INVESTIGATION OF THE PREVALENCE OF SKELETAL PATTERNS IN THE MALAY POPULATION USING ANB ANGLE AND PRINCIPAL COMPONENT ANALYSIS OF CEPHALOMETRIC VARIABLES

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Abstract

Prevalence studies of malocclusion should distinguish how skeletal classification was done because of the moderate correlation that exists between dental arches and skeletal patterns. The validity of using the ANB angle as a diagnostic tool to determine skeletal patterns remains questionable. This study aimed to determine the prevalence of skeletal patterns in the Malay population, their association with gender and age groups, and whether the ANB angle is a highly correlated variable in diagnosing skeletal patterns radiographically by using Principal Component Analysis (PCA). Two thousand one hundred eighty-two lateral cephalograms of Malay patients were digitally traced. Respective skeletal patterns were determined using the ANB angles. Descriptive analysis was used to describe the prevalence, whereas the association with gender and age groups were determined using the Chi-Squared and Fisher's Exact tests. PCA was done on all commonly used cephalometric variables in Class III samples. The prevalence for the Class I, Class II and Class III skeletal patterns were 41.3%, 46.1%, and 12.6%, respectively. A significant association was found between gender and skeletal patterns (p = 0.012). Most of the significant variables in principal component (PC) 1 were vertical measurements. ANB angle was not captured in the first five PCs. Class III skeletal pattern was significantly less prevalent in the Malay population when compared to other skeletal patterns, especially in males. Vertical, sagittal cephalometric measurements and incisor angulation variables were more highly correlated than the ANB angle and, therefore, may be more useful to diagnose the Class III skeletal pattern.

Keywords: Cephalometry, Skeletal Pattern, Prevalence, Principal Component Analysis, ANB angle

Introduction

Malocclusion is among the most common dental disorders in the oral cavity, along with dental caries and periodontal diseases. Malocclusions can be dental or skeletal in aetiology or both. These two aetiologies are closely interrelated yet different entities in aetiology, treatment plans, and prognosis (1). Well-proportionate maxilla and mandible demonstrate a normal skeletal pattern known as Class I. However, when the maxilla and mandible grow disproportionately, it results in a larger-than-normal skeletal pattern discrepancy (2). On the other hand, dental malocclusion depends on the relationship between the teeth in the maxilla and mandible, which can happen due to many local factors (3).

According to Zhou et al., there was only a 61% correlation between the anteroposterior relationship between the dental arches (using Angle's classification of malocclusion) and the skeletal pattern (using angular measurement ANB on lateral cephalogram) (4). In other words, a person presenting with Class I malocclusion on Angle's classification may have a Class II or Class III skeletal pattern and vice versa. However, another study also reported a similar percentage of 57% (5). Therefore, when performing prevalence studies of malocclusion types in a region or population, it is important to distinguish how the classification is done and which type of malocclusion is being reported.

Although few epidemiological studies were done in Malaysia, those studies determined the prevalence of malocclusion instead of skeletal patterns in all three ethnicities (6, 7). In the Malay population (8), all the studies used Angle's molar relationship classification to classify malocclusion, which is a different method and results in the only type of malocclusion being reported from this study. Only one previous study in Malaysia determined the cephalometric norm and prevalence of skeletal patterns using cephalometry in Malaysia's Malay and Chinese populations (9).

Apart from that, a previous study on the Malaysian Malay population reported that a significant difference in the occlusal status was found between the gender, but it was also based on Angle's Classification (8). However, no previous studies investigated the association between the prevalence of skeletal patterns with age group. Therefore, it was thought that because the mandibular growth completes at around the age of 15 years in females and 17 years in males (10, 11), thus the lateral radiographs that were taken at a young age may not be representative of the actual skeletal pattern, especially when the mandible was still growing. Hence, it is essential to investigate the association between the prevalence of types of skeletal patterns in different gender and age groups consisting of children, adolescents, and adults.

Because there were only limited studies and data, there was a need to investigate the prevalence of skeletal patterns using cephalometry in the Malaysian Malay population, and this study was the first to be conducted in the northern region. This prevalence study of the Malay population's skeletal patterns can serve as baseline data and evidence for the nation's future orthodontic services and resource allocation planning.

Classically, cephalometric parameters like Wits Appraisal, overjet, ANB, SNA, and SNB angle were commonly used to classify Class III skeletal pattern on cephalometric radiographs. This study and previous studies used cephalometric measurements, such as ANB angle, to determine the prevalence of skeletal patterns in the respective countries' populations (12–14). However, previous authors questioned the validity of these traditional variables, including the ANB angle. Furthermore, they mentioned other parameters that may have been overlooked after the results of their study showed that these traditionally used variables were not as significant or highly correlated when Principle Component Analysis (PCA) was done on their data set, which consisted of a large sample of individuals with Class III skeletal pattern (15, 16).

Therefore, the first objective of this study was to determine the prevalence of the skeletal patterns, which were classified into Class I, Class II, and Class III, using the ANB angle on the lateral cephalograms of the Malay population. The second objective of the study was to determine the association between the prevalence of skeletal patterns in different gender and age groups in the same population. Finally, the third objective was to test the hypothesis that ANB angle is not the best or the most highly correlated variable in diagnosing skeletal pattern radiographically by performing Principal Component Analysis (PCA) on all commonly used cephalometric variables in a sample of Malay Class III subjects.

Materials and Methods

The ethical approval for this study was obtained from The Human Research Ethics Committee of Universiti Sains Malaysia (*USM*) (*JEPeM*) (USM/JEPeM/20090471). The study performed was a retrospective cross-sectional observational study. The data for this study was obtained from the records at the orthodontic clinic in Penang, Malaysia. Lateral cephalometric radiographs of Malay dental outpatients attending the clinic were obtained retrospectively and analysed. The inclusion criteria were Malay patients with good quality pre-orthodontic treatment radiographs. Any redundant lateral cephalograms or subjects without pre-orthodontic treatment radiographs were excluded. The required sample size was calculated using the prevalence value taken from a previous study done in Malaysia using the exact ANB measurement (9). Therefore, the largest sample size required in this study was 309.

The dental imaging software used was Planmeca Romexis® 3.8.3.R. (Planmeca Romexis, Planmeca, Finland). The lateral cephalograms were viewed on this software, and measurements were made using the existing "angular measurement tools" on the same software. Cephalometric landmarks were traced digitally, and the value of interest, the ANB angle, was obtained from the difference between the SNA and SNB measurements. The researchers were calibrated with an expert (orthodontist) using interclass and intraclass correlation analyses, and measurement only commenced once an excellent agreement had been achieved.

The skeletal patterns were then classified into skeletal Class I, II, and III based on their ANB angles of the Eastman standard (17). The ANB values of each skeletal pattern are as follows:

Class I: ANB angle between 1^o to 5^o

Class II: ANB > 5^o

Class III: ANB < 1^o

The data were analysed statistically using SPSS version 27.0 (SPSS Inc., Chicago, USA). Descriptive analysis was used to describe the frequency and prevalence of each skeletal pattern in different gender and age groups. The ages of the sample were categorised into three age groups, and the age range was determined based on the World Health Organization (WHO) classification, which defines children as individuals less than nine years old and adolescents are individuals between 10 to 19 years old, and adults are those between 20 years old and above (18). All age groups were used to determine the association with the skeletal pattern. Numerical data was then presented in their mean and standard deviation (SD), and qualitative data were presented as frequency and percentage. The Chi-Square test of Independence or Fisher's Exact test was applied to compare if the differences between the gender and age groups were significant. The statistical significance level was set at 5% ($p < 0.05$) unless otherwise adjusted with Bonferroni corrections for multiple comparisons.

Afterwards, 62 cephalometric variables, which included 32 angular measurements, 24 linear measurements, and six derived cephalometric variables, were selected, and their values were obtained from the lateral cephalograms of the Class III subjects in this study (Table 1).

Table 1: A list of 62 cephalometric variables used in this study

Cephalometric Variables
APDI
A to N Perpendicular
B to N Perpendicular
FH to AB
AB to Mandibular Plane
Overjet
U1 to FH
U1 to NA (mm)
U1 to NA (degree)
L1 to NB (mm)
L1 to NB (degree)
Saddle Angle
Articular Angle
Gonial Angle
Bjork Sum
Anterior Cranial Base Length
Posterior Cranial Base Length
Upper Gonial Angle
Lower Gonial Angle
Ramus Height
Mandibular Body Length
Body to Anterior Cranial Base Ratio
SN to Go-Me
Facial Depth
Facial Length on Y-axis
Y-axis to SN
Posterior Facial Height
Anterior Facial Height
Facial Height Ratio
Facial Plane
Facial Convexity
U1 to SN
U1 to Facial Plane (mm)
Effective length of maxilla
Effective length of mandible
Maxillomandibular differential
Mandibular Plane Angle
Facial Axis Angle
Pogonion to Nasion Perpendicular
Upper Incisor to Point A Vertical
Facial Angle
Y-axis
Incisor Occlusal Plane Angle
Incisor Mandibular Plane Angle
Upper Incisor to APog line
Facial Axis
Facial Taper
Mandibular Arc
Convexity of Point A
SNA
SNB
ANB
SN to Maxillary Plane (SNMx)
Wits Appraisal
U1 to Maxillary Plane Angle (U1A)
L1 to Mandibular Plane Angle (L1A)
Interincisal Angle
Maxillary Mandibular Plane Angle (MMPA)
Upper Anterior Facial Height (UAFH)
Lower Anterior Facial Height (LAFH)
Lower AFH to Facial Height ratio
Li-APog

Class III skeletal pattern was selected as the ANB angle tends to overestimate this type of skeletal discrepancy (19). All values were recorded, normalised with statistical adjustment using mean values, and then analysed with

Principal Component Analysis using Metaboanalyst V5.0 software (Wishart Research Group, Alberta, Canada). When PCA was used on the cephalometric variables of Class III skeletal pattern subjects, it could find the most highly correlated cephalometric variables in the dataset that could explain the maximum amount of variance in the subjects. It is because PCA reduces the dimension of multiple variables into fewer variables (components) and ranks them in order of importance that contributes to the data. In addition, the principal component analysis scree plot was also obtained to explain the variance graphically. PCA dictates which cephalometric variables best describe the Class III skeletal pattern on cephalometric radiographs.

Results

Two thousand one hundred eighty-two lateral cephalograms that fit the selection criteria were traced digitally and analysed. The mean age of the patients in years was 21.84, with a standard deviation of 6.33. The overall number of patients with Class I, Class II and Class III is given in Table 2. The number of male and female patients and the number of patients in each age group are given in Table 3. Both male and female subjects with Class III skeletal pattern were significantly less prevalent than male and female subjects with Class I and II skeletal patterns.

Table 2: Distribution of three different skeletal patterns in Malay population

Skeletal pattern	Frequency	Percentage, %	Cumulative percentage, %	95% confidence interval
Class I	902	41.3	41.3	39.3 – 43.4
Class II	1005	46.1	87.4	44.0 – 48.2
Class III	275	12.6	100	11.2 – 14.1

Table 3: Factors associated with types of skeletal pattern

Variable	*n*	Class I Freq (%)	Class II Freq (%)	Class III Freq (%)	χ^2 statistic (*df*)	*p* value
Gender*						
Male	376	140 (37.2)	172 (45.7)	64 (17.0)	8.90 (2)[a]	0.012[a]
Female	1806	762 (42.2)	833 (46.1)	211 (11.7)		
Age Group						
Children (age ≤ 9)	11	6 (54.5)	3 (27.3)	2 (18.2)		
Adolescents (10 ≥ age ≤ 19)	797	325 (40.8)	365 (45.8)	107 (13.4)	-	0.589[b]
Adults (age ≥ 20)	1374	571 (41.6)	637 (46.4)	166 (12.1)		

[a]Chi-square test of Independence
[b]Fisher Exact test
*Significant at $p < 0.05$

The Chi-Square Test of Independence was done to determine the association of gender and age groups to the skeletal pattern. According to age groups, there was no significant difference in the distribution of skeletal patterns ($p = 0.589$) (Table 3). However, gender showed a significant association, and the influential group was determined using the post-hoc Bonferroni test, and the *p* value was adjusted to 0.008 (Table 4).

Table 4: Post hoc Bonferroni test with adjusted residuals

	Male		Female	
Variables	**Adjusted residual**	***p* value**	**Adjusted residual**	***p* value**
Class I	-1.8	0.072	1.8	0.072
Class II	-.1	0.920	.1	0.920
Class III*	2.8	0.005	-2.8	0.005

*Significant at $p < 0.008$ after Bonferroni correction.

Principal Component Analysis was done on all the 7874 cephalometric values obtained from Class III skeletal pattern subjects in this study. 82.9% of the variance explained was obtained in the first five principal components (PCs). The first two PCs already explained more than half (>50%) of the variance (Figure 1). Table 5 contained the cephalometric variables that contributed the most to the PCs and explained the highest percentage of variance.

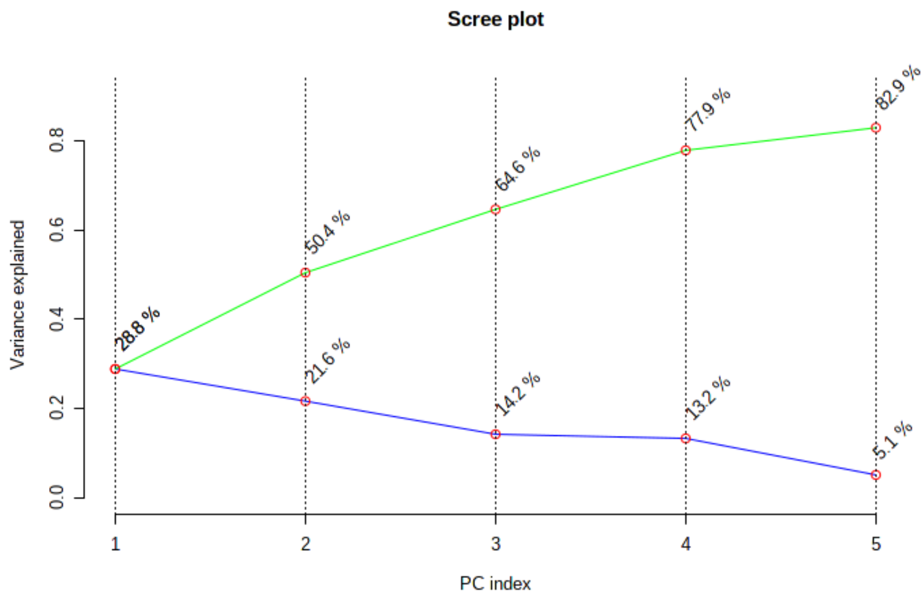

Figure 1: Scree plot and variance explained by the first five PCs (Green line represents the cumulative variance and blue line represents the variance explained for each PC)

Table 5: Most significant cephalometric variables in the first five PCs

Principal Component	**PC 1**	**PC 2**	**PC 3**	**PC 4**	**PC 5**
Variance Explained, %	28.8	21.6	14.2	13.2	5.1
Cumulative Variance		50.4	64.6	77.9	82.9
	Facial Convexity	IMPA	Interincisal Angle	Anterior Facial Height	U1 to SN
	LAFH	L1 to Mandibular plane angle	Facial length on Y-axis	Facial Length on Y-axis	Pogonion to Nasion Perpendicular
	Posterior Facial Height	Incisor Occlusal Plane Angle	Effective length of mandible	Effective length of mandible	B to N Perpendicular
	Anterior Facial Height	Posterior Facial Height	Posterior Facial height	LAFH	U1 to FH
	Wits Appraisal	U1 to SN	Anterior Facial height	Maxilloma-ndibular differential	U1 to NA (^{o})

Discussion

It is well known that dentofacial skeletal features vary between different ethnicities. Literature review revealed that skeletal pattern such as Class III is highly prevalent in Mongoloid Asians, including Malaysians, compared to other races or regions of the world (20–22). A systematic review of the worldwide prevalence of malocclusion reported that approximately 74.7% of the population was Class I (range: 31%-97%), 19.56% was Class II (range: 2%-63%), and 5.93% was Class III (range: 1%-20%). The large differences in percentage were most likely due to the different sampling methods of the different studies (21). In another study, the world's average prevalence of Class III was around 7.04% (20).

In this study, the prevalence of Class I skeletal pattern was 41.3%, Class II: 46.1%, and Class III: 12.6%. Based on the literature reviews, the prevalence of Class I malocclusion in the Malay population was reported to be in the range of 33.3% to 39.3%, Class II: 12% to 30%, and Class III: 12.2% to 48.7% (6–8). The large variation between different studies was due to different sampling methods. For example, one of the few studies (6) was done only on orthodontic patients of the clinic. Hence, there was a higher proportion of Class II and Class III malocclusion, as they were more likely to seek orthodontic treatment than patients with Class I malocclusion, which was considered normal. This type of sampling was why the prevalence of Class I skeletal pattern was lower in this study which used the same convenience sampling method by recruiting only potential orthodontic patients from clinic settings.

However, it was worth noticing that while the previous studies aforementioned had investigated the prevalence of malocclusion of the Malaysian and the Malay population, all had used Angle's Classification to classify the occlusal status of the population, meaning that the prevalence represented more of the dental origin rather than the underlying skeletal pattern (6). Therefore, only a little comparison could be made with these studies due to different categorisation methods. Nonetheless, it was noted that all previous studies reported that Malay had a high prevalence in Class III malocclusion.

One previous study used the angular measurement of ANB on the lateral cephalograms to classify patients. They reported the prevalence in Class I: 51.7%, Class II: 40.2%, and Class III: 6.8%, with no significant difference between gender. Therefore, it was concluded that most country and their prevalence studies would agree with this result (12). However, the study's classification criteria differed slightly from ours, with the ANB angle of 0^o to 4^o classified as Class I, ANB > 4^o as Class II and ANB < 0^o as Class III. Another study on Malaysia's Malay population also used the same method and reported the prevalence of Class I skeletal pattern to be 41.87%, Class II: 33.74%, and Class III: 24.39% (9). Compared to previous studies, this study reported a higher prevalence of Class II and a lower prevalence of Class I skeletal pattern due to the convenience sampling method used, which reduced the proportion of the Class I skeletal pattern. Nonetheless, this study concurred with the previous study in which the Class III skeletal pattern was much more prevalent in the Malay population than in other regions of the world. This finding calls for further research on the possible genetic predisposition for a higher Class III skeletal pattern prevalence for the Malay population.

The mean age of the sample population in this study was young, at 21.84±6.33 years old. It was also noted that a much higher percentage of females (82.8%) in the sample population compared to males (17.2%) could be due to young age, and female patients in this region were more concerned about their aesthetics than those older and male counterparts, hence, were more likely to seek orthodontic consultation and treatment. Both male and female subjects with Class III skeletal pattern were significantly less prevalent than male and female subjects with Class I and Class II skeletal patterns, and male subjects had a significantly more prevalent Class III skeletal pattern. Hence, the hypothesis that no significant association existed between the prevalence of skeletal patterns and gender was rejected. It was in agreement with the literature that the Malay male subjects were more likely to have Class III malocclusion than their female counterpart (8). Sexual dimorphism and growth in the mandible between males and females could be accounted for the difference observed (23, 24).

It is believed that children and adolescents will tend to have more Class II skeletal pattern because of the differential growth in both jaws, in which a fully grown maxillary jaw occludes against an incompletely grown mandibular jaw at a young age. However, on the contrary, this study found no significant difference between children, adolescents, and adults in the prevalence of Class I, Class II or Class III skeletal patterns. Hence, the hypothesis was accepted.

In this study, there were a few reasons why the angular measurement ANB was used instead of Angle's classification to categorise the malocclusion. Firstly, cephalometric tracing represents the skeletal pattern, growth of its structure, and genetic predisposition (25). The use of dental traits often does not represent the actual underlying skeletal pattern (5). Many local factors and aetiologies unrelated to growth and genetics can cause dental malocclusion (3), reducing its reliability in assessing the underlying skeletal pattern of a population. Furthermore, the treatment mechanics of dental malocclusion and skeletal pattern discrepancy differ (1), necessitating a different classification method for each type of malocclusion.

However, using angular measurement ANB to classify skeletal patterns had limitations and weaknesses. Different authors used different criteria to categorise skeletal patterns. Some used ANB angle $3^{o}\pm1$ as Class I (26, 27), while some used $2^{o}\pm2$ (12). Non-standardisation of the criteria used for skeletal pattern classification may cause the over or underreporting of Class II and Class III skeletal patterns. In addition, the validity of point Nasion in ANB had been questioned because it can be affected by the length of the cranial base, which was known to be significantly different in different ethnicities, and ANB is also affected by the inclination of incisors (28). Although the cephalometric norm for the Malay population exists in the literature, the Eastman Standard using ANB angle $3^{o}\pm2$ as Class I (17) was used in this study for standardisation.

Due to these limitations, PCA was done to determine the most significant cephalometric variables that explained most of the variance in this dataset of Class III skeletal pattern Malay subjects. The PCA results allowed researchers to investigate and provide insight into critical cephalometric parameters that can represent subjects with Class III skeletal pattern and help diagnose other skeletal discrepancies in the future. While the first five PCs in other studies captured approximately 67% to 74% of the variance explained, this study captured a higher percentage of variance explained at 82.9%. The variability was probably due to the more homogenous samples in terms of race in this study as opposed to other previous studies, which accounted for the differences in craniofacial morphological features (29).

Most of the significant variables in PC 1 in this study were vertical skull measurements. These variables concurred with the study, which was also done in another Asian population, the Chinese (16). Malay and Chinese as sub-races fall under the same category of Mongoloid race. This made an interesting finding as vertical parameters were heavily weighted in PCA results in Mongoloid, while studies involving Caucasoid race (15, 30) mainly contained sagittal parameters in PC 1 and ranked vertical measurements in PC 2. However, the latest and most recent study in the Southern European population also reported most vertical cephalometric variables in PC 1 (29). When results from this study were taken together with the findings of previous studies, it can be inferred that differences exist between ethnicities.

In this study, PC 2 comprised mostly lower incisor inclination measurements identical to Bui et al. (15). Meanwhile, other studies sorted cephalometric variables measuring lower incisor inclination at PC 3, which were almost similar in weightage as well. Therefore, this interesting finding highlighted the importance of mandibular incisor proclination or retroclination in different presentations of Class III skeletal pattern phenotypes, and not all mandibular incisors simply present with compensation at a retroclined angle in Class III skeletal pattern. Furthermore, PC 3 and 4 in this study consisted of mainly anterior-posterior sagittal measurements and vertical measurements, which coincided with most studies, and was closely matched with the study by Bui et al. (15). In addition, the interincisal angle was also captured in PC 3 of our study, similar to Bui et al. (15) . Lastly, PC 5 in this study contained the upper incisor angulation variable as the major part. While Bui et al. (15) did not capture any upper incisors angulation in their PCA results, Moreno-Uribe et al. (30) and Cai Li et al. (16) obtained the same results as upper incisors angulation variables predominantly contributed to their PC 5.

This study captured Wits Analysis in the first PC, while PCA results from other studies typically ranked Wits Analysis at PC 4-8. This opposing result again triggered the controversy and discussions in previous studies, which argued that traditional and commonly used Class III parameters like Wits Analysis were not as crucial as other cephalometric variables. This study supported Wits Analysis as an essential measure for Malay patients with Class III skeletal pattern. On the other hand, some of the cephalometric variables captured in previous studies, for instance, ANB, maxillary length, saddle angle, and cranial base measurements, were not captured in the first five PCs in this study, similar to a previous study in the Chinese population (16). Hence the hypothesis that ANB angle was not a highly correlated variable in Class III skeletal pattern subjects in Mongoloid population was accepted. The variability in Wits Analysis was most likely due to sample populations of different races and nationalities (31), which accounted for the differences in craniofacial morphological features. Thus, ethnicity should be considered when evaluating the subclass of Class III skeletal pattern. Secondly, this study included only adults but covered a wide range of severity from mild to severe, which was different from some of the earlier studies that included only subjects with severe Class III skeletal pattern needing orthognathic surgery.

Nevertheless, despite the minor differences, this study had almost matching results from PCA and duplicated most of the correlated cephalometric variables ranked according to their significance in explaining the variance in our data set. Therefore, when the results from this study were compared with findings from previous studies, it can be inferred that differences exist between ethnicities. However, cephalometric variables measuring the vertical and sagittal dimension and incisor angulation nonetheless played vital roles, probably more important than using ANB angle, in evaluating and representing the different manifestation of Class III skeletal pattern subjects.

The sample population was representative of the Malay population in the Seberang Perai Utara district of Penang. However, as this study was done only in one centre in the northern region of Malaysia, and the convenience sampling method was used, the prevalence results may not be generalised to represent the Malay population of the entire country. Nevertheless, this study indicated a high prevalence of underlying skeletal pattern discrepancy, especially of Class III, among Malay patients seeking orthodontic treatment, especially the male patients in this region, which needed to be taken seriously and should raise a concern among the country's major stakeholders to tackle the problems by increasing orthodontic speciality training and facilities and promoting education of the public.

As skeletal pattern discrepancy is a difficult-to-treat condition (32), more research focus and effort should be placed into this area of interest. The finding in this study that males were more affected by Class III malocclusion compared to females opened the possibility of investigating the difference in genetic makeup between male and female Malay, which caused the vulnerability. This research on the influence of hereditary factors on class III skeletal pattern is vital for the nation where most of the population has a much higher prevalence rate than other countries. Identifying hereditary factors and high-risk children in families will be extremely valuable because skeletal class III malocclusion is a condition that will benefit from early diagnosis and treatment.

Conclusion

Most Malay populations presented with Class I and Class II skeletal patterns, whereas the Class III skeletal pattern was significantly less prevalent in both male and female groups. The skeletal pattern, however, was not associated with the age groups in this population. In addition, vertical, sagittal cephalometric measurements and incisor angulation variables were more highly correlated than other commonly used parameters like ANB angle and, therefore, may be more beneficial to classify and represent Class III skeletal patterns in the future.

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