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Geometric morphometric analysis of malocclusion on lateral cephalograms in Malaysian population

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Abstract: Geometric morphometrics is a new approach for shape identification in diagnosis of malocclusion. Lateral cephalogram is an X-ray that taken for diagnosing malocclusion in dental setting. The aim of this study was to determine the differences of craniofacial shape in malocclusion by application of two-dimensional geometric morphometrics and to compile the database of malocclusion in adult Malaysian population. Lateral cephalogram radiographs of 381 adults Malaysia (age 18–45) were retrieved retrospectively and assigned to three groups according to their occlusion: class I, class II, and class III. The geometric morphometric shape study incorporated nine landmarks and was analyzed in details using tpsUtil p software. Geometric morphometric analysis such was done using MorphoJ software. The results of the principal component's analysis (PCA) yielded 14 main components responsible for 100% of the variation exhibited by the malocclusion with three highly significant PCA. The highest Mahalanobis distances were exhibited by the malocclusion class II and III population. The Procrustes ANOVA showed that the shape effect was highly significant ($P<0.01$). The discriminant function analysis showed the high percentage of 80% discriminate among the malocclusions after cross-validation. There are significant differences for ANB angle (A point-Nasion-B point) in all malocclusion groups. Class II has the widest ANB angle while class III has the most acute ANB angle. Skeletal shape was clearly associated with dental malocclusion and showed considerable variation. Geometric morphometrics is an alternative research tool and can be used for diagnosing individual classification of malocclusion.

Key words: Malocclusion, Geometric morphometrics, Lateral cephalogram, Malaysian

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Introduction

Occlusion is defined as a balance of contacts between the maxillary (upper) teeth and mandibular (lower) teeth [1]. A malocclusion occurs when there is a misalignment of maxillary teeth and mandibular teeth when the jaw close as the teeth were twisted, irregularly arranged or inappropriate to one another, leading to abnormal bite patterns [2]. In adults, malocclusion is the second most common dental diseases that impair functional activity like chewing or speech and may cause imbalance of facial bones [3]. Malocclusion is classified into namely class I (neutrocclusion), class II (distocclusion), and class III (mesiocclusion) according to Angle's classification method based on the relative position of the upper and buccal segments [4].

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To determine the type of malocclusion, impression-taking for dental modeling and conventional radiograph cephalometry are taken. Lateral cephalometry tracing consists of manual application of conventional linear and angular measurement [5]. This conventional tracings are limited to landmarks and straight lines and fail to discrete the change of curve, shape, growth, and display as displacement of vector rather than generalized distortion [6]. Moreover, it may cause potential errors and incomplete shape description, confounded shape and size that challenge the validity and reliability of the result interpretation [7]. Therefore, these methods are time constraining for confirmation of diagnosis, does not provide a sufficient description on morphology of craniofacial morphology, and the treatment process becomes disrupted [6, 8, 9].

To overcome these shortcomings, we focused on using geometric morphometrics (GM). GM is a method that utilizes Cartesian coordinates of anatomical landmark for the quantitative analysis of the landmarks [10]. GM describes the details of coordinates in shape after landmark standardization for orientation, scale and position, independent of size [11, 12]. Besides, GM studies the co-relation of shape components with other factors such as age, sex, race, and population [13]. GM has been used to study growth, treatment effects, and shape variation in various dental researches [14].

Present study has compiled an extensive population database from lateral cephalograms of adult population in Malaysia, which focused on the analysis of malocclusion size and shape using lateral cephalograms on Malaysian population using 2-dimensional (2D) GM method. The difference in craniofacial shape according to the classification of malocclusion was investigated. This research could also be an alternative approach to improve accuracy of the skeletal dental diagnosis in a shorter duration, specifically in malocclusion determination in adult Malaysian population.

Materials and Methods

Study design

This retrospective study was conducted at Polyclinic Universiti Sains Islam Malaysia (USIM) according to the ethics obtained from the Institution of Ethics Committee, USIM (ethnic number: USIM/FPg-MEC/2016/No. (40)). The sample consists of 381 lateral cephalograms taken from the database in the e-clinical USIM and respective archived images from Planmeca Romexi's software from 2012 to 2017. The sample included Malaysian patients regardless of gender or race. These patients consist of three main racial groups namely, Malay, Chinese and Indian. All samples range from 18 to 45 years of age with complete orthodontic records were included in the study. Patients who were non-Malaysian, had craniofacial anomalies, possess mixed dentition and had previous history of orthognathic surgery were excluded from the study. The obtained results were classified according to Angle's classification of malocclusion as below [15].

- Class I (neutrocclusion): normal alignment of mesiobuccal cusp of the upper first molar with buccal groove of the mandibular first molar.
- Class II (distocclusion): the mesiobuccal cusp of the maxillary first molar positioned anterior to the mesiobuccal groove of the mandibular first molar.
- Class III (mesiocclusion): the mesiobuccal cusp of the maxillary first molar positioned posterior to the mesiobuccal groove of the mandibular first molar.

Materials

The Planmeca Romexis software (Helsinki, Finland) from Policlinic USIM was used to retrieve the lateral cephalograms radiograph images. The tpsUtil software (Rohlf, F.J. 2008. tpsUtil, file utility program. version 1.40. Department of Ecology and Evolution, StateUniversity of New York at Stony Brook) was utilized in the landmark application. MorphoJ (version 1. 06d) software (Faculty of Life Sciences, University of Manchester, Manchester, UK) and SPSS version 21 (IBM Corp., Armonk, NY, USA) were used for the data analysis and visualization of the 2D data. Another software namely, Excel, Notepad++ (SourceForge Media, LLC dba Slashdot Media, La Jolla, CA, USA) and Inscape (Boston, MA, USA) were used in managing the data.

Landmarking application

A total of nine 2D landmarks was designed and acquired using tpsUtil version 1.40. Landmarks were chosen to correspond to those commonly used in the traditional metrical and geometric morphometric systems and familiar to most orthodontists in lateral cephalogram tracing for malocclusion determination (Table 1, Fig. 1) [16]. A pilot study was performed in which measurements were taken on different days and by the different observers to evaluate intra- and inter-operator reliabilities analysis.

Shape analysis and statistical analysis

MorphoJ software version 1.06d was used to analyze the

Table 1. Definition of landmarks

Number point	Landmark	Definition
1	Nasion (Na)	The junction of the nasal and frontal bones at the most posterior point on the curvature of the bridge of the nose
2	Anterior nasal spine (ANS)	The most anterior point on the maxilla at the nasal base
3	A-point (A)	An arbitrary measure point on the innermost curvature from the maxillary anterior nasal spine to the crest of the maxillary alveolar process. A-point is the most anterior point of the maxillary apical base
4	B-point (B)	An arbitrary measure point on the anterior bony curvature of the mandible. B point is the innermost curvature from chin to alveolar junction
5	Menton (Me)	The lowest point on the symphysis of the mandible
6	Gonion	A point midway between the points representing the middle of the curvature at the left and right angles of the mandible
7	Porion (Po)	The midpoint of the upper contour of the external auditory canal (anatomic porion) or a point midway between the top of the image of the left and right ear-rods of the cephalostat (machine porion)
8	Sella (S)	The center of the hypophyseal fossa (sella tursica)
9	Posterior nasal spine	The sharp posterior extremity of the nasal crest of the hard palate

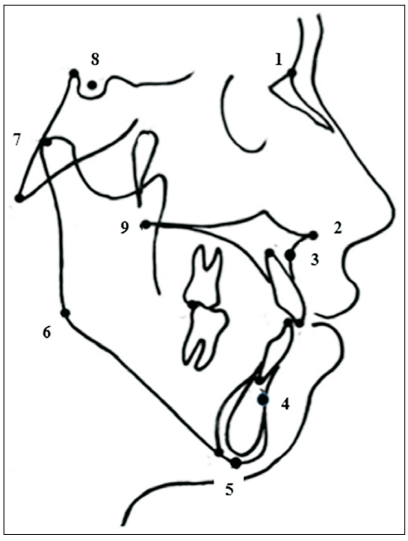

Fig. 1. Map of nine anatomical landmarks: 1, nasion (Na); 2, anterior nasal spine (ANS); 3, A-point (A); 4, B-point (B); 5, menton (Me); 6, gonion; 7, porion (Po); 8, Sella (S); 9, posterior nasal spine.

2D coordinates of the landmarks. Generalized Procrustes analysis (GPA) was done on the raw landmark coordinates from all lateral cephalograms to eliminate the non-shape variation of the samples. This process involved translating, rescaling, and rotating the configurations relative to each other to minimize the total sum of squares [17]. The scaling procedure adjusts the landmark coordinates such that each mandible had a unit centroid size, which was used as a biologically meaningful expression of the overall size of the landmark configuration, and thus of the mandible [18]. A series of principal component analysis (PCA) was used to explore the relationships between samples of different malocclusion. The shape difference revealed by the PCA was visualized and explored using principal component (PC) plots and wire-frame.

Discriminant function analysis with cross-validation was used to assess classification accuracy. Both analyses use the PC scores from GPA/PCA of the sample. The number of variables relative to the number of individuals tends to be large in geometric morphometric analyses as there are two coordinates per landmark. Procrustes ANOVA assessed the variation among individuals and measurement of error in the samples. Canonical variate analysis (CVA) investigates the shape characters that best distinguish significant groups between different malocclusion groups. The angular of craniofacial skeletal measurements were also measured. Statistical analyses were performed using MorphoJ, Gen stat version 8.10 and SPSS version 21.0.

Results

Demographic data

A total of 381 lateral cephalograms were collected and comprised of 178 patients (46.7%) from class I, 128 patients (33.6%) from class II, and 75 patients (19.7%) from class III malocclusions. Malaysians ranged from 17 to 49 years old were included in the study (mean, 23.38 years; median, 21.90 years); 95 males and 286 females were pooled together for all analyses.

Generalized Procrustes analysis

GPA produces a new matrix of Procrustes coordinates, which superimposed each set of landmarks before rescaling and rotating to a centroid size. Fig. 2 showed scatterplot of the superimposed landmark configurations from GPA that represented the morphological shapes of nine landmarks on all 381

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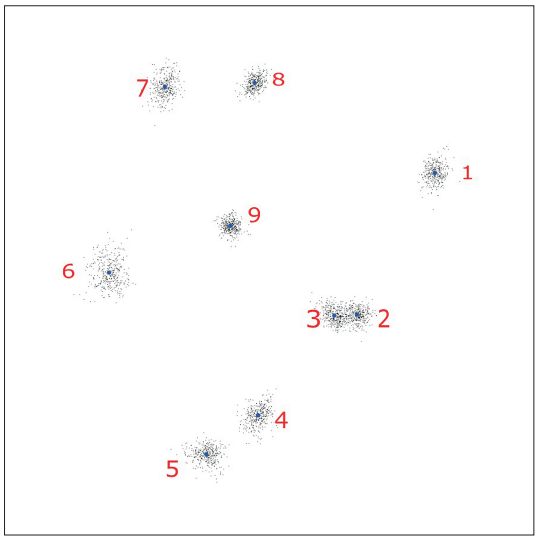

Fig. 2. Generalized procrustes analysis consisting of scatterplot of the superimposed landmark configurations.

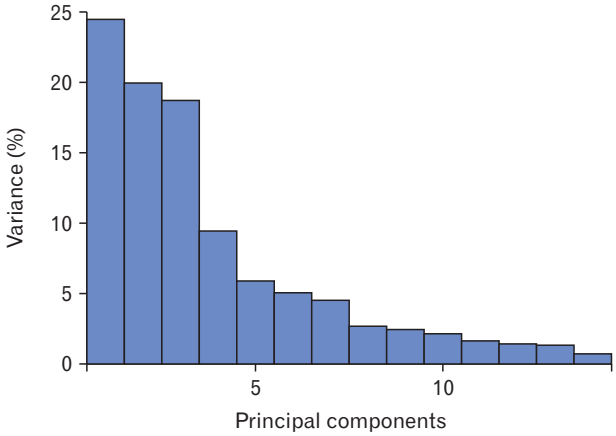

Fig. 3. Screen plot showing the amount of variance for all classes of malocclusion.

lateral cephalogram radiographs.

Principal component analysis

PC analysis displayed multivariate analysis and major features of shape variation in a data set. Fig. 3 showed the amount of variance for all classes of malocclusion. There was a gradual decrease in percent variance with a drop between PC1 and PC14 exhibiting the largest difference. The first-three PCs were statistically meaningful and portrayed as 63.24% of total shape variability, with PC1 account for the most significant variance (24.47%), PC2 described 19.98% and PC3 18.80% (Fig. 4).

The lollipop graph with shape changes and percent variance of the first-three PC accounts for the most variance in the entire sample generated by MorphoJ. PC1 contributed to 24.47% of the total variance in the sample, while PC2 contributed to 19.98% of the total variance, and PC3 contributed to about 18.80% (Fig. 4). The lollipop graph represents the changes of its mean shape and its variation attributed to PC1 to PC3. Each point represents a landmark on the mandible, with the line representing the mean shape, and the blue line representing the distance and amount of variation exhibited on that location (Fig. 4).

All nine landmarks exhibited some level of variation with B-point, menton, gonion, and porion, being the most prominent. Sella and posterior nasal spine showed little or no variance in the population, while the remaining landmarks exhibited moderate variance (Fig. 4). In this study, the PC was also presented in the wire-frame graph by MorphoJ. The wire-frame graph showed the comparison shape between light-blue color and dark-blue color. Dark-blue lines represent shape change in positive and negative direction; light-blue lines represent the mean shape (Fig. 4).

Procrustes ANOVA

The outputs of the Procrustes ANOVA analysis were presented in separate ANOVA tables for centroid size and shape (Table 2). In this study, there were no differences in terms of centroid size (P=0.361) while the Goodall's F statistic (F) showed a low amount of difference in centroid size (F=1.02). In contrast, there were significant differences in shape (P<0.001) with a high F value of (F=10.95).

Canonical variate analysis

CVA shows that there was substantial individual overlap between the groups. There was significant difference between class I, class II, and class III malocclusions in mean shape. The class II and class III populations exhibited the highest Mahalanobis distances. The wire-frame graph showed the comparison of mean shape in positive and negative directions with scaling factor of –4 to 6 for CV1 and CV2 (Fig. 5). The mean of craniofacial shapes of the three malocclusion groups was described in Fig. 6. In class III group, the average mandible was more prognathic while in class II group, the average mandible was more retrognathic.

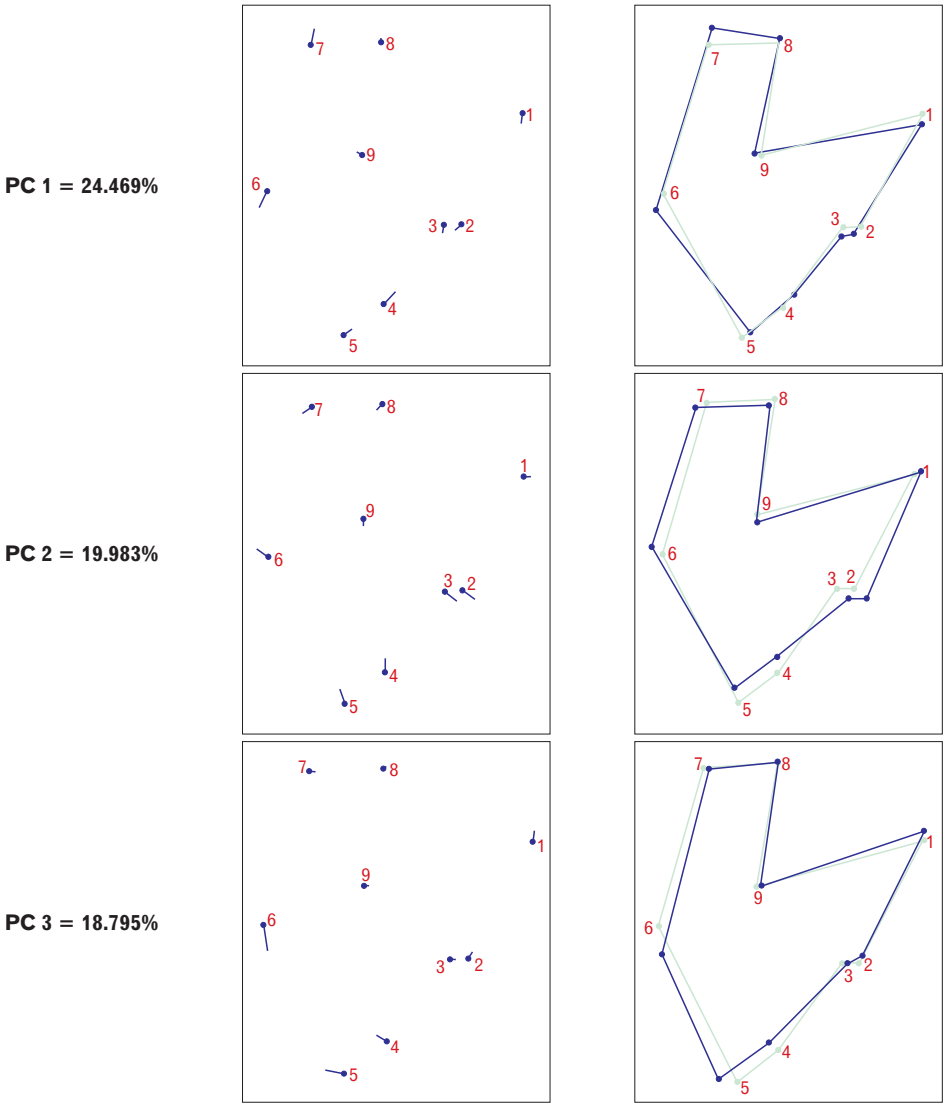

Fig. 4. Lollipop graph with shape changes of first-three principal component (PC).

Table 2. The centroid size and shape

Effect	SS	MS	*df*	*F*	*P*-value
Centroid size	7,445.378226	3,722.689113	2	1.02	0.3608
Shape	0.11217016	0.0040060772	28	10.95	0.0001*

Sums of squares (SS), mean squares (MS), degrees of freedom (*df*), and Goodall's F statistic (*F*). *$P<0.05$.

Discriminant function analysis

Class I and class II

The results showed that GM can be correctly classified according to class I and class II with 60% and 67% classification accuracy and 57% and 60% after cross-validation respectively using MorphoJ software (Tables 3–5).

Class I and class III

The results showed that GM can be correctly classified according to class I and class III with 79% and 72% classification accuracy and 76% and 68% after cross-validation respectively using MorphoJ software (Tables 3–5).

Class II and class III

The results showed that GM can be correctly classified according to class II and class III with 83% and 76% classification accuracy and 80% and 71% after cross-validation respectively using MorphoJ software (Tables 3–5).

Craniofacial skeletal angular

Our study demonstrated that there were significant differences for ANB angle (A point-Nasion-B point) across

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all malocclusion groups. Class II had the widest ANB angle while class III had the most acute ANB angle. However, the gonial angle (menton-gonion-porion) and cranial base angle (nasion-sella-basion) were not statistically significant between all groups (Table 6).

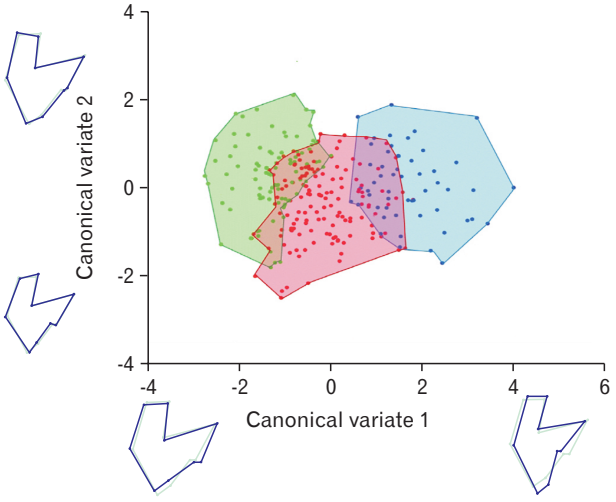

Fig. 5. Scatter plot of the first two between-group principal components of shape. Class I patients are shown by red filled region, class II patients by green filled region, class III patients by blue region. Shape differences associated with canovial variate axes are visualized by wire-frame graphs illustrating the shape changes corresponding to scores of –4 and 6 for CV1 and –4 and 6 for CV2.

Discussion

Difference in malocclusion and craniofacial phenotype is contributed by variation in shape, size, and inclination of the maxilla [19]. Geometric morphometric analysis is more reliable than conventional cephalometry as it provides visual

Table 3. Discriminant function test after cross-validation test on MorphoJ software: class I and II

	Class I (cross-validation)	Class II (cross-validation)	Total	Classification accuracy (cross-validation) (%)
Class I	106 (102)	72 (76)	178	60 (57)
Class II	42 (51)	86 (77)	128	67 (60)

Table 4. Discriminant function test after cross-validation test on MorphoJ software: class I and III

	Class I (cross-validation)	Class III (cross-validation)	Total	Classification accuracy (cross-validation) (%)
Class I	140 (135)	38 (43)	178	79 (76)
Class III	21 (24)	54 (51)	75	72 (68)

Table 5. Discriminant function test after cross-validation test on MorphoJ software: class II and III

	Class II (cross-validation)	Class III (cross-validation)	Total	Classification accuracy (cross-validation) (%)
Class II	106 (103)	22 (25)	128	83 (80)
Class III	18 (22)	57 (53)	75	76 (71)

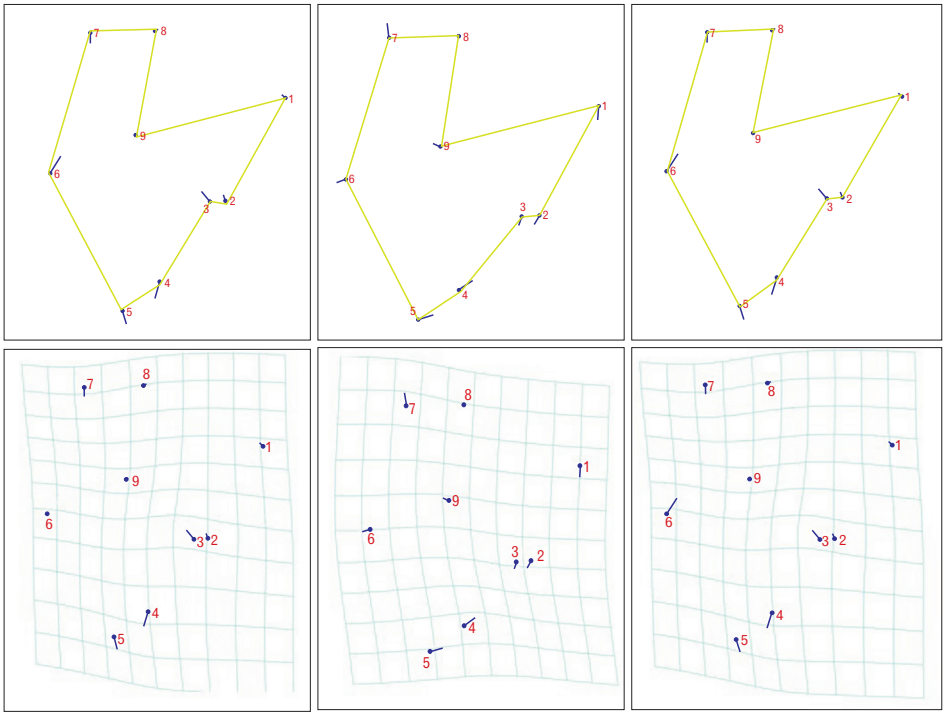

Fig. 6. Wire-frame and transformation grid graphs illustrating the mean shape of three different class of malocclusion.

Table 6. Group means and standard deviations for selected angular and linear measurements

	Gonial angle	ANB angle	Cranial base angle
Class I	134.3 (6.84)	2.56 (1.68)	150.9 (9.84)
Class II	135.2 (7.67)	4.098 (2.29)	151.9 (9.12)
Class III	135.9 (6.09)	1.842 (1.18)	151.8 (9.89)
P-value (between group)	0.25	0.000*	0.611

ANB, A point-Nasion-B point. *$P<0.05$.

morphology differences at the actual sites and does not require conventional reference lines [20]. In this study, geometric morphometric method was used to identify the relative skeletal and dental shape components in the morphometric space using lateral cephalograms in class I, class II, and class III malocclusions in adult Malaysian population. Classification of malocclusion is significant in our study, suggesting a close correlation between craniofacial morphology and its malocclusion.

Present study showed the highest Mahalanobis distances were exhibited by the class II and III malocclusion samples. Although there are differences in mean shape for the three classes of malocclusion, the distribution of individual's craniofacial shape overlapped within the groups (Fig. 5). These results were similar with previous study performed on Caucasian population [12]. Our study showed that class II and class III malocclusion groups overlapped with the class I group respectively, suggesting that craniofacial shape is not the single factor of malocclusion, but it does significantly contribute to misalignment of teeth [12, 19]. Similar findings were shown using class II and class III malocclusion where it showed that these groups were also overlapped with class I in a canonical variate analysis of American population [21, 22].

ANB angle has been commonly used for anteroposterior association of skeletal jaw which ranges from 1° to 5° according to Steiner's analysis [23]. ANB angle is an important factor of cephalometric parameter in malocclusion [24]. Our present study showed a significant difference of ANB angle between all malocclusion groups in Malaysian population, which is coincided with the results of previous studies done on Pakistani population [25]. Another study inform the northeastern region of Romania suggested that the ANB angle had quantitative characteristics that represent a relationship of bony structures of class III malocclusion [26]. However, present study showed that there were no differences in gonial angle between groups. Similarly to findings by Okşayan et al. [27], which found that, there were no significant differences in gonial angle values between all malocclusion groups using panoramic radiographs and lateral cephalometric radiographs. In addition, the cranial base was similar for all malocclusion groups (Tables 3–5). These suggested that the cranial base and gonial angle have less relation with malocclusion types. These results were similar to the study carried out by Mitteroecker and Gunz [28] which claims that the morphology of cranial bases were alike in class III malocclusion patients. The cranial base angle range between all classes was also small which is in accordance with previous studies [21, 22]. However, in other studies, they suggested that the cranial base is one of the contributing factors for class II or class III development [21, 29].

Discriminant function analysis is useful in identifying if the plot of landmarks is effective in category prediction [30]. The classification was mostly accurate especially for class II and class III using skeletal landmarks, with success rates of 80% and 71% respectively (Tables 3–5), demonstrating its distinct craniofacial shape. In Malaysia, previous study on the population-specific sex discriminating osteometric standards on crania for human identification. About 22 parameters of crania were measured. Results showed that all parameters were significantly higher in males than in females except for orbital height of the left eye by independent *t* test ($P<0.01$). The classification accuracy ranged from 78.2% to 86.2%. The cranium can be used to distinguish between males and females in the Malaysian population [31].

Our study limitations include gender distribution within groups and data restricted to 2-dimensional. Despite this limitation, our outcomes provided a novel insight into geometric morphometric analysis of variation in craniofacial shape within various malocclusion groups for adult Malaysian population.

In conclusion, craniofacial shape can be correlated within malocclusion groups, with maxillary shape showed more variation compared to the cranial base. An extensive population database from multiple landmarks from lateral cephalographs of the Malaysian population was compiled, which will initiate a new database for cross-platform software as a new diagnostic tool that will shorten the duration of diagnosis of the orthodontic patient.

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Author Contributions

Conceptualization: AA, CKW, NMI, SMA, NHN. Data acquisition: MNIMN, SMA, NMI, AA, NAAJ, CKW. Data analysis or interpretation: MNIMN, SMA, NMI, NHN, AA, NAAJ, CKW. Drafting of the manuscript: MNIMN, AA, NAAJ, CKW. Critical revision of the manuscript: AA, CKW, MNIMN, NAAJ, NHN. Approval of the final version of the manuscript: all authors.

Conflicts of Interest

No potential conflict of interest relevant to this article was reported.

References

1. Ramfjord SP, Ash MM. Occlusion. 3rd ed. Philadelphia: WB Saunders Co.; 1982.
2. Gruenbaum T. Famous figures in dentistry mouth. JASDA 2010; 30:18.
3. Parmesh H, Mathur VP. National Oral Health Care Program. Indian Pediatr 2002;39:1001-5.
4. Katz MI. Angle's classification revisited. Am J Orthod Dentofacial Orthop 2007;132:716-7.
5. McIntyre GT, Mossey PA. Size and shape measurement in contemporary cephalometrics. Eur J Orthod 2003;25:231-42.
6. Moyers RE, Bookstein FL. The inappropriateness of conventional cephalometrics. Am J Orthod 1979;75:599-617.
7. Bookstein FL. Reconsidering "The inappropriateness of conventional cephalometrics". Am J Orthod Dentofacial Orthop 2016; 149:784-97.
8. Halazonetis DJ. Morphometrics for cephalometric diagnosis. Am J Orthod Dentofacial Orthop 2004;125:571-81.
9. Rein TR, Harvati K. Geometric morphometrics and virtual anthropology: advances in human evolutionary studies. Anthropol Anz 2014;71:41-55.
10. Cooke SB, Terhune CE. Form, function, and geometric morphometrics. Anat Rec (Hoboken) 2015;298:5-28.
11. Díaz Muñoz A, Soto GM. Skeletodental diagnosis using a geometric morphometric approach. Int J Odontostomat 2014;8:5-11.
12. Freudenthaler J, Čelar A, Ritt C, Mitteröcker P. Geometric morphometrics of different malocclusions in lateral skull radiographs. J Orofac Orthop 2017;78:11-20.
13. James Rohlf F, Marcus LF. A revolution morphometrics. Trends Ecol Evol 1993;8:129-32.
14. Krey KF, Dannhauer KH. Morphometric analysis of facial profile in adults. J Orofac Orthop 2008;69:424-36.
15. Mageet AO. Classification of skeletal and dental malocclusion: revisited. Stomatol Edu J 2016;3:38-44.
16. Wellens HL, Kuijpers-Jagtman AM, Halazonetis DJ. Geometric morphometric analysis of craniofacial variation, ontogeny and modularity in a cross-sectional sample of modern humans. J Anat 2013;222:397-409.
17. Dryden IL, Mardia KV. Statistical shape analysis. Chichester: Wiley; 1998. p.2716-7.
18. Klingenberg CP. Size, shape, and form: concepts of allometry in geometric morphometrics. Dev Genes Evol 2016;226:113-37.
19. Enlow DH, Kuroda T, Lewis AB. The morphological and morphogenetic basis for craniofacial form and pattern. Angle Orthod 1971;41:161-88.
20. Franchi L, Baccetti T, McNamara JA Jr. Thin-plate spline analysis of mandibular growth. Angle Orthod 2001;71:83-9.
21. Moreno Uribe LM, Howe SC, Kummet C, Vela KC, Dawson DV, Southard TE. Phenotypic diversity in white adults with moderate to severe Class II malocclusion. Am J Orthod Dentofacial Orthop 2014;145:305-16.
22. Moreno Uribe LM, Vela KC, Kummet C, Dawson DV, Southard TE. Phenotypic diversity in white adults with moderate to severe Class III malocclusion. Am J Orthod Dentofacial Orthop 2013; 144:32-42.
23. Proffit WR. Diagnosis and treatment planning for alveolar surgery, with special reference to soft tissue considerations. Trans Eur Orthod Soc 1973:604-8.
24. Iwasaki H, Ishikawa H, Chowdhury L, Nakamura S, Iida J. Properties of the ANB angle and the Wits appraisal in the skeletal estimation of Angle's Class III patients. Eur J Orthod 2002;24:477-83.
25. Ghani S, Jabbar A. Correlation of ANB angle and wits appraisal in different malocclusion groups. J Pak Dent Assoc 2013;22:130-133.
26. Zegan G, Dascălu C, Mavru RB, Anistoroaei D. Cephalometric features of class III malocclusion. Rev Med Chir Soc Med Nat Iasi 2015;119:1153-60.
27. Okşayan R, Aktan AM, Sökücü O, Haştar E, Ciftci ME. Does the panoramic radiography have the power to identify the gonial angle in orthodontics? ScientificWorldJournal 2012;2012:219708.
28. Mitteroecker P, Gunz P. Advances in geometric morphometrics. Evol Biol 2009;36:235-47.
29. Bookstein FL. Landmark methods for forms without landmarks: morphometrics of group differences in outline shape. Med Im-

age Anal 1997;1:225-43.
30. Ousley SD. Forensic classification and biodistance in the 21st century: the rise of learning machines. In: Pilloud MA, Hefner JT, editors. Biological Distance Analysis: Forensic and Bioarchaeological Perstpectives. San Diego, CA: Academic Press; 2016. p. 197-212.
31. Ibrahim A, Alias A, Nor FM, Swarhib M, Abu Bakar SN, Das S. Study of sexual dimorphism of Malaysian crania: an important step in identification of the skeletal remains. Anat Cell Biol 2017; 50:86-92.