Original Article

Bolton Tooth Size Discrepancies in Skeletal Class I Individuals Presenting with Different Dental Angle Classifications

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ABSTRACT
The objective of this study was to investigate the frequency and association of Bolton tooth size discrepancies with dental discrepancies. Forty-eight skeletal Class I, 60 Class II, and 44 Class III subjects with similar skeletal characteristics were included in this study. Analysis of variance was performed to compare the mean ratios of Bolton analysis as a function of the Angle classification and sex. To determine the prevalence of tooth size imbalances among the three groups of occlusions and the two sexes, chi-square tests were performed. To determine the correlation of tooth size imbalances with certain dental characteristics, Pearson's correlation coefficients were calculated. No statistically significant differences were determined for the prevalence of tooth size discrepancies and the mean values of Bolton's anterior and overall ratios among the occlusal groups and sexes. Bolton's anterior ratio discrepancies had significant correlations with midline shifts ($P < .05$) in Angle Class I cases, with U1-SN angle ($P < .01$) in Angle Class II cases, and with L1-APog distance ($P < .05$) in Angle Class III cases. Bolton discrepancies related to overall ratio had significant correlations with overjet ($P < .05$) in Class I cases, with overbite ($P < .05$) and U1-SN angle ($P < .01$) in Class II cases, and with IMPA ($P < .01$) in Class III cases. A high prevalence of tooth size discrepancies in an orthodontic patient population and the statistically significant correlation of some of these with some dental characteristics suggest that the measurement of interarch tooth size ratios might be clinically beneficial for treatment outcomes.

KEY WORDS: Bolton tooth size discrepancy; Malocclusion; Dental discrepancies

INTRODUCTION

A proper balance should exist between the mesiodistal tooth size of the maxillary and mandibular arches to ensure proper interdigitation, overbite, and overjet at the completion of orthodontic treatment. Bolton's method of diagnosing tooth size discrepancies by analyzing the mesiodistal tooth size ratio between the maxillary and mandibular teeth has been widely used in scientific studies since its publication.[1,2]

Various studies have investigated ethnic[3–10] and sex[11–13] differences in the intermaxillary tooth ratios. In fact, tooth development is a matter of both genetic and environmental factors. As in other physical properties of human beings, teeth vary in size between the two sexes and among individuals from different geographical regions.

Lavelle,[4] studied anterior tooth size in 160 subjects and stated that the teeth in the lower arch are larger in Class III cases than in Class I and II cases, with the inference that a Bolton discrepancy is greater in Class III cases than in the other malocclusion groups. Similarly, Sperry et al,[14] concluded that the frequency of mandibular tooth size excess (overall ratio) was greater in cases of mandibular prognathism than in Angle Class I and Class II cases. They also stated that in those cases with mandibular tooth size excess, there was a suggestion that the magnitude of the excess was greater in cases of mandibular prognathism than

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TABLE 1. Descriptive Statistics of the Sample

	Angle Class I	Angle Class II	Class III
N	48 (26 Females, 22 Males)	60 (32 Females, 28 Males)	44 (20 Females, 24 Males)
Age	14.75 ± 1.21	13.75 ± 1.52	15.20 ± 1.63
ANB	2.6 ± 1.1	3.1 ± 0.6	2.2 ± 0.5
SNGOGN	34.6 ± 2.3	33.3 ± 3.2	34.2 ± 2.7
Post Σ	395 ± 2.7	394 ± 3.09	395 ± 2.7

in Angle Class I and Class II cases. Araujo and Souki[15] reported that the mean anterior tooth size discrepancy for Angle Class III subjects was significantly greater than that for Class I and Class II subjects. Nie and Lin[16] demonstrated that a significant difference was found for intermaxillary tooth size ratios among different malocclusion groups, with the ratios showing that Class III > Class I > Class II. Furthermore, they added that intermaxillary tooth size discrepancy might be one of the important factors in the cause of malocclusions.

Alkofide and Hashim,[17] however, determined no significant difference in the incidence of tooth size discrepancies existed for the overall ratio and anterior ratio between the different malocclusion groups, except for the anterior ratio in Class III malocclusion. Crosby and Alexander,[18] also reported no difference in the incidence of tooth size discrepancies from one malocclusion group to another, but they did not include Class III subjects in their sample.

These previously published studies did not distinguish between skeletal and dental anomalies. The novel aspect of this report is the hypothesis that a Bolton tooth size discrepancy might be associated with the occlusion in terms of creating dental discrepancies. To investigate the correlations of intermaxillary tooth size imbalances with occlusion and dental discrepancies, this study included 152 white subjects of similar skeletal growth pattern presenting with different Angle classifications. The premise was that when skeletal anomalies and differential growth pattern of the jaws are eliminated, any associations of Bolton tooth size discrepancies with dental characteristics can better be determined. Therefore, besides presenting the frequencies of tooth size imbalances and mean values of Bolton's anterior and overall ratios for Angle Class I, Angle Class II, and Angle Class III subjects of same skeletal pattern, we also aimed to determine whether there was a relationship between intermaxillary tooth size discrepancy and certain dental characteristics.

MATERIALS AND METHODS

Pretreatment lateral cephalometrics and dental casts of 850 cases, chosen from the records of the Ege University School of Dentistry, Department of Orthodontics, were investigated. Steiner's ANB and GoGnSN angles and Bjork's sum of posterior angles were used for distinguishing skeletally normal patients from individuals with skeletally Class II, Class III, and vertical anomalies. Only the cases presenting with 1° to 4° of ANB, 27° to 37° of GoGnSN, and 392° to 400° of Bjork's angle of sums were included.

All the study casts were of good quality and had been taken between the ages of 12 and 15 years, with all the teeth (except than the third molars) completely erupted. Care was taken not to include casts with tooth deformities, mesiodistal restorations or abrasion, or all. The sample included 48 Angle Class I, 60 Angle Class II, and 44 Angle Class III subjects forming a final sample of 152 subjects (Table 1). All subjects had skeletal Class I jaw relationships and a normal vertical growth pattern. Sample sizes were uneven because of the selection of all available cases.

On the dental cast of each patient, each tooth from the maxillary and mandibular right first molar to the left first molar was measured at the largest mesiodistal dimension to the nearest 0.01 mm, using a digital caliper with a LCD (liquid crystal display) digital output. Bolton's anterior and overall ratios, molar relationship (mm), overjet (mm), overbite (mm), curve of Spee (mm), midline discrepancy (mm), and dental crowding according to Hays-Nance (mm) were determined for each subject (Table 2).

To further compare the cephalometric positions of the incisors of the three groups of individuals, additional data were obtained from lateral cephalometric films (Table 2). All radiographs were taken on the same cephalostat with the patient in a standing position, the teeth in centric occlusion, and the Frankfort plane parallel to the horizontal.

All the measurements were performed by the same investigator. Thirty individuals (10 from each group) were randomly selected from the sample and remeasured at 1-month intervals by the same individual investigator to ensure measurement accuracy, using the Wilcoxon nonparametric test. No statistically significant differences were found ($P > .05$). Analysis of variance (ANOVA) was performed to compare the mean ratios of the Bolton analysis as a function of the Angle classification and sex. To present the prevalence of tooth size imbalances among the three study groups of malocclusion and the two sexes, chi-square tests were used. To further determine the correlations of

TABLE 2. Measurements Included in the Study

Dental Cast Measurements	
Bolton's anterior ratio	Sum mandibular 3–3/sum maxillary 3–3.
Bolton's overall ratio	Sum mandibular 6–6/sum maxillary 6–6.
Molar relationship (mm)	The distance of the mesiobuccal cusp of the maxillary first molar to the buccal groove of the mandibular first molar. Calculated both for left and right sides.
Overjet (mm)	Horizontal overlap of the incisors.
Overbite (mm)	Vertical overlap of the incisors.
Curve of Spee (mm)	The depth of curve of Spee calculated for mandibular arch.
Midline discrepancy (mm)	The distance between the maxillary and mandibular midlines. Recorded both as to the left and to the right side in case of midline shift.
Dental crowding (mm)	Present arch length minus the necessary arch length.
Cephalometric Measurements	
U1-SN°	The angle formed by the intersection of the upper incisor to anterior cranial base.
IMPA°	The angle formed by the intersection of the lower incisor to mandibular plane.
L1-APog (mm)	The linear distance between APog line and the mandibular incisor.

TABLE 3. Mean Ratios of Bolton Anterior Analysis Compared by ANOVA as a Function of Angle Classification and Sex[a,b]

Sex	Group	Mean	SD	N	ANOVA
Females	Class I	77.92	3.58	26	
	Class II	78.64	4.02	32	NS
	Class III	76.82	3.93	20	
Males	Class I	78.43	3.37	22	
	Class II	78.21	4.35	28	NS
	Class III	79.04	3.01	24	
Total	Class I	78.15	3.42	48	
	Class II	78.44	4.11	60	NS
	Class III	78.03	3.66	44	

[a] Comparison among the groups $P = .894$: for $\alpha = 0.95$, power $= 0.58$. Comparison between the sexes $P = .386$; $\alpha = 0.95$, power $= 0.66$.
[b] ANOVA indicates analysis of variance; NS, not significant.

TABLE 4. Mean Ratios of Bolton Overall Analysis Compared by ANOVA as a Function of Angle Classification and Sex[a,b]

Sex	Group	Mean	SD	N	ANOVA
Females	Class I	91.13	2.28	26	
	Class II	90.83	3.01	32	NS
	Class III	89.61	2.84	20	
Males	Class I	91.58	2.46	22	
	Class II	90.65	2.93	28	NS
	Class III	91.81	1.96	24	
Total	Class I	91.34	2.32	48	
	Class II	90.75	2.92	60	NS
	Class III	90.81	2.59	44	

[a] Comparison among the groups $P = .177$; for $\alpha = 0.95$, power $= 0.70$. Comparison between the sexes $P = .272$; $\alpha = 0.95$, power $= 0.64$.
[b] ANOVA indicates analysis of variance; NS, not significant.

tooth size imbalances with molar relationship, overjet, overbite, curve of Spee, midline discrepancy, dental crowding, and cephalometric positions of the incisors, Pearson's correlation coefficients were calculated.

RESULTS

The mean anterior and overall ratios for males and females in each occlusal category are presented in Tables 3 and 4. ANOVA revealed no statistically significant differences among the three occlusal groups ($P = .894$ for anterior ratio and $P = .177$ for overall ratio) or between the two sexes ($P = .386$ for anterior ratio and $P = .272$ for overall ratio) when Bolton' anterior and overall ratios were compared as a function of sex and malocclusion classification. No interaction was determined between sex and malocclusion group ($P = .460$ for anterior ratio and $P = .526$ for overall ratio). The distribution of sex among our three study groups was determined to be reasonable by chi-square testing ($P = .807$).

To determine the prevalence of tooth size discrepancies among the three occlusal categories and the two sexes, the individuals were classified as ''normal'' for the Bolton's anterior and overall ratios when they were within ±1 SD. No significant differences were determined in the Bolton anterior ($P = .449$) and overall ($P = .704$) tooth size prevalence between the two sexes (Tables 5 and 6). Again, no significant differences were determined in the Bolton anterior ($P = .689$) and overall ($P = .906$) tooth size among the three malocclusion categories (Tables 7 and 8).

TABLE 5. Results of Chi-square Testing Demonstrating No Significant Difference ($P > .05$) in the Prevalence of Tooth-size Discrepancy Between Females and Males

Anterior Ratio	Females (%)	Males (%)
$<$Bolton ± SD	22 (64.7)	12 (35.3)
Bolton ± SD (normal)	32 (48.5)	34 (51.5)
$>$Bolton ± SD	24 (46.2)	28 (53.8)

The correlations of tooth size discrepancies with occlusal discrepancies in each group were determined by calculating the Pearson's correlation coefficients. The results are presented in Table 9. According to the results of this study, tooth size discrepancy did not

TABLE 6. Results of Chi-square Testing Demonstrating No Significant Difference ($P > .05$) in the Prevalence of Tooth-size Discrepancy Between Females and Males

Overall Ratio	Females (%)	Males (%)
<Bolton ± SD	20 (58.8)	14 (41.2)
Bolton ± SD (normal)	40 (51.3)	38 (48.7)
>Bolton ± SD	18 (45)	22 (55)

TABLE 7. Results of Chi-square Testing Demonstrating No Significant Difference ($P > .05$) in the Prevalence of Tooth-size Discrepancy Among the Three Study Groups

Anterior Ratio	Class I (%)	Class II (%)	Class III (%)
<Bolton ± SD	14 (41.2)	14 (41.2)	6 (17.6)
Bolton ± SD (normal)	18 (27.3)	24 (36.4)	24 (36.4)
>Bolton ± SD	16 (30.8)	22 (42.3)	14 (26.9)

TABLE 8. Results of Chi-square Testing Demonstrating No Significant Difference ($P > .05$) in the Prevalence of Tooth-size Discrepancy Among the Three Study Groups

Overall Ratio	Class I (%)	Class II (%)	Class III (%)
<Bolton ± SD	10 (29.4)	16 (47.1)	8 (23.5)
Bolton ± SD (normal)	24 (30.8)	28 (35.9)	26 (33.3)
>Bolton ± SD	14 (29.2)	16 (40)	10 (25)

have any statistically significant correlation with the molar relationship in skeletal Class I and normal divergent individuals, which indicated that a tooth size discrepancy was not the cause of the malocclusion. However, statistical data revealed a statistically significant relation between some of the variables and Bolton tooth size discrepancies. Anterior ratio imbalances had significant correlations with midline shift ($P < .05$) in Angle Class I cases, with U1-SN ($P < .01$) in Angle Class II cases, with L1-APog distance ($P < .05$) in Angle Class III cases. The discrepancies in the overall ratio had correlations with overjet ($P < .05$) in Class I cases, overbite ($P < .05$) and U1-SN angle ($P < .01$) in Class II cases, and IMPA ($P < .01$) in Class III cases.

DISCUSSION

The original Bolton[1,2] norms were calculated using 55 models with excellent occlusion, of which 44 were orthodontically treated. Bolton's estimates of variation were underestimated because his sample was derived from perfect Class I occlusions. The population and sex composition of Bolton's sample was not specified, which implies potential selection bias.[7] Therefore, our results were not directly compared with Bolton norms.

According to statistical data, the mean values of anterior and overall ratios were not statistically significant between the two sexes and among the three malocclusion groups. However, our three malocclusion groups showed a high incidence of Bolton tooth size discrepancies, which might have affected the mean values of the groups. Ethnic characteristics[3–10] and greater morphologic variability[16,19,20] in upper incisor width are believed to affect the anterior ratio, which was found to be slightly higher than the Bolton[1,2] norms (77 ± 1.6) in our study.

In addition, this study contained a larger dispersion from high to low within each group when compared with that of Bolton. Crosby and Alexander[18] also verified similar high standard deviations and ranges. They suggested that this might be the result of differences in the samples because Bolton[1,2] originally included 44 treated and 11 untreated good occlusion casts in his study. It has also been suggested that mesiodistal maxillary tooth sizes are smaller in Class III subjects, and this might serve as an explanation of anterior Bolton tooth size discrepancy. However, these studies[4,14–16] included skeletal Class III subjects, and a direct comparison with our study would be somewhat disputable because of the morphological differences of the samples.

The prevalence of intermaxillary tooth size discrepancies were reported to be statistically higher in Class III individuals[9,14–16] possibly because of different morphologic characteristics. In a study group of individuals with the same skeletal pattern, no significant differences were found in the Bolton tooth size prevalence as a function of sex and malocclusion category. However, the prevalence of Bolton anterior and overall tooth size discrepancies was found to be very high in the sample of this study. Of the 154 individuals involved in this study, 86 (55.8%) had an anterior tooth size ratio discrepancy, whereas 74 (48%) had an overall tooth size ratio discrepancy. The values in this study were greater than that of Bolton, who reported anterior tooth size discrepancies greater than ±1 SD in 29% of the patients studied in his private practice. Richardson and Malhotra[5] also verified similar discrepancies in 33.7% of their patients. The results of this study were closer to the findings of Bernabe et al[10] and Araujo and Souki.[15] Araujo and Souki[15] stated that the higher percentage of tooth size discrepancy in their sample might be explained by the strong genetic mix of the Brazilian population. Because the present sample consisted of patients who applied for orthodontic treatment, the presence of a larger percentage of tooth size discrepancies than that in Bolton's[1,2] sample seems reasonable.

Recently, 2 SD outside the Bolton's mean ratio have been accepted as a clinically significant ratio for determining tooth size discrepancy.[8,18,20] However, according to Bernabe et al,[10] even the 2 SD range from the Bolton standard did not predict clinically significant anterior and total-width ratio discrepancies. They used

TABLE 9. Correlations Between Intermaxillary Tooth-size Discrepancies and Dental Characteristics of the Groups

	Bolton Anterior Ratio		Bolton Overall Ratio	
Correlations	Pearson's Correlation	*P*	Pearson's Correlation	*P*
Class I Subjects				
Right molar relationship	—	—	—	—
Left molar relationship	—	—	—	—
Overjet	−0.398	.054	−0.473	.020*
Overbite	−0.296	.161	−0.183	.392
Curve of Spee	−0.169	.431	−0.108	.615
Midline shift to left	0.494	.014*	0.370	.075
Midline shift to right	−0.123	.568	−0.118	.584
Maxillary crowding	−0.234	.270	−0.198	.354
Mandibular crowding	−0.250	.238	−0.270	.246
U1-SN°	−0.074	.732	−0.158	.462
IMPA°	0.244	.251	0.340	.104
L1-APog	0.124	.563	−0.059	.785
Class II Subjects				
Right molar relationship	0.014	.943	0.009	.961
Left molar relationship	−0.064	.736	−0.056	.769
Overjet	−0.091	.631	−0.015	.939
Overbite	−0.340	.066	−0.362	.049*
Curve of Spee	−0.238	.206	−0.088	.153
Midline shift to left	0.031	.872	−0.024	.901
Midline shift to right	0.190	.314	0.185	.326
Maxillary crowding	0.025	.897	0.153	.419
Mandibular crowding	−0.080	.675	−0.072	.704
U1-SN°	0.489	.006**	0.623	.000**
IMPA°	−0.197	.296	−0.222	.237
L1-APog	0.232	.217	0.062	.744
Class III Subjects				
Right molar relationship	−0.100	.659	0.065	.773
Left molar relationship	0.270	.223	0.017	.940
Overjet	−0.344	.117	−0.120	.596
Overbite	−0.332	.131	−0.252	.258
Curve of Spee	−0.376	.085	−0.280	.206
Midline shift to left	−0.141	.531	−0.060	.792
Midline shift to right	0.169	.451	0.058	.797
Maxillary crowding	0.270	.224	0.383	.078
Mandibular crowding	0.294	.184	0.350	.110
U1-SN°	0.144	.523	0.277	.213
IMPA°	0.246	.269	0.572	.005**
L1-APog	−0.442	.039*	−0.311	.160

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

average maxillary and mandibular tooth sums from their sample of 200 children to estimate the millimeter discrepancies in tooth size beyond the 2 SD range from Bolton's mean. On the basis of their sample averages, 2 SD from the Bolton's mean for the anterior ratio is probably clinically significant for the low range (−2 SD) but not for the high range (+2 SD), whereas 1 SD from the Bolton's mean for the total ratio is probably clinically significant.

Therefore, rather than to conclude that either one or 2 SD outside the Bolton's mean ratio was a clinically significant ratio when determining tooth size discrepancy, correlations between interarch tooth size discrepancy and certain dental characteristics were calculated. Recently, Redahan and Lagerström[21] investigated the pre- and posttreatment relationship between anterior interarch tooth size ratio and various dental and skeletal variables. Their pretreatment bivariate regression analysis failed to show a relationship ($P < .05$) between any of the variables. However, they investigated a random sample and did not specify the occlusal characteristics.

In this study, Pearson's correlation analysis determined that various dental characteristics were statistically related to the interarch tooth size discrepancies in different occlusal categories (Table 9). For example, in individuals presenting with Class I molar relationship, a maxillary overall tooth size excess might lead to an increase in overjet, whereas an anterior tooth size excess might lead to midline shift. A tooth size discrepancy was also found to be associated with the inclinations of the maxillary and mandibular incisors in individuals presenting with Class II and Class III molar relationships. A mandibular tooth size excess brought about an increase in maxillary incisor inclination (U1-SN angle) and a decrease in overbite in Class II subjects. This might be possible when considering the dentoalveolar compensation mechanism, which has a direct role in achieving better function. Essentially, the subject has an underlying skeletal Class I jaw relationship, and the maxillary incisors tip forward to function with the mandibular arch when there is excess tooth material present.

The reverse might be true when considered in this manner. There appears to be a natural compensation in the anterior region. According to results of this study, the response of the mandibular incisors in Class III molar subjects was not as clear when an interarch tooth size discrepancy was present. The change in L1-APog distance was statistically related to an anterior tooth size discrepancy and seemed to be somewhat the same as described for the U1-SN angle in Class II subjects. However, when an overall mandibular tooth size excess existed, the IMPA angle seemed to increase relatively. This kind of tooth size discrepancy could be related to future posttreatment relapse in the mandibular incisor area, especially if there is an existing mandibular anterior tooth size excess that is left untreated.[18]

Above all, it is very difficult to measure the laws of nature and its adaptations. Although a large individual variability might have existed in the growth pattern of the subjects and the sample size was small, a tooth size discrepancy potentially altered some of the dental relations in orthodontic patients. Therefore measurement of interarch tooth size ratios before treatment is clinically beneficial for future expectations. In the light of the present findings, it is suggested that a follow-up study regarding the changes of occlusal characteristics in a similar group of individuals with Bolton intermaxillary tooth size discrepancies will be very beneficial.

CONCLUSIONS

- In a skeletally similar sample of 152 subjects, no statistically significant differences were determined for the Bolton anterior and overall tooth size prevalence and means among the Angle Class I, II, and III groups. Sex also was not discriminating.
- Molar relationships did not relate to intermaxillary tooth size discrepancies. A Bolton's anterior and overall ratio discrepancy did not affect the occlusion in this manner.
- Statistically significant correlations between various dental characteristics and intermaxillary tooth size discrepancies were determined. Therefore, an orthodontist should be aware of such discrepancies and their probable effects on occlusion and dental relations when solving the malocclusion jigsaw.

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