 13] and it may vary from individual to individual. There are multiple factors that may contribute to facial asymmetry, including congenital anomaly, developmental condition, and acquired injury or disease.[14,15] For children with marked craniofacial asymmetry induced by congenital and developmental conditions, certain functional and psychosocial issues may arise.[16] Elementary school is a crucial period during socialization,[17] and often children with marked head and/or facial asymmetry would be labeled as abnormal and could suffer from pressure or "bully" from their peers. When dental orthopedics alone fails to provide satisfactory correction of dentofacial asymmetry, surgical management often becomes the solution for this group of children.[14, 18] Yet, to date, outcome evaluation of restoring symmetry largely relies on rather subjective assessment from a surgeon's esthetic criteria.[19,20]

In this setting, there were outstanding studies carried out to measure craniofacial norms through different equipment and methods.[2,4,21] Among them, anthropometry appears to be the most direct and intuitive way. Cephalometry features the ability to measure the bony structure,[4] and 2D photogrammetry is also widely used for its convenience.[3,5] However, 3D stereophotogrammetry stood out to become a state-of-the-art technique in this field owing to several favorable characteristics.[10,11,22-25] The high level of technical precision as well as the desired intra- and inter-observer reliability regarding landmark identification, the ability of creating a 3D coordination system in graphics, and the avoidance of radiation exposure have all contributed to the popularity of the 3dMD system in the past decade.[10,11,22-25]

Recently, in a well-delineated 3D craniofacial image study, Cho et al. assessed the craniofacial asymmetry of healthy, normal pediatric subjects in the United States, but only a small group of Asian (4%) subjects were enrolled among a total sample of 533 individuals aged between 0 and 17.6 years.[10] This study slightly modified the methods developed by the previous study[10] to assess the craniofacial form in healthy Taiwanese subjects. These methodological differences include the use of additional anatomical landmarks to register and transform the template to the 3D craniofacial image. The outcomes of this study are unique, as they represent only healthy Asian subjects between 6 and 12 years old. While the asymmetry range previously reported by Cho et al. and that obtained in this study are the same, we believe that the head shape morphology between the two groups is different. The composite heads developed in this study can provide craniofacial surgeons in Taiwan and other Asian countries a standard for evaluating children with craniofacial differences.

In the current study, participants were recruited from several elementary schools in Taiwan. We selected children of this age range not only because they were young with much less acquired facial deformities but also because they were equipped with wrinkle-free facial texture, and mostly, they were mature enough to understand and comply with the research instructions. The constantly growing craniofacial morphology in these children was also ideal for further longitudinal studies.

None of the children participated in this project has ever been reported with a history of congenital craniofacial anomalies, major craniofacial trauma, craniofacial operations, or any concerns regarding their head or face shape from themselves or their parents. Although we admit that some inevitable bias may exist in this group of children, we presume they are valid enough to represent the normal population in Taiwan.

In this report, craniofacial norms including mean head circumference, transverse width, and height were all slightly larger in males than in females, as described for craniofacial norms of the normal pediatric population in the United States.[10] Different from the previous study,[10] we discovered that the mean head anteroposterior length was larger in females. The possible explanation could be that female subjects often have larger amount of hair bulking over the posterior aspect of the skull region, which may have created biased elongation of the anteroposterior length parameter. Despite all the efforts that were undertaken to minimize the deformation effect, the presence of hair still casts inevitable impairment when analyzing the posterior head through 3D stereophotogrammetric images.[10,26]

Similar to the former normal US pediatric-based study,[10] healthy Taiwanese children did not present significant differences between males and females for skull or facial asymmetry values. The mean facial asymmetry (0.96 ± 0.53 mm, range 0.31–3.65 mm) in our sample was also within the previous observations (1.2 ± 0.6 mm, ranging from 0.4 to 5.4 mm).[10] Nonetheless, the mean skull asymmetry (2.47 ± 1.26 mm, ranging from 0.89 to 10.30 mm) for Taiwanese children appeared greater than that reported in the prior study (1.5 ± 0.5 mm range, 0.46–4.78 mm).[10] While the slight differences in the methodology between the two studies[10] may explain some of these differences, the age and ethnic group distributions are probably the main factors determining these differences. Therefore, the comparative discussions between our current findings and the previous study[10] should be carefully interpreted, and extrapolations to other age and ethnic groups are not recommended.

From the created average head shape model, we noticed that certain craniofacial areas over the right side were more protruded than those on the left side, regardless of gender or age. In addition, the difference between two sides appeared to increase with age. It has been reported that in patients with minor facial asymmetry, the right hemiface is usually wider.[27-31] Haraguchi et al. reported that 79.9% of patients had a wider right hemiface in 1800 Japanese subjects by measuring 2D frontal facial photographs.[31] They also concluded that this phenomenon is more likely to be a hereditary trait rather than an acquired trait.[31] The average head and face shape model created in our study also supports the right side laterality. In addition to the fact that right side laterality was found in both genders, we noticed that male subjects are more likely to have right side laterality in both face and head regions. A similar phenomenon was also described in the past literature.[29] However, the exact mechanisms that underlie these presentations are still unknown and may be worthy of further study.

Different from the previous normal US pediatric-based results showing that the maximum asymmetry was in the posterior lateral region of the average head model,[10] we observed the anterior lateral part to be the most asymmetric region. In both current and previous studies,[10] the least asymmetric region was observed in the cranial midline.

Despite the fact that the 3dMD system has been proven to be one of the most reliable and precise tools in studying craniofacial forms,[10,11,22-25] certain drawbacks should be considered. Skull areas covered with hair have been difficult to define with the real soft tissue surface and thus made it barely possible for an ideal placement of landmarks in the posterior skull region. As described for female individuals, the nylon cap helped minimize the deformation effect but the influence was inevitable. Furthermore, despite standard data collection (remain neutral facial expression as far as possible), some of the elementary school children may have presented insufficient compliance and it may somewhat contribute to the bias in analyzing facial asymmetry in ours and previous similar studies.

The goal of our study is to establish a big data bank of 3D craniofacial photography and set up the head shape model as references for all age groups, including Taiwanese newborns, children, and adults. The studied craniofacial norms and the calculated head shape model could then be widely applied as a tool to evaluate a myriad of outcomes in craniofacial reconstructions including, but not limited to, alveolar bone grafting, fat graft surgery, rhinoplasty, and orthognathic surgery procedures. Ongoing 3D data collection from our group will be reported in the future. Further studies by other groups could collect additional 3D craniofacial normal values from infancy to maturity in other ethnic groups.

Conclusions

This study shows that the baseline craniofacial form of the Taiwanese elementary school children is asymmetric, with the laterality of more protruded head on the right side.

Declaration of Competing Interest

All authors declare that they have no conflict of interest.

Acknowledgments

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Ethical approval

The study protocol was approved by the Ethics Committee for Human Research, No. 201601192B0, Chang Gung Memorial Hospital, Taoyuan, Taiwan.

Permission for photograph use

Permission was obtained for using photographs in this manuscript.

Author contribution statement

C.K.H., R.R.H., and S.W.W. conceptualized and designed the study, organized data collection, carried out the analyses, and wrote the manuscript. R.D., A.A.K., and L.J.L. critically reviewed the manuscript. P.Y.C conceptualized and designed the study and critically reviewed the manuscript.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.bjps.2019.09.005.

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