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SEXUAL DIMORPHISM AND AGE ESTIMATION OF THE CHILDREN MANDIBLE FROM DENTAL PANORAMIC TOMOGRAPHY (DPT): A GEOMETRIC MORPHOMETRIC ANALYSIS

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SDG Elements:
Peace, Justice and Strong Institutions

ABSTRACT

Forensic odontology is the field of dentistry that identifies human remains. The mandible is the strongest bone in the face and remains intact even in mass disasters. Geometric morphometrics is a shape analysis that uses landmark coordinates that can visualise the variation of the structure. A total of 305 DPT images of 159 male and 146 female Malay children were classified into two age groups: Group 1 (ages 3–7) and Group 2 (ages 8–12). These images were analysed using geometric morphometric analysis. Twenty landmarks were digitised using the tpsDig2 software. MorphoJ was used to perform discriminant function analysis (DFA), canonical variate analysis (CVA), principal component analysis (PCA), generalised Procrustes analysis (GPA), and Procrustes ANOVA. There were significant differences in mandible shape and size between the two age groups and sexes ($p < 0.05$). The first five principal components (PC1–PC5) explained 75% of the shape variation. The DFA showed 82% accuracy in classifying children into age groups after cross-validation. However, the accuracy among males and females dropped to 62%, due to overlapping characteristics and the absence of secondary sexual traits in children under 12. Geometric morphometry can capture unique morphological shape variables, thus enabling the assessment of sexual dimorphism and age estimation using mandibles to aid forensic odontology. This research supports SDG 16: Peace, Justice and Strong Institutions, by enhancing scientific tools for victim identification and justice in the aftermath of disasters and crimes involving children.

Introduction

Forensic odontology is crucial in handling and presenting dental evidence in court (Krishan et al., 2015). Odontologists identify bodies, estimate age, and recognise victims in mass deaths, examine bite marks, investigate abuse and malpractice cases (Mohammed et al., 2019). They are vital in identifying disaster victims from industrial accidents, aviation, natural disasters, and terrorist attacks of various causes (Mohammed et al., 2019). In the cases of decomposed or burnt bodies, when other identification methods fail, forensic odontology is essential (Mohammed et al., 2019). During severe disasters, dental professionals help in diagnosis, referrals, decontamination, infection control, notifications, immunisations, prescriptions, triage, and improvement of medical care (Bhoopathi et al., 2010). Biological profile is created summarising ancestry, sex, age of death, and stature for identification (Adserias-Garriga et al., 2018). Age estimation helps narrow down missing persons and for legal consideration. Adult age can determine by observing ageing-related changes in dental eruption, bone growth, and specific morphological features, while for children, evaluations focus on physical traits, facial features, dental development, and signs of sexual maturity (Schmeling, 2023).

Forensic odontologists use the mandibles and the maxilla to estimate age and sex. The mandible, strong and protected by facial muscles, is often found intact and aids in age and sex (Pereira et al., 2020). Since the mandibular ramus generally remains intact, many studies focus on it to determine age (Bhuyan et al., 2018). The gonial angle is obtuse at birth, narrows with age, and widens again in old age (Pereira et al., 2020). It becomes more acute during growth as the mandibular ramus grows taller than the body (Pereira et al., 2020; Raghda Al-Shamout et al., 2012). Male mandibles are typically larger and stronger than females, and growth rates differ between sexes. The mandible experiences a teenage growth spurt, being the last skull bone to stop growing (Chandramani Bhagwan More et al., 2017). Differences in mandibular development and growth rates are the key to sex differentiation. The mandibular ramus, a highly sexually dimorphic structure, and the height of the coronoid are effective in determining sex. Studies show that women's gonial angles generally have higher mean values than men's (Christensen et al., 2014; Sharma et al., 2016; Tunis et al., 2017).

The geometric morphometrics method (GMM) is an advance in coordinate-based methodologies in the application of statistical shape. GMM address the limitations of simple linear, volume, or area-based techniques that often obscure geometric interrelations between measurements (Faridah Mohd Nor et al., 2019; Liuti & Dixon, n.d.). Bookstein (1984, 1986, 1987, 1991) developed the GMM to investigate the morpho space of objects by utilising landmarks quantified as Cartesian (x, y, z) coordinates and multiple coordinate points to represent shape (Liuti & Dixon, n.d.) This approach maintains the geometry of the landmark configuration and facilitates the analysis of shape and forms (Faridah Mohd Nor et al., 2019)). Geometric morphometric data can be configured as two-dimensional (2D) or three-dimensional (3D) landmark point coordinates. These coordinates allow for more precise distance estimations than traditional morphometrics (Faridah Mohd Nor et al., 2019; Liuti & Dixon, n.d.). GMM has the advantage of deconvoluting form by distinguishing the influences on shape that are size-dependent or independent, offering an edge over conventional morphometric techniques (Liuti & Dixon, n.d.). Furthermore, GMM is more responsive to visual representation of form.

The radiographic method of age identification is more straightforward and economical compared to other methods (Poongodi et al., 2015). Dental panoramic tomography (DPT) of the dry skull is widely used in forensic and scientific investigations and is among the highest quality examinations available for dry skull radiographs (Sharma et al., 2016). DPT is a 2D dental radiograph examination that takes a single picture of the entire mouth, including the teeth, upper and lower jaws, and surrounding tissues and structures. The jaw has a curved shape like a horseshoe that will appear flat on the DPT to provide information about the teeth and bones.

To facilitate future victim identification among Malaysians, this study created a database of the young Malay population obtained from various landmarks from mandibles in DPT using geometric morphometric analysis. The aim of the study was to analyse the variation in mandible size and shape using geometric morphometric analysis in the Malay children's population according to different age and sex.

Methodology

A retrospective study was conducted at the Faculty of Dentistry, Universiti Sains Islam Malaysia (USIM). Data were taken from the USIM Dental Clinic and DPT radiographs obtained from the Planmeca Romexis software from the 2012-2024 database. Radiographs of patients who met the needed criteria were selected and analysed, while these cases included male and female from the Malay ethnic group of different ages. Patients with a history of mandibular surgery and any other serious developmental disorders were excluded from the study. Age, sex, and race were documented for each sample. This research retrieved the database of cases under Planmeca Romexis at the USIM Faculty of Dentistry. No personal identification details of the individuals were documented. Privacy was maintained by providing a unique code for the samples. The ethics application was obtained from the USIM Institutional Ethics Committee (USIM/JKEP/2024-299). The research project was registered with the Research and Innovation Management Centre.

Landmark Application

The landmarks were applied using the tpsDig2 (Ver.2.31) programme. A total of 20 2D-dimensional hard tissue markers, which were defined in Table 1 and Figure 1, were applied to the mandible during this study. The landmark marking was demonstrated first by the supervisor, and then the Kappa correlation intra-rater reliability test was done to test the accuracy and consistency of the landmarking by the students and the inter-rater reliability test 2 weeks afterwards to achieve the acquired accuracy and consistency between both students of landmarking the mandible.

Table 1. The definition and number of landmarks on the mandible of DPT

No.	Landmark	Definition
1.	Coronion (Co)	The most superior point in the coronoid process (right)
2.	Mandibular notch (Mn)	The lowest point in the mandibular region (right)
3.	Condylion superior (Cds)	The most superior point in the mandibular condyle (right)
4.	Inferior alveolar foramen (IaF)	The most inferior point in the inferior alveolar canal (right)
5.	Posterior ramus (Pr)	Posterior ramus, which is horizontally located straight from 4 and 20 (right)
6.	Gonion (Go)	The most lateral external point of the horizontal and ascending rami of the lower jaw (right)
7.	Body mandibular notch (Bmn)	The deepest part on the body of the mandible (right)
8.	Gnathion (Gn)	The middle point on the lower border of the mandible
9.	Body mandibular notch (Bmn)	The deepest part on the body of the mandible (left)
10.	Gonion (Go)	The most lateral external point of the horizontal and ascending rami of the lower jaw (left)
11.	Inferior alveolar foramen (IaF)	The most inferior point in the inferior alveolar canal (left)
12.	Posterior ramus (Pr)	Posterior ramus, which is located horizontally straight from 11 and 16 (left)
13.	Condylion superior (Cds)	The most superior point in the mandibular condyle (left)
14.	Mandibular notch (Mn)	The lowest point on the mandibular region (left)
15.	Coronion (Co)	The most superior point in the coronoid process (left)
16.	Anterior ramus (Ar)	Anterior ramus located horizontally straight from 11 and 12 (left)
17.	First molar (Fm)	Distal to the first molar of the lower arch (left)
18.	Incisor (Icr)	Between two mandible central incisors
19.	First molar (Fm)	Distal to the first molar of the lower arch (right)
20.	Anterior ramus (Ar)	Anterior ramus located horizontally straight from 4 and 5 (right)

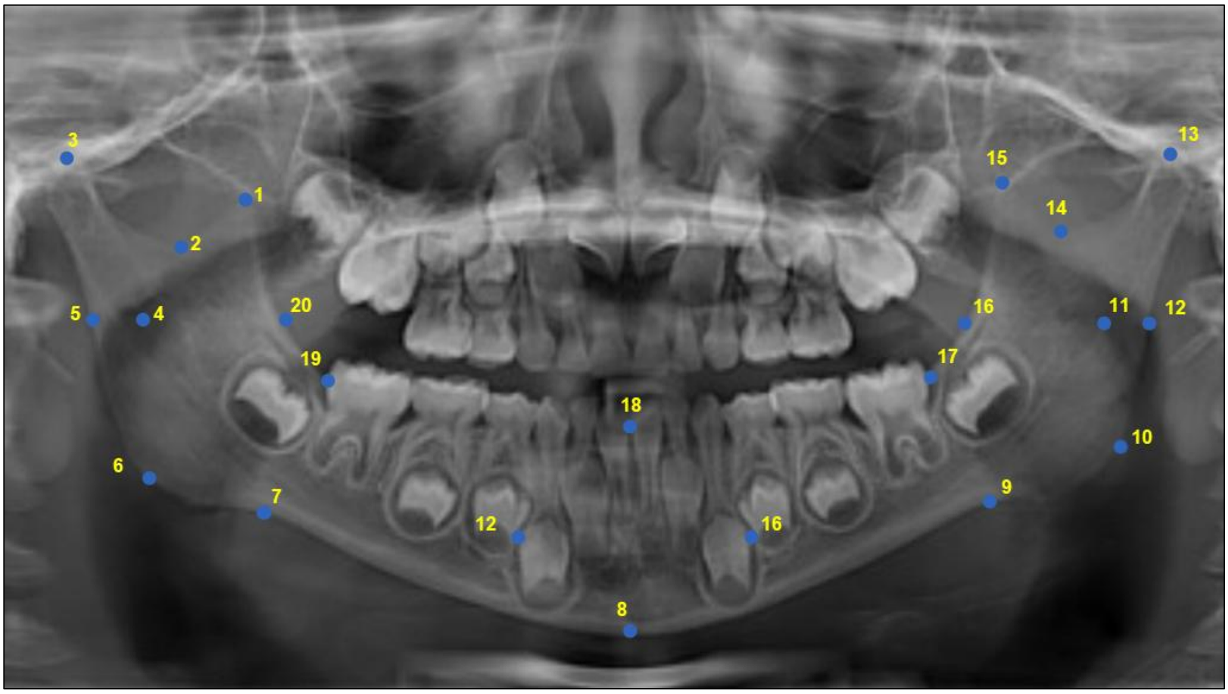

Figure 1. 20 mandible landmarks on DPT

Shape Analysis and Statistical Analysis

The 2D-dimensional coordinates of the landmarks were analysed using the MorphoJ shape analysis programme MorphoJ. To remove nonshape variation from the sample, a generalised procrustes analysis (GPA) was performed on the raw landmark coordinates from each mandible in the DPT. Translation, rescaling, and rotation procedures were involved in this process. To provide a biologically appropriate statement of the total size of the hard tissue landmark configuration, the scaling technique modified the landmark coordinates. Thus, each mandible in DPT has a unit centroid size.

The data was sorted using principal component analysis (PCA) according to shape similarity. The PC plots and wireframe were used to analyse and depict the shape differences found by the PCA. For the grouped data, Canonical Variate Analysis (CVA) was used as an exploratory technique. On the basis of the sample centroids, CVA calculated the Mahalanobis distances between groups. Discriminant function analysis using cross-validation was used to evaluate the accuracy of the classification. The PC scores from the GPA/PCA of the sample were used in both analyses.

Results

Generalised Procrustes Analysis (GPA)

The GPA was used to eliminate the nonshape variation among the samples, whereby differences in the landmark coordinates due to the position of specimens during the digitisation process were minimised, and the sizes were standardised. The data comprised 305 observations with 20 landmarks (Figure 2). The blue dots represent the mean landmark positions, and the small black dots represent the landmark positions for individual configurations in the sample. The numbers of the landmarks are indicated by red numbers.

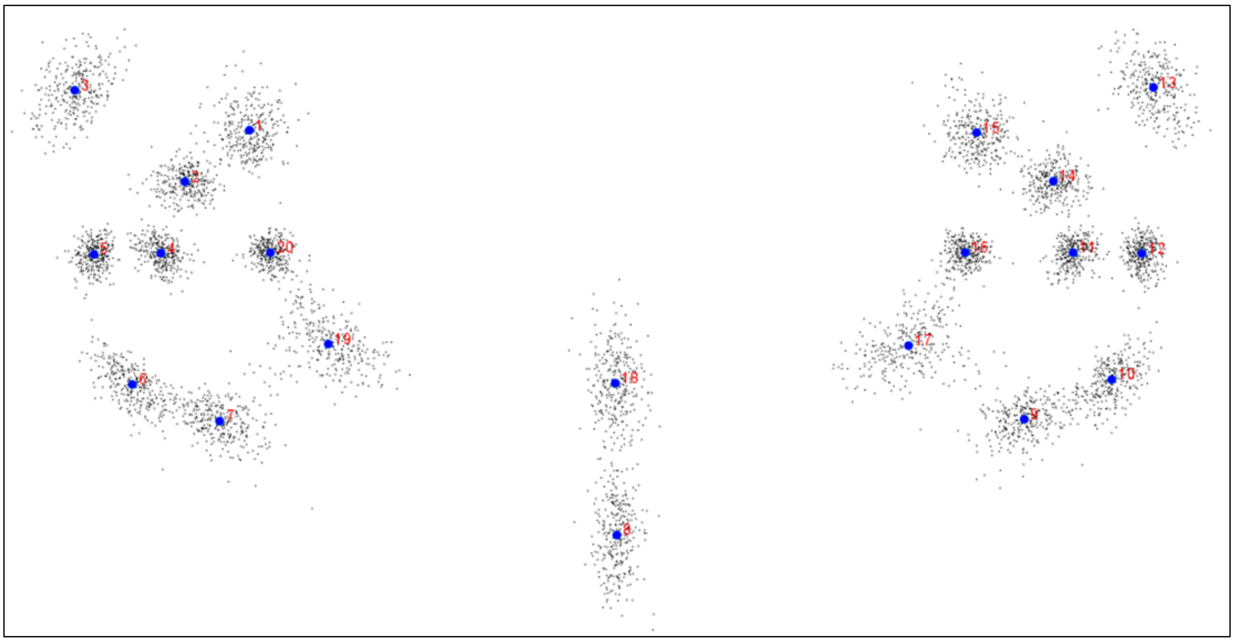

Figure 2. Generalised Procrustes Analysis (GPA)

Principal Component Analysis (PCA)

PCA is a method for exploratory multivariate analysis. It has a function in displaying the major features of shape variation in a data set and as a ordination method to discover patterns. The results of the analysis of the main component yielded 36 main components responsible for 100% of the variation exhibited by the mandible. This also indicated that there were 36 variables that affected the shape of the mandible, as the number of principal components was correlated with the number of variables. The analysis indicated 36 principal components, which means that there were variances in 36 different dimensions in the data. The total variance in the data set was 0.005 indicating a small variance. Table 2 lists the eigenvalues generated by the PCA, the corresponding principal components, and the percent variance of each PC. Figure 3 is the corresponding screen plot of the percent variance and principal components.

As shown in Table 2, the decrease in percent variance was gradual, with the drop between PC1 and PC5 showing the largest difference. PC1 contributed 34.75% of the total variance in the sample, PC2 contributed 20.71% of the total variance, and PC3 contributed approximately 9.02%. MorphoJ can generate scatter plots for any two combinations of the 36 PCs, but since the first few PCs account for the most variance in the entire sample, discussion of the results will focus on the first few PCs.There are 36 main components in this study, with PC1 to PC5 showing significant differences (Table 2, Figure 3).

Table 2. Table of Eigenvalues, percent variance and cumulative percent of each principal component

PC	Eigenvalues	Percent variance %	Cumulative variance %
1.	0.00141435	34.75	34.75
2.	0.00084284	20.71	55.46
3.	0.00036691	9.02	64.48
4.	0.00022839	5.61	70.09
5.	0.00019934	4.90	74.99
6.	0.00013139	3.23	78.22
7.	0.00012426	3.05	81.27
8.	0.00009402	2.31	83.58
9.	0.00008190	2.01	85.59
10.	0.00006515	1.60	87.19
11.	0.00005809	1.43	88.62
12.	0.00005303	1.30	89.92
13.	0.00004672	1.15	91.07
14.	0.00003979	0.98	92.05

Table 2. Table of Eigenvalues, percent variance and cumulative percent of each principal component *(continued…)*

PC	Eigenvalues	Percent variance %	Cumulative variance %
15.	0.00003600	0.88	92.93
16.	0.00003057	0.75	93.68
17.	0.00002765	0.68	94.36
18.	0.00002509	0.62	94.98
19.	0.00002417	0.59	95.57
20.	0.00002208	0.54	96.11
21.	0.00002177	0.54	96.65
22.	0.00001861	0.45	97.10
23.	0.00001675	0.41	97.51
24.	0.00001493	0.37	97.88
25.	0.00001427	0.35	98.23
26.	0.00001285	0.32	98.55
27.	0.00001083	0.27	98.82
28.	0.00001037	0.25	99.07
29.	0.00000946	0.23	99.30
30.	0.00000790	0.19	99.49
31.	0.00000639	0.16	99.65
32.	0.00000614	0.15	99.80
33.	0.00000372	0.09	99.89
34.	0.00000203	0.05	99.94
35.	0.00000140	0.04	99.98
36.	0.00000082	0.02	100

Changes in the mean shape and its variation in PCs may be presented in wireframe graphs. Figure 4 is the wireframe graph generated from the analysis of the main components showing changes in shape. The wireframe graph shown in Figure 4 shows the shape changes attributed to PC1. Each point represents a landmark on the mandible, with the light blue line representing the mean shape and the dark blue line representing the variation exhibited at that location. The 20 landmarks exhibited some level of variation, with the coronoid process, the mandibular foramen, the posterior ramus and the gonion being the most prominent. The gnathion, pogonion, mental foramen and second premolar showed little or no variance in the population, while the remaining landmarks exhibited moderate variance. In PCA, the variance is described in terms of PC, and each PC is numbered in order of decreasing variance. PC1 accounts for the most variation in the sample, and the PCs following the first account for the rest of the decreasing order (i.e., PC2 explains a higher percentage of variation than PC3, PC3 is higher than PC4, etc.).

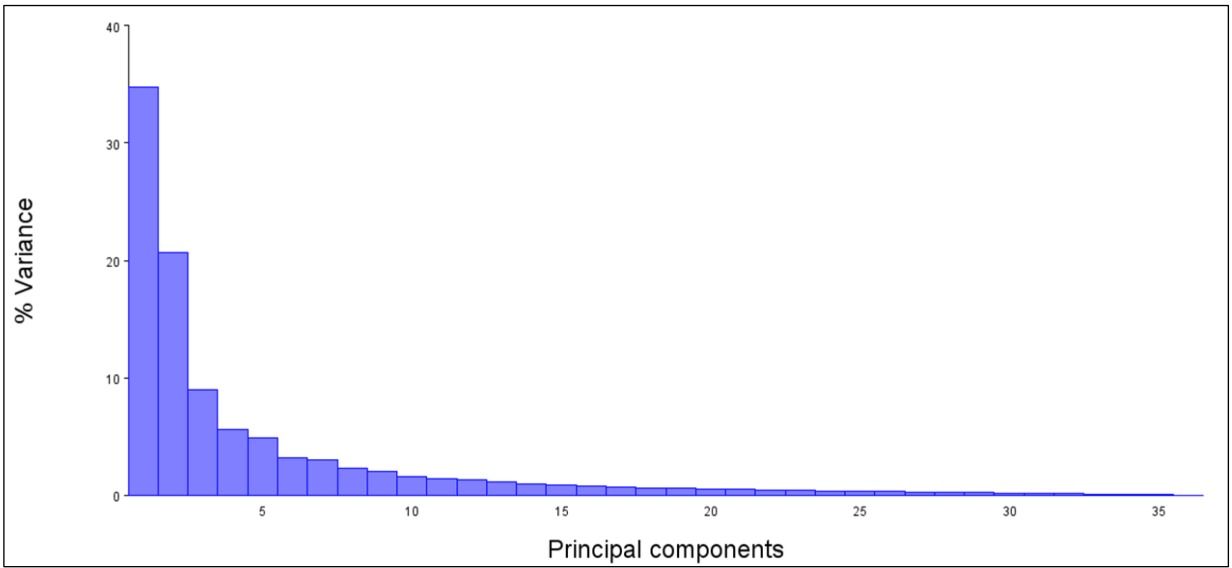

Figure 3. Screen plot showing the amount of variance in the shape of the mandible

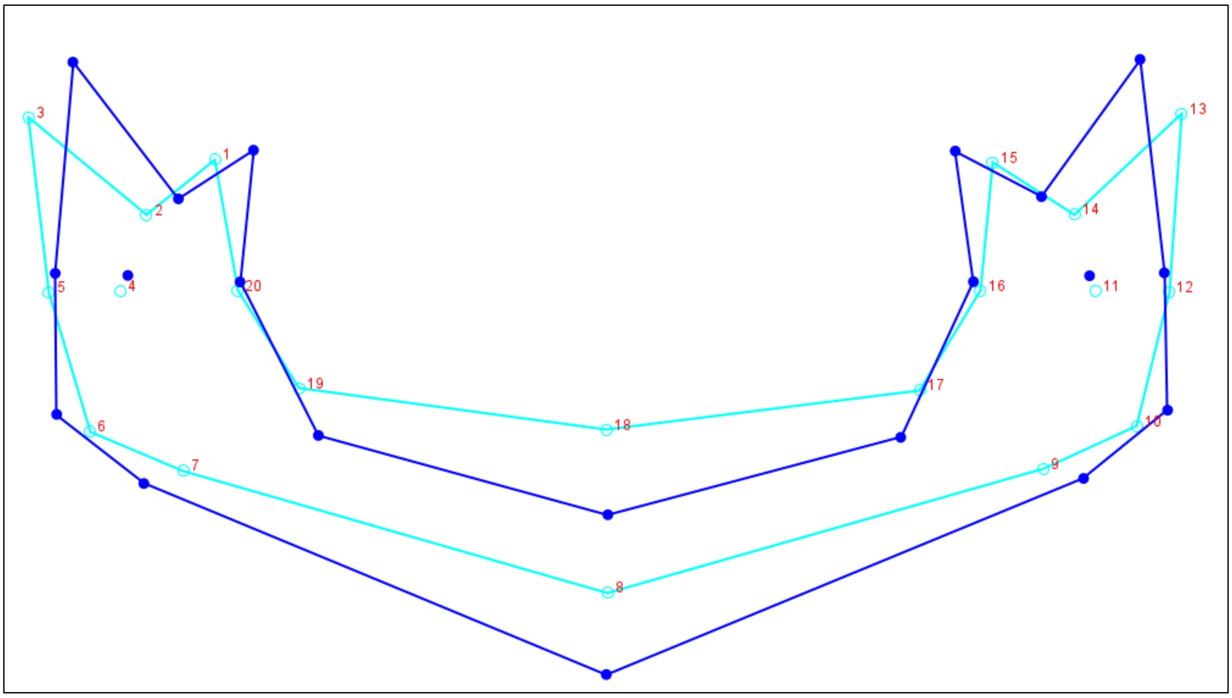

Figure 4. Wireframe graph with shape changes of the first principal component

As shown in the table of eigenvalues (Table 2), 100% of the variance in the mandible sample was explained by 36 PCs, but the differences between one PC and the next are small, except for PC1 and PC2. PC2 accounted for 20.71% of the variation. PC2 showed changes in the coronoid process and the chin (Figure 5).

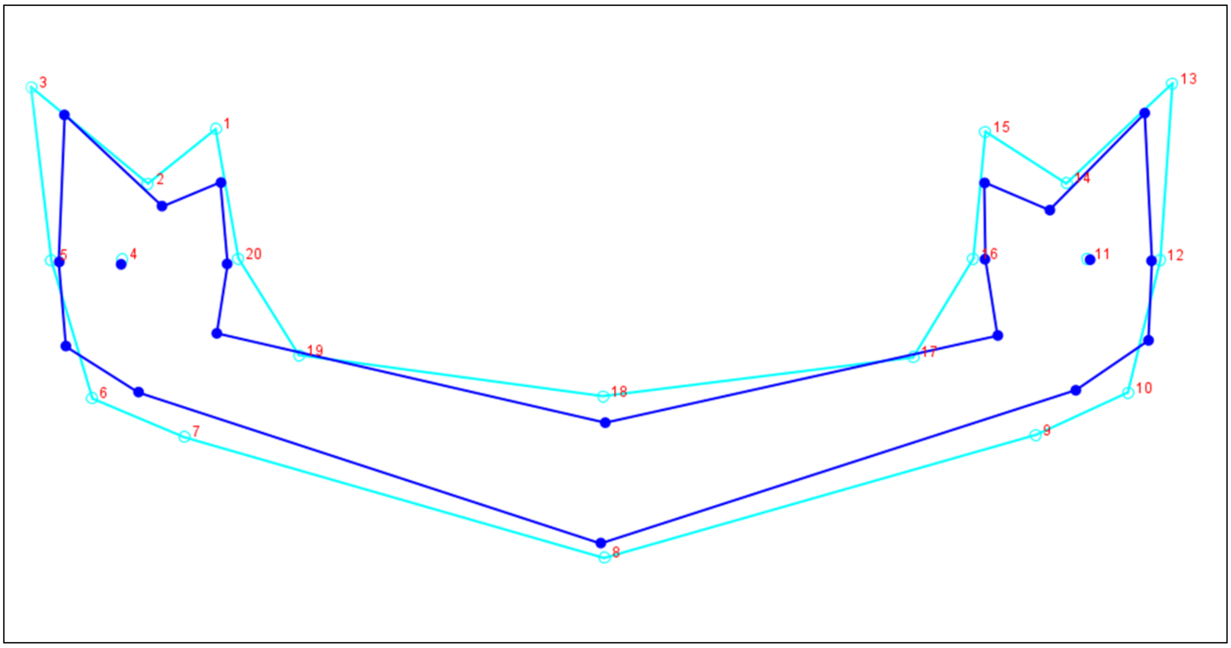

Figure 5. Wireframe graphs illustrating the shape changes on the PC2 axis

The PC3 accounted for 9.02% of the variation. The PC3 showed changes in condylar process, chin and angle of mandible (Figure 6).

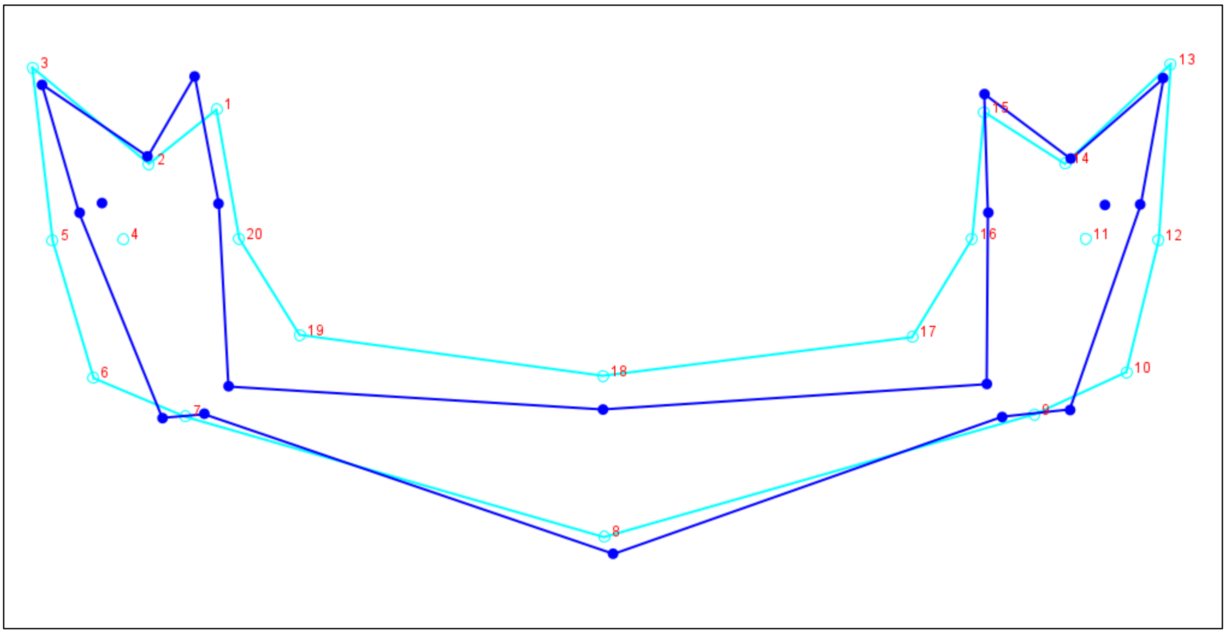

Figure 6. Wireframe graphs illustrating the shape changes on the PC3 axis

Procrustes ANOVA

The variation between individuals and the measurement of errors in the samples can be assessed using Procrustes ANOVA.The results of the Procrustes ANOVA analysis showed the different effects (sex and age group) and were presented in separate ANOVA tables for the size and shape of the centroid (Table 3, Table 4). In this study, the size of the centroid showed a highly significant difference in the age group ($p<0.01$), and less difference in the sex groups. The results showed that the size difference was high in the age groups and had almost less of an effect on sex.

Table 3. The effect of size on the age groups and sex

Effect	SS	SS%	MS	dF	F	P
Age Group	2621314.55	99.03	2621314.55	1	67.18	<0.0001**
Sex	25751.14	0.97	25751.14	1	0.54	0.4625
Total	2647065.69					

Sums of squares (SS), mean squares (MS), degrees of freedom (df). **p< 0.01

Table 4. The effect of shape on the age groups and sex

Effect	SS	SS%	MS	dF	F	P
Age Group	0.13	93.58	0.0034	36	36.36	<0.0001**
Sex	0.009	6.42	0.0005	18	5.89	0.0002
Total	0.14					

Sums of squares (SS), mean squares (MS), degrees of freedom (df). **p< 0.01

The results showed that the shape effect was higher in percentage in age parameters with 93.58% and lower in percentage of sex parameter with 6.42% of total sum of squares (SS), respectively (Table 4). For the age group, Procrustes' ANOVA showed a significant variation in the mandible ($p< 0.01$). The results showed that the shape has a significant 75 effect in age, but a smaller effect in the sex group. Morphological variation determined by Procrustes ANOVA indicated that the shape variation between the sex and age groups was highly significant ($p< 0.0001$) (Table 4).

Canonical variate analysis (CVA)

The next step in geometric morphometric analysis was to see the most significant landmarks that can differ in biological profile and subgroups. For the biological profile consisting of more than two groups, such as the sex and age groups, the differences were assessed by CVA. CVA is a multivariate statistical method that is used to find the shape characters that best distinguish between multiple groups of samples.

Age Group

Subjects were divided into two age groups. Of the 305 specimens, 133 subjects were in Group 1 (3-7) and 172 specimens were in Group 2 (8-12). CV1 showed changes in the protrusion of the chin while CV2 showed changes in the height of the mandible body (Figure 7).

1. 3-7 years old (Group 1, n= 133)
2. 8-12 years old (Group 2, n= 172)

Figure 8 showed that there was a significant difference between group 1 and group 2 located in the centre between young and old. The Mahalanobis distances showed that there was a significant difference in shape between age groups ($p< 0.0001$). The p-values were obtained from the permutation test (10000 rounds of permutations) for the Mahalanobis distances between the groups (Table 5). The distances between the age groups showed a significant difference in the size of the mandible from the permutation test (10000 permutations rounds) for the distances between the age groups ($p< 0.0001$) (Table 5).

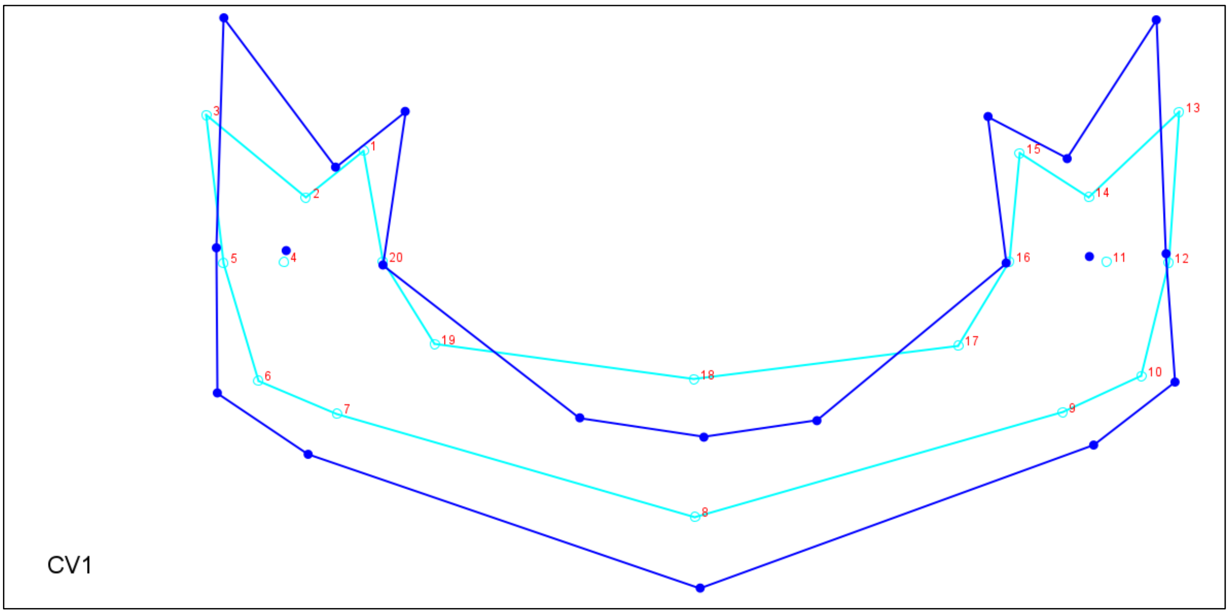

Figure 7. Wireframe graphs illustrating the shape changes on the CV1

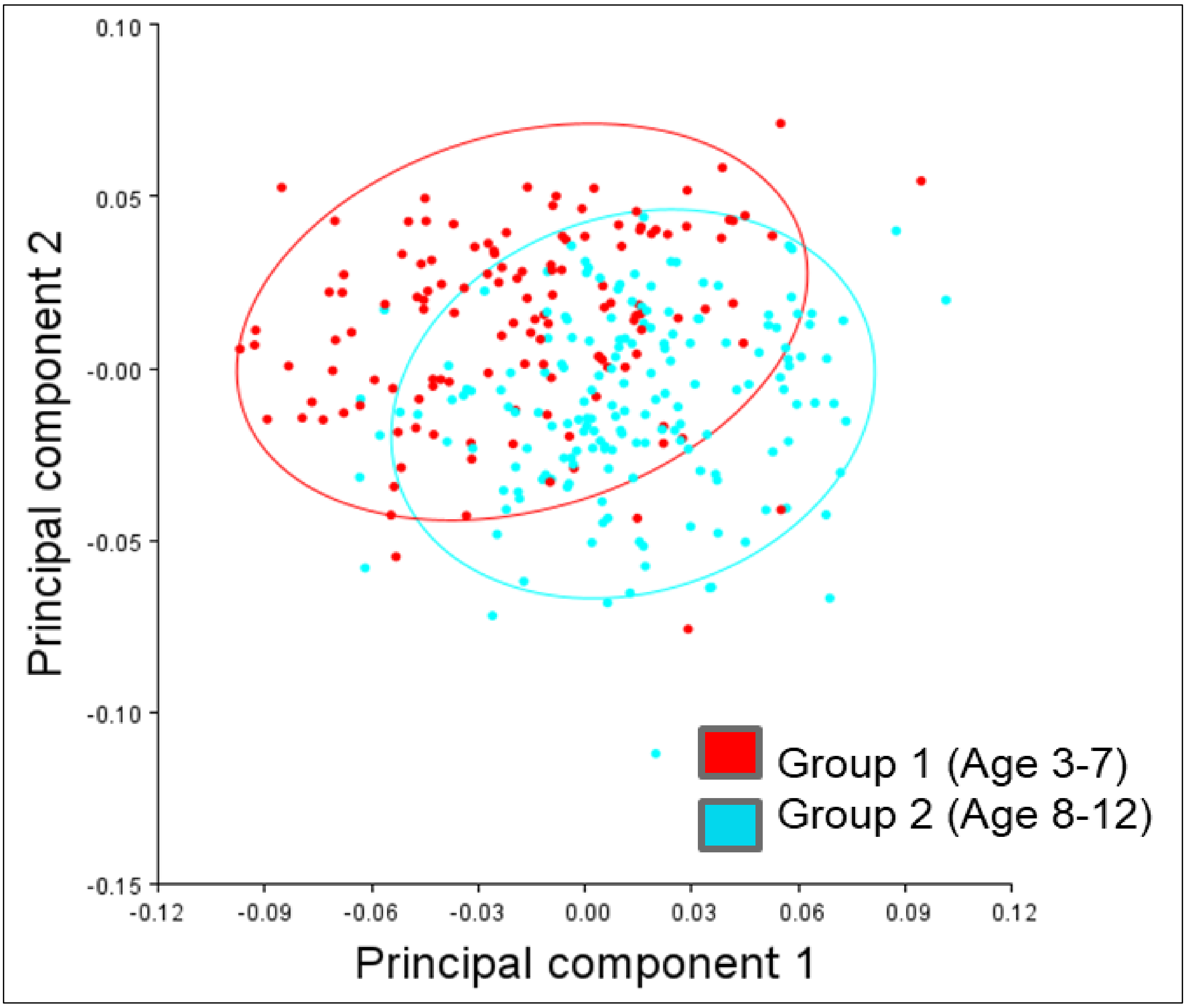

Figure 8. Canonical variate analysis in different age groups

Table 5. Mahalanobis distances and Procrustes distances among age groups

Mahalanobis distance		**Procrustes distance**	
Age group	Group 2	Age group	Group 2
Group 1	2.3395 **p<0.0001	Group 1	0.0420 **p<0.0001

P Values from permutation test (10000 permutations rounds) for mahalanobis distances among groups, **p > 0.01

Sex Group

Subjects were divided into two age groups. Of the 305 specimens, 146 subjects were in Group 1 (Female) and 159 specimens were in Group 2 (Male). There are less significant differences between the mandibles of men and women.

i. Female (Group 1, n= 146)

ii. Male (Group 2, n= 159)

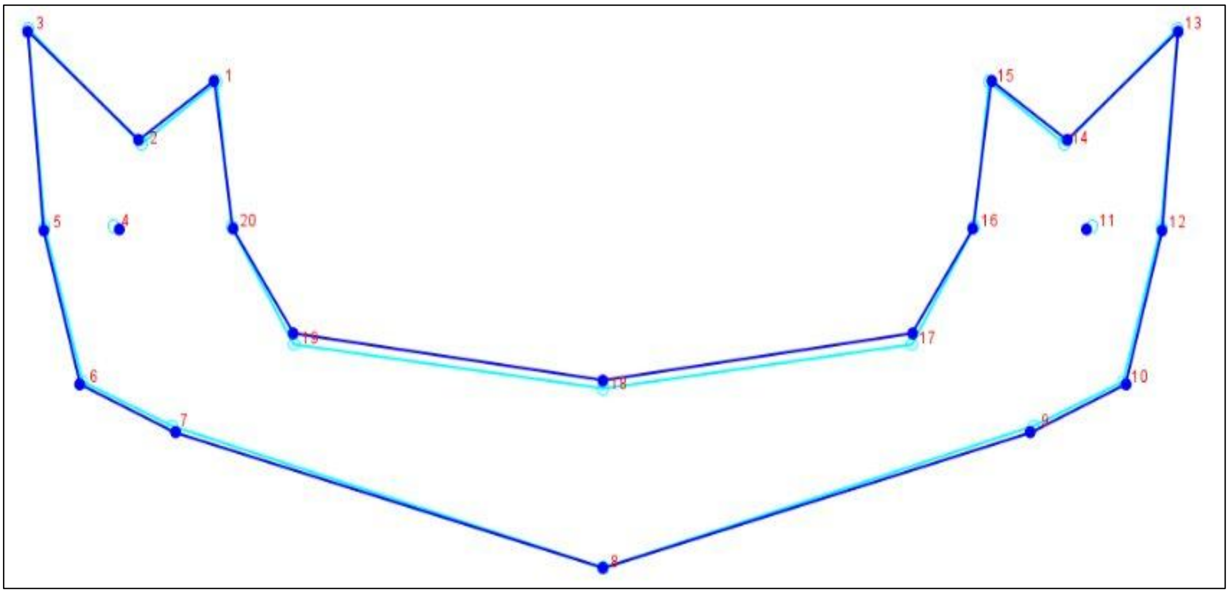

Figure 9. Wireframe graphs illustrating the differences of mandibles in male and female children

Table 6. Mahalanobis distances and Procrustes distances among sex groups

Mahalanobis distance		Procrustes distance	
Sex group	Male	Sex group	Male
Female	0.8836 **p>0.0001	Female	0.0111 **p>0.0001

P Values from permutation test (10000 permutations rounds) for mahalanobis distances among groups, **p > 0.01

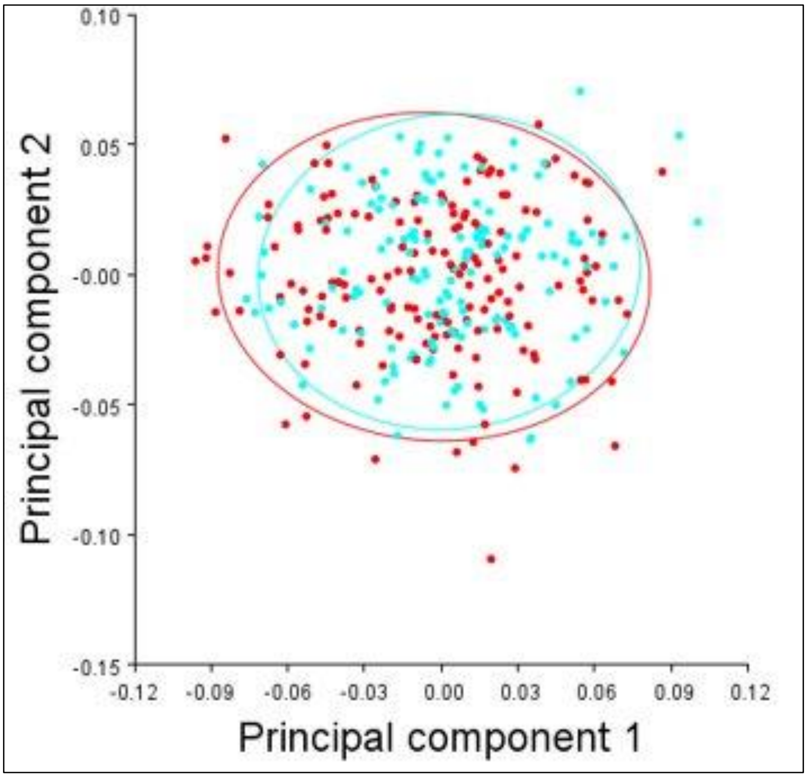

Figure 10. Canonical variate analysis in different sex groups

Figure 10 showed that there were no significant differences between group 1 and group 2 because both ellipses overlapped each other. Mahalanobis distances showed that there were no significant differences in shape between sex groups ($p > 0.0001$). The p values were obtained from the permutation test (10000 rounds of permutations) for the mahalanobis distances between groups (Table 6). The distances of the procrustes between the sex groups did not show significant differences in the size of the mandible from the permutation test (10000 permutation rounds) for the distances of the procrustes between the age groups ($p > 0.0001$) (Table 6).

Discriminant Function Analysis (DFA)

The discriminant function test was performed using MorphoJ.The distances between the procrustes were measured at each point of reference for each individual.

Age Group

About 88.2% of the original cases grouped were correctly classified. Cross-validation was performed only for those cases in the analysis. In cross-validation, each case was classified by the functions derived from all cases. About 81.97% of the cross-validated grouped cases were correctly classified according to age group (Table 7).

Table 7. Discriminant function analysis in different age groups

Classification Results					
		age	**Predicted Group membership**		**Total**
			Group 1	Group 2	
Original	Count	Group 1	117	16	133
		Group 2	20	152	172
	%	Group 1	87.97	12.03	100
		Group 2	11.63	88.37	100
Cross-validated	Count	Group 1	108	25	133
		Group 2	30	142	172
	%	Group 1	81.20	18.80	100
		Group 2	17.44	82.56	100

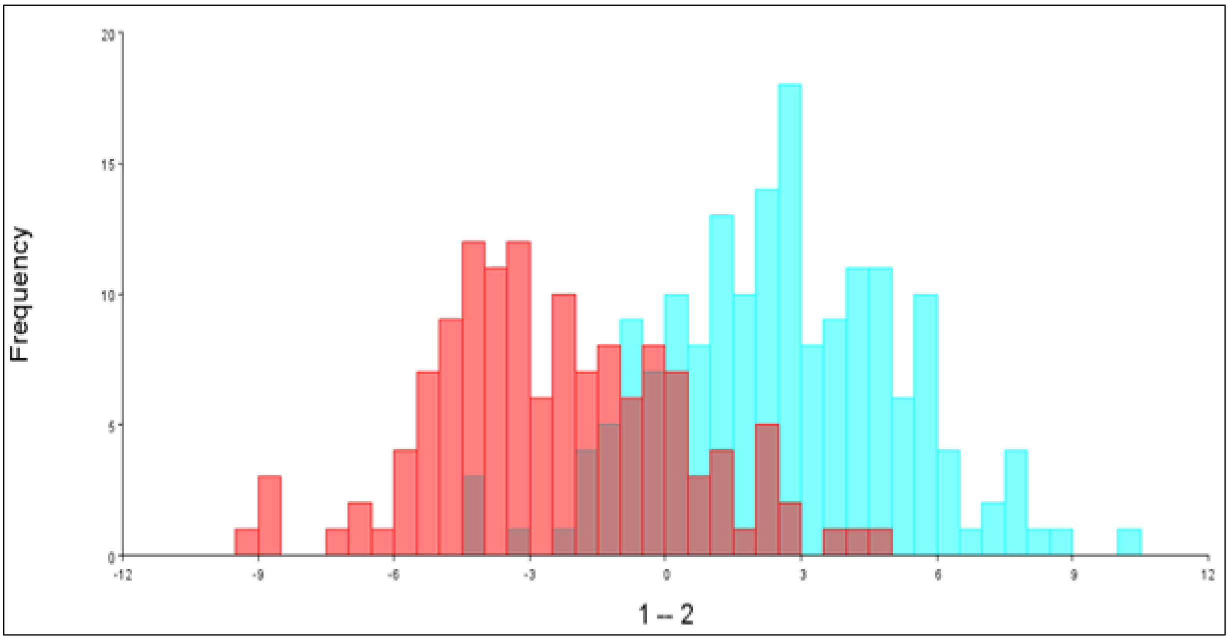

Figure 11. Discriminant function analysis in different age groups after cross-validation.

Sex Group

About 68.83% of the original cases grouped correctly were correctly classified. Cross-validation was performed only for those cases in the analysis. In cross-validation, each case was classified according to the functions derived from all cases. Approximately 65.55% of the cases of the cross-validated group were correctly classified according to age group (Table 8).

Table 8. Discriminant function analysis in different sex groups

Classification Results					
		Sex	**Predicted Group membership**		**Total**
			Female	Male	
Original	Count	Female	101	45	146
		Male	51	108	159
	%	Female	69.18	30.82	100
		Male	31.51	68.49	100
Cross-validated	Count	Female	96	50	146
		Male	56	103	159
	%	Female	66.03	33.97	100
		Male	34.94	65.06	100

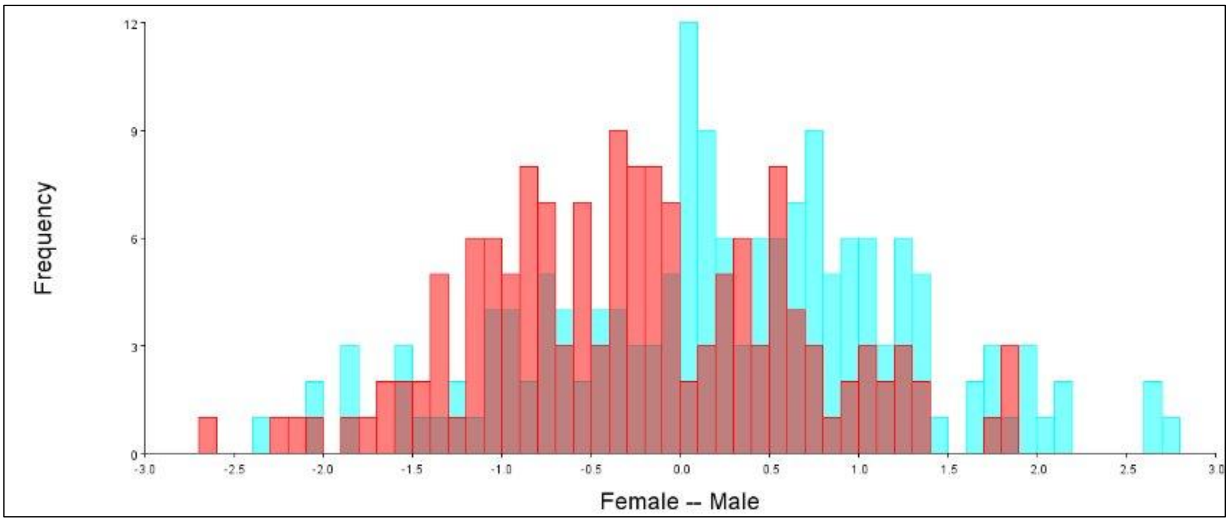

Figure 12. Discriminant function analysis in different sex groups after cross-validation.

Discussion

The estimation of sexual dimorphism and age is crucial in forensic odontology in the identification of human remains. In cases where mandibles were left lacking due to unerupted or delayed eruption or missing teeth, it will be challenging to identify the age of the victims based on tooth eruption. Therefore, the mandible itself can be used. The mandible is the largest and strongest bone in the human skull. It forms the lower jawline and sculpts the inferior third of the face (Reece Edward M. & Rohrich Rod J., 2008). It is the strongest and most durable facial bone that retains its shape better than others. Since the mandible is made up of a dense layer of compact bone, it is frequently resistant to postmortem injury, and thus better maintained than many other bones (Kumar & Lokanadham, 2013). In a forensic context, the use of geometric facial morphometrics to estimate age in children and adolescents shows promise.

The team of anthropologists, forensic scientists, and criminalists typically searches human skeletons to use as their tools for further investigations when identifying and estimating an individual's age. Generally, the goal of forensic anthropologists is to determine the broad morphological characteristics of the remains. Gender, age of death, race, height, cause of death, any individuality traits, and an estimate of the passing of time were included. Based on odontological characteristics, forensic odontologists employed the maxilla, mandible, and teeth because they survive severe body injury (Kawashima et al., 2016).

Numerous research studies have been conducted using a variety of notable mandibular landmarks that have a great deal of promise for age estimation in forensic investigation. According to Chole et al. (2013), the gonial angle and antegonial region of the mandible are two of the most important characteristics that correspond to age. The morphology and growing process of the mandible also have an impact on age estimation (Rai et al., 2008). The mandible is just a shell at birth, with the major teeth' sockets unevenly divided from one another. Ramus is a rather short person. Comparatively speaking, the coronoid process is higher than the condylar process level. The first primary molar tooth and the lower edge of the mandible are where the mental foramen is located. About 175˚ is the mandibular angle. In our research, the landmarks that we choose are the one that shows signs of differentiation such as the other study, such as the coronoid process, the first molar, the chin of the mandible, and others to see the differences among ages based on their mandible on the DPT.

Age, sex, and race in the human mandible can be determined applying the geometric morphometric analysis approach in conjunction with metrical factors and morphological traits (Sikka & Jain, 2016). Geometric morphometrics, in general, is a method of characterizing shape using landmark coordinates that can capture morphologically unique shape variables. Since the markers must be homologous, their placement should be decided upon in detail (Slice, 2007). The mandible's size and shape will reveal the dimorphism; thus, the entire form will be examined. The statistical method known as Principal Component Analysis (PCA) is used to examine shape variability, and these variations can show each group's pattern. Data collection can be interpreted using a quantitative approach and statistical analysis techniques. In our study for sex, we found that the shape variation of the samples is hardly distinguishable among sexes, since the samples that we obtained only involved children up to the age of 12 years where they had not reached puberty yet, therefore showing no significant differences in the shape of the mandible in our study.

Traditional morphometrics, which measures linear distances such as length, width, and height, as well as areas, angles, and ratios and counts, was the method previously employed. Variation in form among groups was then distinguished using multivariate statistical methods. Although there are some drawbacks, this method is extremely easy to apply. The primary drawback is that the size of a shape can typically influences how linearly a distance is measured, making shape analysis challenging. As a result, the pictorial representation of the shape cannot be recreated. Additionally, since the data may not contain the precise landmarks that were measured, linear measurements of two different shapes may yield results that are identical. Geometric morphometrics was created to solve these problems. The estimation of age using geometric morphometrics on teeth was investigated. After analysing tooth morphology, size, and form, it was discovered that there are notable variations in the size and shape of teeth (Parés-Casanova et al., 2020). In our study PCA, we found in wireframe where the mandible of the specimen shows various variations of the shape of the mandible. It accounts for about 36 variations of the shape of the mandible gained from all of our samples, which can be appreciated using the PCA and adding wireframe where the variation of the mandible can be visualised.

A form of scan called dental panoramic tomography gives a panoramic image of the maxilla, mandible, and all the teeth, whether they have erupted or not. DPT offers biological data sources that can be used for scientific purposes. According to a preliminary comparison research, it can be used to estimate age, sex, and race with an accuracy of up to 88% (Jambunath & Govindraju, 2016). According to several studies, panoramic radiographs can be relied upon for reliable and repeatable measurements of mandibles, both linear and angular (Markande et al., 2012). According to Larheim and Svanaes, the gonial angle determined by DPT and the measurement made on a dried mandible were nearly comparable. Aside from that, the DPT radiograph shows the differentiation between all teeth and developing teeth germs. As such, we can determine age and evaluate dental maturity. In our study during landmarking, some of the samples cannot be seen clearly, which hardens the process of landmarking of the samples. Landmarks such as the ID canal are some of the most common landmarks that are not very clear in the samples that we obtained. The radiograph quality also contributes to the obstacle that we faced during the landmarking procedure. Some of the radiographs also do not fully capture the patient’s mandible such as half of the ramus was not seen in the DPT, and some samples also had the chin to be uncaptured in the radiograph. We also discovered the age of the samples obtained sometimes does not match with their dentition which may occur due to wrong input of the data during the data inserting process before the taking of the DPT. All these findings unfortunately need to be excluded from our study to obtain a precise result without the interruption that had been found which also reduces the number of samples that can be studied in this research.

In this study, it shows strong evidence for the effectiveness of GM in estimating the age of children by examining the shape of the mandible in DPT. A notable difference in size and shape was observed, as the mandible undergoes changes throughout an individual's life along with the influences of growth hormones to induce the growth and development of the mandible. Previous research suggested that growth hormone could greatly increase mandibular growth by altering the condyle and ramus of the mandible. Thus, resulting in a variation in the direction of mandibular growth from posterior to anterior (Wójcik & Beń-Skowronek, 2020). The length of the mandibular body increases, particularly in the area posterior to the mental foramen to provide space for tooth eruption with an increase in depth as bone growth occurs at the level of the alveolar ridge (Zulkifli NAF, 2023). The size and shape of the mandible show a significant difference ($p<0.0001$), with the sum of the square proportion accounting for 99.03% and 93.58%, respectively. The discriminant function test showed that the mandible represented 81.97% of the classification precision after cross-validation between age groups. In our research, it can differentiate the samples into the range of age that had been allocated which are the group of age 3-7 and the age group of 8-12. These group was chosen as it is balanced in terms of the number of the sample within those group. GM can classify the samples in our research correctly between both of the group age.

A Mahalanobis distance of 2.3395 indicates a significant difference between age groups reflecting different stages of development in children. Indicates that the observed morphological variations are unlikely to be due to random variation. Generally, Mahalanobis distances greater than 2 are considered significant in multivariate studies, indicating that the groups differ from each other in the measured attributes. Under forensic conditions, finding these variances can help estimate the age of people and perhaps distinguish between people based on age-related changes in jaw morphology. The Procrustes distances assess the dissimilarity of two shapes based on size, position, and orientation. The value of 0.042 indicates how much the shape of the mandible changes during growth and development. Variations may be due to normal growing processes, with young children's mandibles having more rounded features and older children's mandibles having more prominent angles and sharper features as they become older.

However, the morphological differences between the shapes of the male and female mandibles were not distinctly pronounced in this study, likely due to overlapped features and developmental similarities. The limited sample size, which included only children up to the age of 12, restricted the ability to observe a more definitive sexual dimorphism. This limitation was mainly due to the lack of data available for older age groups. In prepubertal children, the absence of fully developed hormonal influences and secondary sexual characteristics makes it difficult to distinguish sex-based differences in skeletal structures, including the mandible (Azhari et al., 2019). During puberty, hormonal changes play an essential role in shaping craniofacial morphology, and both male and female mandibles undergo significant growth and differentiation. Therefore, future research should include a wider age range, particularly children up to 17 years of age. At this age, puberty is typically complete and secondary sexual characteristics are more pronounced, providing a more comprehensive and accurate data set to analyse sex-based differences in mandibular morphology. In other studies, the size and shape of the mandible shows changes as childhood draws near. Mandibular body length increases, particularly in the region posterior to the mental foramen, to provide room for the eruption of teeth. Because bone growth also takes place on the alveolar ridge, mandibular body depth also increases. On the other hand, the mandibular angle is lowered to 140˚ and the placement of the mental foramen is comparable to the preceding phase. The mandible grows till adulthood. Our study cannot produce the differences of the shape of the sexes as growth of the mandible can be seen when the samples reached their puberty where the growth visualize the differences of the shape of the bone between sexes.

The mandibular body and ramus are larger in maturity than they were in childhood. The condylar process level rises above the coronoid process level. The middle point of the mandible's upper and bottom borders is where the mental foramen is situated. The mandibular angle ranges from 110˚ to 120˚, nearly resembling a straight angle. As people age, their mandible shrinks significantly because of tooth loss and alveolar ridge resorption. In very old age, the condylar process may bend backward. The mental foramen is located close to the upper border of the jaw as a result of increased alveolar ridge erosion. About 140˚ is the mandibular angle. Expanding the sample in this way would improve the reliability and applicability of the findings in forensic and anthropological studies. In our study, the mandible shows increasing of the size of the mandible which differentiate between ages and hence, produced a significant difference among age which can be determined based on their DPT of the mandible.

Compared to several ethnic groups in Malaysia, a study stated that the variation in mandible between ethnic groups is not significantly different (Alias, 2018) indicating that the mandible of Malaysians, which are the only races included in this study, is not distinguishably dissimilar from other ethnic groups in Malaysia, such as Chinese and Indian.

In the future, the research can be improved in some areas to obtain a more accurate and precise result for age estimation and also sex determination. Some suggestions can be applied such as the research can be collected by using 3D imaging such as using cone beam computed tomography (CBCT) to obtain a better view instead of using the two-dimensional radiograph which some areas may be fully appreciated and located during the landmarking procedure. Other than that, the number of samples should be collected to have a more specific estimation according to the age and sex, not only in range but specifically to the age or sex of the sample. The lack of samples led us to only determine the range instead of the specific age of the sample which was not specific and concise. Furthermore, to be able to detect the sample in the Malaysian population, other ethnic such as Chinese and Indian need to be included in the future to be inclusive and able to detect the sample in Malaysia not only based on age and sex but also their ethnicity. Last but not least, as the research involves a lot of data and time consumption, especially during the landmarking procedure which had to be done manually, the usage of artificial intelligence (AI) can be applied in the study, especially for landmarking where the process can be shortened with the involvement of AI. These suggestions can be applied in the future to improve the study of this research and provide a more accurate estimation for both age and sex.

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Conclusion

The application of geometric morphometric analysis (GM) to the mandible has demonstrated a significant potential for age estimation in forensic odontology, but not significantly for sex estimation. This analytical approach provides a reliable and quantitative method to assess morphological variations, which are strongly associated with age-related changes in mandibular development. GM analysis offers a promising tool, particularly to estimate the age of children, as their mandibles undergo distinctive growth patterns during development. By capturing and analysing these morphological changes, researchers can achieve more accurate and reliable age assessments. The findings of our research further underscore the utility of GM analysis in forensic contexts, highlighting its effectiveness in determining the age of children according to the mandibular morphology. This approach holds great promise in the advancement of dental forensic investigations and in improving the accuracy of age estimation models.

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