Original Article

Bolton's Tooth Size Discrepancy in Malaysian Orthodontic Patients: Are Occlusal Characteristics Such as Overjet, Overbite, Midline, and Crowding Related to Tooth Size Discrepancy in Specific Malocclusions and Ethnicities?

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Abstract

Introduction: Tooth size, occlusal traits, and ethnicity are closely interrelated, and their impact on desirable orthodontic treatment outcome cannot be underestimated. This study was undertaken to assess the occlusal characteristics and ethnic variations in occlusion of Malaysian orthodontic patients and evaluate their correlation with Bolton's tooth size discrepancy. **Materials and Methods:** On 112 pretreatment study models of orthodontic patients, molar relationship, overjet, overbite, spacing, crowding, midline shift, and Bolton's ratios were assessed. ANOVA, one-sample *t*-test, Chi-squared test, and Spearman's rho correlation coefficient were used for statistical analysis. **Results:** Significant difference between anterior ratio of our study and Bolton's ideal values was found, for the entire study sample and Chinese ethnic group. Differences between races and malocclusion groups were not statistically significant ($P > 0.05$). Significant correlations were found as follows – in Angle's Class I malocclusion between 1) anterior ratio and overbite, 2) overall ratio and maxillary crowding and spacing; in Angle's Class II malocclusion between 1) anterior ratio and overjet and midline shift, 2) overall ratio and mandibular crowding; in Angle's Class III malocclusion between 1) anterior ratio and mandibular crowding and both maxillary and mandibular spacing 2) overall ratio and mandibular crowding. **Conclusions:** Significant differences in anterior ratio and Bolton's ideal values for the Malaysian population were found, indicating variations in anterior tooth size as compared to Caucasians. Statistically significant correlations existed between Bolton's ratios and occlusal traits. These findings can be applied clinically in diagnosis and treatment planning by keeping in mind the specific discrepancies that can occur in certain malocclusions and addressing them accordingly.

Keywords: *Anterior ratio, Bolton's discrepancy, ethnicity, Malaysian, malocclusion, occlusal traits, overall ratio*

Introduction

An optimal orthodontic outcome is dependent on the relative sizes of maxillary and mandibular teeth to each other which has been referred to as the "seventh key" in addition to Andrew's six keys to optimal occlusion.[1] An ideal ratio between upper and lower teeth was deduced by Wayne Bolton from his study of 55 excellent occlusions,[2,3] which was 77.2% for anteriors ("anterior ratio") and 91.3% for all teeth ("overall ratio"). Higher or lower ratio values indicate the presence of a tooth size discrepancy (TSD) between maxillary and mandibular arches. Proffit and Fields[4] suggest tooth width discrepancy larger than 1.5 mm be included in the problem list since it may cause difficulties in treatment. Bolton suggested that a discrepancy greater than ± 1 standard deviation (SD) could create clinical problems, but Crosby and Alexander,[5] Endo *et al*.,[6] Freeman *et al*.,[7] Othman and Harradine,[8] and Santoro *et al*.[9] have deduced values ± 2 SD outside Bolton's mean to be clinically significant.

Bolton also hypothesized that a relationship existed between occlusal features such as overbite and tooth size but failed to find any significant correlation between the two in his study.[3] However, Akyalçin *et al*. found significant correlation between anterior ratio and midline shift in Angle's Class II cases. Overall ratio correlated significantly with overjet in Class I cases, overbite in Class II cases, and lower incisor inclination in Class III cases.[10-12]

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While assessing difference in ratio values among different categories of malocclusion, Crosby and Alexander,[5] Freeman *et al*.,[7] Akyalçin *et al*.,[10] and Johe *et al*.[13] reported no differences between malocclusion groups' and Bolton's ideal values which were derived from ideal occlusion samples. Anterior and overall ratio values of Class I, Class II, and Class III malocclusions were not significantly different from each other according to some authors,[5,10,14,15] whereas others found higher mean anterior ratio values in Angle's Class III individuals.[16-18] Araujo and Souki[18] also found significantly greater prevalence of tooth size discrepancies in Angle's Class I and Class III individuals. Mandibular tooth size excess, smaller maxillary teeth, and larger mandibular teeth have also been found in Class III malocclusions.[19-22]

Reports of ethnic variation in ratio values have been diverging with some studies showing significant differences from Bolton's ideal in certain ethnicities[23-27] and others with no difference.[28-33] Studies have also found significant interethnic differences between Cacuasians, African-americans and Hispanics[33] and between Peruvian and Spanish.[34] African-americans were found to have the highest overall ratios, Caucasians the smallest, and the Mongoloids and Hispanics the intermediate values.[21,33]

Since tooth size, occlusal features, and ethnicity are so inseparably interlinked, there exists a need to comprehensively investigate their interrelationships. The Malaysian population which consists of three main ethnic groups of Malays, Chinese, and Indians lacks such studies on it. Hence, we conducted this study with the objectives to (1) determine the Bolton's anterior and overall ratio for Malaysians with malocclusion and for each malocclusion and ethnic subgroup and compare them with Bolton's ideal values, (2) compare the anterior and overall ratios within malocclusion and ethnic subgroups, (3) assess the level of clinically significant discrepancy in anterior and overall ratios, and (4) determine if there is a correlation between occlusal characteristics, Bolton's ratios, and ethnicity.

Materials and Methods

Pretreatment study models of 273 orthodontic patients visiting the Department of Orthodontics for treatment were assessed for inclusion in our retrospective, explorative study. Ethical approval for this study was obtained from the Institutional Research Ethics Committee. The criteria for being included were that the patients had to be Malaysian citizens and had to have available good quality pretreatment study models where all permanent teeth from first molar to first molar were present, fully erupted and with intact mesiodistal dimensions without any tooth deformities or abnormal morphology. Exclusion criteria were previous history of orthodontic treatment, any missing teeth from first molar to first molar, over-retained deciduous teeth or supernumerary teeth, proximal caries, restorations, or any abnormal tooth morphology affecting mesiodistal width of the tooth.

Based on these inclusion and exclusion criteria, 112 study models were selected and molar relationship, overjet, overbite, midlines, maxillary and mandibular crowding, and/or spacing were recorded. Mesiodistal widths of all teeth from first molar to molar in both arches were measured using the technique described by Moorrees and Reed[35] using electronic digital calipers, Insize© (Series 1108, Resolution 0.01 mm/0.0005"). Bolton's anterior and overall ratio were calculated as sum mandibular 3-3/sum maxillary 3-3 and sum mandibular 6-6/sum maxillary 6-6, respectively. Three examiners (AMI, JNR, MBNN) were trained and calibrated by the expert and principal investigator (MPS). Each examiner's measurements on 30 study models were compared with those of the expert's using Pearson's correlation coefficient. For intraexaminer reliability assessment, 10 study models were selected at random after 6 weeks, and a second set of measurements was obtained each examiner to compare with their first set. Every variable was recorded by all three examiners and an average of the three was recorded as the final reading. From the data collected, frequency, percentage, range, mean, SDs, and confidence intervals were calculated. One-sample *t*-test was to assess the difference between anterior and overall ratio values of our study and Bolton's study, and ANOVA was used to compare differences in TSD between malocclusion groups and ethnicities. Correlation was assessed using Chi-squared test and Spearman's rho correlation coefficient. All the statistical analyses were carried out using Epi Info™ 6.0, and statistical significance was set at $P < 0.05$.

Results

One hundred and twelve pretreatment study models consisting of 84 females with average age 19.77 ± 4.86 years and 28 males with average age 20.07 ± 4.45 years were assessed. The distribution of ethnic groups was 50 Chinese, 32 Indians, and 30 Malays and malocclusion groups was 46.4% Class I, 33% Class II, and 20.5% Class III [Table 1]. Interexaminer and intraexaminer reliability analyzed using Pearson's coefficient correlation and Spearman's rho coefficient correlation, respectively, found that measurements for all 3 examiners were highly correlated, at statistically significant levels ($P < 0.05$).

Anterior ratio values in our study were Class I – 77.9% ± 2.47%, Class II – 78% ± 2.5%, Class III – 77.5% ± 2.96%, Chinese – 78.1 ± 2.23, Malays – 78.1 ± 3.12,

Table 1: Distribution of ethnicities and malocclusion in the study sample

Ethnicity	Class I, *n* (%)	Class II, *n* (%)	Class III, *n* (%)	Total, *n* (%)
Malay	10 (33.3)	9 (30.0)	11 (36.7)	30 (26.8)
Chinese	27 (54.0)	14 (28.0)	9 (18.0)	50 (44.6)
Indian	15 (46.9)	14 (43.8)	3 (9.4)	32 (28.6)
Total	52 (46.4)	37 (33.0)	23 (20.5)	112

and Indians – 77.2% ±2.49%. Anterior ratio of our entire study sample differed statistically significantly from Bolton's ideal values (P = 0.01) and so did the Chinese subgroup [Table 2].

For overall ratio, all malocclusion categories and racial groups showed values slightly lower (91 ± 1.99) than Bolton's ideal value of 91.3%. No statistically significant differences in overall ratios within malocclusion or ethnic subgroups or between subgroups and Bolton's ideal values were detected (P > 0.05). Clinically significant ± 2 SD discrepancy for anterior ratio was seen in 19.6% individuals and for overall ratio was seen in 8% individuals [Table 3].

Among Class I individuals, significant positive correlation between anterior ratio and overbite (r_s = 0.30, P = 0.028), overall ratio and maxillary spacing (r_s = 0.30, P = 0.038), and significant negative correlations between overall ratio and maxillary crowding (r_s = −0.34, P = 0.014) were found [Table 4 and Figure 1].

In Class II malocclusion, statistically significant negative correlations were detected between overjet and anterior ratio among all ethnic groups and in overall study sample (r_s = −0.53, P = 0.001) except in the Indians in whom the overall ratio was strongly negatively correlated with overjet (r_s = −0.57, P = 0.034). Significant positive correlations between anterior ratio and midline shifts and overall ratio and mandibular crowding were found in both overall study participants and the Chinese [Table 5 and Figure 2].

In Class III malocclusion, highly significant positive correlations were found between both overall (r_s = 0.56, P = 0.006) and anterior ratios (r_s = 0.55, P = 0.007) and mandibular crowding. In addition, in Malays, strong negative

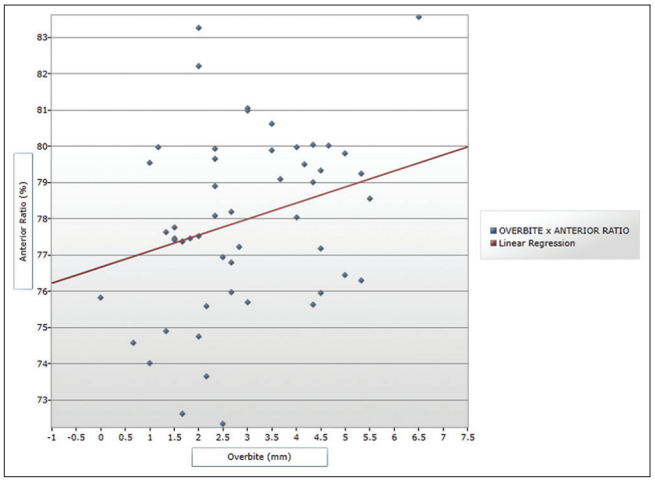

Figure 1: Scatter plot depicting positive correlation between anterior ratio and overbite in Class I malocclusion

Table 2: Mean anterior and overall ratio values in different angle's malocclusion categories and ethnic groups and their comparison with Bolton's ideal values (one-sample *t*-test)

	n	Anterior ratio, mean±SD (range)		*P*	Overall ratio, mean±SD (range)		*P*
		Present study	Bolton's study		Present study	Bolton's study	
Angle's malocclusion							
I	52	77.9±2.47 (72.3-83.5)	77.2±1.65 (74.5-80.4)	0.05	91.2±2.00 (86.4-95.9)	91.3±1.91 (87.5-94.8)	0.72
II	37	78.0±2.50 (73.7-83.2)		0.06	90.9±2.10 (86.9-95.3)		0.25
III	23	77.5±2.96 (72.6-82.8)		0.63	90.8±1.82 (87.4-93.6)		0.20
Distribution according to ethnic groups							
Malay	30	78.1±3.12 (73.3-83.5)	77.2±1.65 (74.5-80.4)	0.12	91.1±2.30 (87.1-95.9)	91.3±1.91 (87.5-94.8)	0.64
Chinese	50	78.1±2.23 (72.3-82.3)		0.01*	91.1±1.69 (86.9-95.3)		0.41
Indian	32	77.2±2.49 (72.6-82.3)		1.00	90.7±2.13 (86.4-94.9)		0.12
Total sample	112	77.8±2.57 (72.3-83.5)		0.01*	91±1.99 (86.4-95.9)		0.098

*P<0.05, statistically significant. SD – Standard deviation

Table 3: Distribution of ±2 standard deviation of anterior and overall ratio values (Chi-squared test)

	Anterior tooth size ratio			Overall tooth size ratio		
	Normal, *n* (%)	±2SD, *n* (%)	*P*	Normal, *n* (%)	±2SD, *n* (%)	*P*
Molar malocclusion						
Class I	44 (84.6)	8 (15.4)	0.316 (NS)	48 (92.3)	4 (7.7)	0.665 (NS)
Class II	30 (81.1)	7 (18.9)		33 (89.2)	4 (10.8)	
Class III	16 (69.6)	7 (30.4)		22 (95.7)	1 (4.35)	
Distribution according to ethnic group						
Malay	21 (70.0)	9 (30.0)	0.248 (NS)	26 (86.7)	4 (13.3)	0.314 (NS)
Chinese	42 (84.0)	8 (16.0)		48 (96.0)	2 (4.0)	
Indian	27 (84.4)	5 (15.6)		29 (90.6)	3 (9.4)	
Total	90 (80.4)	22 (19.6)		103 (92)	9 (8)	

NS – Not significant; SD – Standard deviation

Table 4: Spearman's rho correlation coefficient for correlation between anterior and overall ratio values and occlusal traits

Ethnicity	TSD	Correlation angle's Class I individuals						
		Overjet	Overbite	Maxillary crowding	Mandibular crowding	Maxillary spacing	Mandibular spacing	Midline shift
Malay (*n*=10)	Anterior ratio	−0.321	0.462	0.024	0.334	−0.177	−0.075	0.289
	Overall ratio	−0.152	0.547	−0.202	0.105	0.046	0.021	−0.117
Chinese (*n*=27)	Anterior ratio	0.164	0.359	−0.358	0.033	0.418*	0.119	−0.179
	Overall ratio	0.063	0.147	−0.381	0.072	0.512*	0.241	−0.324
Indian (*n*=15)	Anterior ratio	0.324	0.358	−0.269	0.206	0.240	0.262	−0.123
	Overall ratio	0.308	0.321	−0.383	0.083	0.056	0.207	−0.076
Total (*n*=52)	Anterior ratio	0.161	0.304*	−0.212	0.143	0.231	0.138	−0.076
	Overall ratio	0.082	0.246	−0.340*	0.110	0.289*	0.205	−0.182
Ethnicity	**TSD**	**Correlation angle's Class II individuals**						
		Overjet	**Overbite**	**Maxillary crowding**	**Mandibular crowding**	**Maxillary spacing**	**Mandibular spacing**	**Midline shift**
Malay (*n*=9)	Anterior ratio	−0.787*	0.184	0.264	0.051	−0.156	0.000	0.540
	Overall ratio	−0.494	0.276	0.306	−0.094	−0.485	−0.137	0.409
Chinese (*n*=14)	Anterior ratio	−0.570*	0.166	0.203	0.372	0.394	0.051	0.569*
	Overall ratio	0.031	0.466	0.207	0.558*	−0.172	0.304	0.323
Indian (*n*=14)	Anterior ratio	−0.377	−0.020	0.042	0.208	0.354	−0.273	0.237
	Overall ratio	−0.569*	0.020	0.198	0.405	0.101	−0.211	0.327
Total (*n*=37)	Anterior ratio	−0.527*	0.042	0.116	0.208	0.255	−0.059	0.402*
	Overall ratio	−0.303	0.260	0.215	0.382*	−0.058	0.041	0.260
Ethnicity	**TSD**	**Correlation Class III molar individuals**						
		Overjet	**Overbite**	**Maxillary crowding**	**Mandibular crowding**	**Maxillary spacing**	**Mandibular spacing**	**Midline shift**
Malay (*n*=11)	Anterior ratio	0.087	0.447	0.412	0.617*	−0.660*	−0.636*	0.442
	Overall ratio	0.487	−0.187	−0.070	0.492	−0.269	−0.229	0.392
Chinese (*n*=9)	Anterior ratio	0.200	−0.283	−0.339	0.324	−0.079	0.046	0.017
	Overall ratio	−0.183	−0.067	−0.068	0.420	−0.426	−0.320	−0.075
Indian (*n*=3)	Anterior ratio	-	-	-	-	-	-	-
	Overall ratio	-	-	-	-	-	-	-
Total (*n*=23)	Anterior ratio	0.233	0.067	0.139	0.549*	−0.265	−0.354	0.211
	Overall ratio	0.288	−0.168	0.000	0.556*	−0.283	−0.318	0.189

*P<0.05, statistically significant. TSD – Tooth size discrepancy

Table 5: Correlation between anterior and overall ratio values and angle's malocclusion categories (ANOVA)

Ethnicity	TSD	Class I	Class II	Class III	Total	*P*
Malay	Anterior ratio	79.1±2.86	78.9±3.43	76.5±2.64	78.1±3.12	0.082
	Overall ratio	92.1±2.37	91.2±2.49	90.3±1.88	91.1±2.30	0.189
Chinese	Anterior ratio	77.9±2.3	78.1±1.75	78.5±2.83	78.1±2.23	0.735
	Overall ratio	91.0±1.72	91.1±1.83	91.3±1.53	91.1±1.69	0.874
Indian	Anterior ratio	77.1±2.30	77.3±2.44	77.7±4.39	77.2±2.49	0.911
	Overall ratio	90.8±2.15	90.5±2.18	91.1±2.54	90.7±2.13	0.851
Total	Anterior ratio	77.9±2.47	78±2.5	77.5±2.96	77.8±2.57	0.706
	Overall ratio	91.2±2	90.9±2.10	90.8±1.82	91.0±1.99	0.697
P	Anterior ratio	0.117	0.331	0.302	0.298	
	Overall ratio	0.269	0.653	0.416	0.610	

TSD – Tooth size discrepancy

correlations between anterior ratio and maxillary (r_s = −0.66, P = 0.027) and mandibular spacing (r_s = −0.64, P = 0.035) were observed [Table 4 and Figure 3]. No correlation between Bolton's anterior and overall ratio and malocclusion categories or ethnicity was detected (P > 0.05) [Table 5].

Discussion

Our study investigated the occlusal traits and tooth size discrepancies in Malaysian orthodontic patients and their interrelationships. The Malaysian population consists of three mainstream ethnic groups – Malays (63.1%),

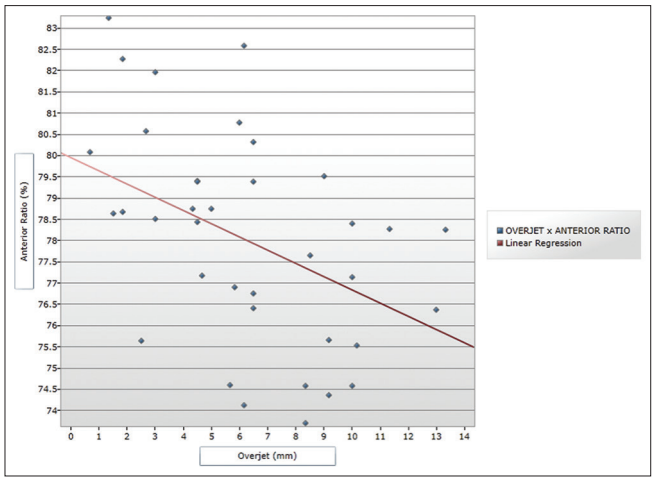

Figure 2: Scatter plot depicting negative correlation between anterior ratio and overjet in Class II malocclusion

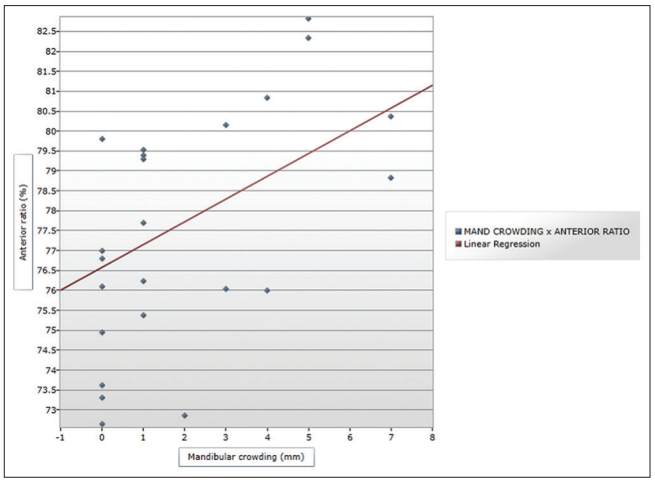

Figure 3: Scatter plot depicting positive correlation between anterior ratio and mandibular crowding in Class III malocclusion

Chinese (24.6%), and Indians (7.3%)[36] However, in our study, the distribution of patients was Chinese – 44.6%, Indians – 28.6%, and Malay – 26.8% indicating the pattern of seeking private dental services in our institution among ethnicities.

Tooth size discrepancy

The mean overall ratio for total samples in our study was 91%, slightly lower than Bolton's ideal of 91.3% with no significant difference between the two and the mean anterior ratio was 77.8% which was statistically significantly higher than Bolton's ideal value of 77.3% (P = 0.01) [Table 2]. This finding was in agreement with Rahman and Othman who conducted a similar study on the 3 ethnic groups of Malaysian population.[28] Ling and Wong[37] and Yuen *et al*.[38] found the mesiodistal width of mandibular anteriors in Asians to be larger as compared to Caucasians, which could have led to the higher anterior ratio values than ideal in Malaysian studies and also the finding of statistically significant higher anterior ratio value (78.1 ± 2.23) among Chinese samples when compared to Bolton's ideal value in our study (P = 0.01). Significant differences in anterior ratio from Bolton' values were also noted in American Dominican,[9] Japanese,[31] Spanish,[34] and Peruvian[34] populations with malocclusion indicating ethnic groups differ more in the size of their anterior teeth than the posteriors.

The Malays and Chinese showed similar mean anterior ratios which were greater than Bolton's ideal (78.1% ± 3.12, 78.1% ± 2.23) and overall ratio values which were lesser than ideal (91.1% ±2.3, 91.1%±1.69) and Indians had lowest mean values (77.2 ± 2.49, 90.7 ± 2.13 respectively) [Table 2]. This could imply larger mandibular anteriors in Malays and Chinese and larger maxillary teeth in Indians, which also correlates with occurrence of higher prevalence of Class III and Class II malocclusion, respectively, in these ethnicities. However, no statistically significant differences were found in both ratios, when the three ethnic groups and malocclusion categories were compared with each other (P > 0.05). Rahman and Othman[28] however found a significant difference for both anterior ratio (P = 0.004) and overall ratio (P = 0.015) between Malays and Chinese in their study.

The range for anterior and overall ratios in the present study was 72.3%–83.5% and 86.4%–95.9%, respectively. Both ratios in our study were more widely dispersed as indicated by larger SD and wider ranges of ratios as compared to Bolton's ideal range of 74.5%–80.4% and 87.5%–94.8%, respectively [Table 2]. Bolton's values were derived from individuals with "excellent occlusion"[2] whereas all our study participants had malocclusion, and it has been implied that tooth size could be a factor in the etiology of malocclusion, which could explain the observation of more discrepancies in our study.

When the ratio values of different categories of malocclusion in our study were compared with Bolton's values, no statistically significant difference was detected similar to other studies[5,7,10,13] [Table 2]. As observed by Crosby and Alexander,[5] Akyalçin *et al*.,[10] O'Mahony *et al*.,[14] and Uysal and Sari,[15] no difference in Bolton's values between malocclusion categories was detected in our study either. Mean values for anterior ratio were in the order of Class II > Class I > Class III, with Class III value (77.5%) being lowest and closest to Bolton's ideal. This finding contradicted all other studies where they found highest mean values in Class III malocclusion.[16-18,30] This could be due to ethnic differences, sample size variations, and lack of differentiation of malocclusion according to skeletal pattern in our study. For overall ratio, the order was Class II < Class III < Class I, with Class I value (91.2%) being highest and closest to Bolton's ideal, but differences were not statistically significant.

The level of clinically significant ± 2 SDs for anterior ratio in the current study was seen in 19.6%, which was closer

to the figures of 22.9% by Crosby and Alexander,[5] 21% by Paredes *et al*.,[29] 21.3% by Uysal and Sari,[15] 20.5% by Bernabé *et al*.,[39] 17.4% by Othman and Harradine,[8] and 16.28% by Strujić *et al*.,[20] but lower than in studies by Al-Omari (23.7%),[40] Santoro *et al*. (28%),[9] Freeman *et al*. (30.6%),[7] Wedrychowska-Szulc *et al*. (31.2%),[30] and Othman *et al*. (47.5%).[41] For overall ratio, 8% individuals had ± 2 SDs, closer to values of 9.5% by Al-Omari,[40] 10% by Othman *et al*.,[41] 10.2% by Wedrychowska-Szulc *et al*.,[30] 11% by Santoro *et al*.,[9] lower than the values of 13.4% by Freeman *et al*.[7] and 15.35% by Uysal and Sari[15] and higher than the values in studies by Strujić *et al*. (4.32%),[20] Paredes *et al*. (5%),[29] Bernabé *et al*. (5.2%),[39] and Othman and Harradine (5.2%).[8] Similar to previous studies, discrepancies were more in the anterior ratio as compared to overall ratio [Table 3]. Crosby and Alexander[5] rationalize that this could be due to anterior teeth, especially incisors, displaying the greatest variability in size or it could also be due to the mesiodistal width of anteriors having less mathematical impact in overall ratio calculation as mentioned by Othman and Harradine.[8]

Maximum percentage of clinically significant discrepancy for anterior and overall ratios was seen in Class III (30.4%) and Class II (10.8%) malocclusion categories, respectively. Among racial groups, Malay individuals had the highest percentage of cases with anterior ratio discrepancy (30%) and also overall ratio discrepancy (13.3%), which could be the result of Malays having the highest proportion of individuals with Class III malocclusion [Tables 1 and 3]. However, differences between groups were not statistically significant.

Correlation

In Class I malocclusion category, significant positive correlation between anterior ratio and overbite [Figure 1] and overall ratio and maxillary spacing was detected implying that increase in size of mandibular teeth is accommodated by deepening of bite and spacing in maxillary arch. Among ethnicities, Chinese had a significant correlation between both anterior and overall ratio with maxillary spacing, which is also in line with the finding of statistically significant higher anterior ratio values in them as compared to Bolton's norms. In addition, as the size of the maxillary posteriors increased, overall ratio decreased and maxillary crowding increased as indicated by the significant negative correlations between overall ratio and maxillary crowding (r_s = −0.34, P = 0.014) [Table 4].

In Class II, malocclusion statistically significant strong negative correlations were detected between overjet and anterior ratio among Malay and Chinese ethnic groups and in overall study sample (r_s = −0.53, P = 0.001) which means that when molar relationship is Class II, as maxillary anterior tooth size increases, overjet also increases as a result [Figure 2]. In the Indians, however, the overall ratio was strongly negatively correlated with overjet (r_s = −0.57, P = 0.034). The Indians had the lowest mean values of anterior and overall ratio, 77.2% and 90.7% respectively, implying larger maxillary tooth size as compared to other two races. They also had the highest percentage of Class II malocclusion which is associated with larger maxillary teeth.[30,39] Lopatiene and Dumbravaite also found moderate correlation between overall ratio and overjet and weak correlation between overall ratio and overbite among all study participants.[11] They concluded that a 1 mm increase in overjet resulted in a 0.55% decrease in Bolton ratios.

Significant correlations were also detected between anterior ratio and midline shift, similar to Alam and Iida's study[12] whereas Akyalçin *et al*.[10] detected this correlation in Class I cases. Mandibular crowding moderately correlated with overall ratio at statistically significant levels both in total sample and Chinese subgroup (r_s = 0.382, P = 0.02; r_s = 0.56, P = 0.038; respectively) similar to findings of Norderval *et al*.[42] Although Bernabé *et al*. also found anterior and overall ratios to be significantly higher in crowded dentitions, they concluded that differences were clinically insignificant (<1 mm).[39]

In Angle's Class III malocclusion, highly significant positive correlations were found between both overall (r_s = 0.56, P = 0.006) and anterior ratios (r_s = 0.55, P = 0.007) and mandibular crowding [Table 4]. Lundstrom[43] found that cases with large teeth in one jaw in relation with the other will have a tendency for greater crowding in the jaw with larger teeth, and the larger size of mandibular teeth in Class III cases could be the etiological factor in mandibular crowding. Anterior ratio showed strong significant positive correlations with mandibular crowding [Figure 3] and strong negative correlations with maxillary (r_s = −0.66, P = 0.027) and mandibular spacing (r_s = −0.64, P = 0.035), among the Malay group [Table 4]. Negative correlation with maxillary spacing could be due to smaller-sized maxillary teeth in Class III cases. Bolton's anterior and overall ratio values of none of the malocclusion categories had a significant correlation with ethnicity (P > 0.05) [Table 5], indicating TSDs are reflected more in occlusal features such as overjet, overbite, crowding, spacing, and midline shifts rather than molar relationship *per se*.

The present study was carried out in orthodontic patients; hence, the distribution of malocclusion and ethnicities are not representative of general population characteristics. Patients' ethnicity was based on their self-reporting and not on tracing the ancestry or genealogical pool. In multicultural ethnic populations, the two methods could lead to different inferences since frequent mixing and intermarriages of ethnicities could lead very easily to crossover of one ethnic group into the other in a single generation itself, thus confounding the results. We also grouped malocclusions based only on molar relationship,

which could be different from the underlying skeletal relationship which we did not consider in our study. Future studies may bear these limitations in mind and overcome them while designing their research methodology.

Tooth size and proportion are crucial components of microesthetic evaluation in orthodontic diagnosis and treatment planning to maximize improvement in appearance of patients.[44] Assessing the TSD and identifying the traits of malocclusion it is associated with, are crucial for precision, accuracy and efficiency of orthodontic procedures employed. Lack of knowledge regarding this association may lead to misdiagnosis and failure of treatment since "the eye cannot see what the mind does not know". Problems in tooth size proportions are usually noticed in the finishing stages of treatment in the form of mild, residual deepbites or overjets or mismatched midlines that seem resistant to correction. Understanding that these features could have their root cause in the mismatched maxillary and mandibular tooth widths could then lead one to adjusting the tooth size either through restorations or buildups or interproximal reduction, thus ensuring a successful orthodontic treatment result. Having this prior knowledge can help in anticipating issues that can be potentially encountered in a particular type of malocclusion or ethnicity, which can then be preempted by effective treatment planning.

Conclusions

1. The mean anterior ratio value of Malaysian orthodontic patients – 77.8 ± 2.57 – was statistically significantly higher than Bolton's ideal whereas overall ratio was lower than Bolton's ideal (91 ± 1.99, $P > 0.05$)
2. Anterior ratio of Chinese was significantly higher than Bolton's ideal values
3. Anterior ratios were in the order of Class II > Class I > Class III, and for overall ratio, Class I > Class III > Class II. Differences between malocclusion categories were not significant
4. Among ethnicities, for both anterior and overall ratios, values were in the order of Malay = Chinese > Indians, with differences not being statistically significant
5. Clinically significant ± 2 SD discrepancy occurred in 19.6% for anterior ratio and 8% for overall ratio
6. In Class I malocclusion, significant correlations of anterior ratio were found with overbite and of overall ratio with maxillary spacing and maxillary crowding
7. In Class II malocclusion, significant correlations of anterior ratio were found with overjet and midline shift and of overall ratio with overjet and mandibular crowding
8. In Class III malocclusion, significant correlations of anterior ratio were found with mandibular crowding and spacing in maxilla and mandible and of overall ratio with mandibular crowding.

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Conflicts of interest

There are no conflicts of interest.

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