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Tooth size discrepancy in orthodontic patients among different malocclusion groups

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SUMMARY An appropriate relationship of the mesiodistal (MD) widths of the maxillary and mandibular teeth favours optimal post-treatment results. The aims of this study were to determine whether there is a difference in the incidence of tooth size discrepancies among different skeletal malocclusion groups and if gender dimorphism exists.

The dental casts and lateral cephalometric radiographs of 301 Croatian subjects (127 males and 174 females, mean age 16.86 ± 2.93 years) were selected from a larger sample of records of the archives of the Orthodontic Department, School of Dental Medicine, University of Zagreb, Croatia. The subjects were from malocclusion groups according to Angle classification, with the corresponding skeletal characteristics. The MD dimensions of all teeth from first molar to first molar were measured on the dental casts using digital callipers. Statistical analysis was undertaken using Kolmogorov–Smirnov, *t*, and Scheffé's tests and one-way analysis of variance.

A statistically significant gender difference was found in anterior ratio ($P = 0.017$). A significant difference in the overall and posterior ratio was observed between Class II and Class III subjects. There was a tendency for mandibular tooth size excess in subjects with an Angle Class III malocclusion and for maxillary tooth size excess in those with an Angle Class II malocclusion. The percentage of subjects more than 2 standard deviations from Bolton's means for anterior and overall ratios was 16.28 and 4.32, respectively.

Introduction

A correct maxillary to mandibular tooth size ratio is important for the achievement of correct occlusal interdigitation, overjet, and overbite. Without an appropriate relationship of mesiodistal (MD) tooth dimensions of the maxillary and mandibular teeth, coordination of the arches would be difficult with consequences on the final orthodontic treatment result and its stability (Ballard, 1944; Neff, 1957; Bolton, 1958, 1962).

Bolton (1958) studied tooth size dimensions and their effect on occlusion. Stifter (1958) replicated the Bolton study in Class I dentitions and reported similar results. Previously published indices (Pont, 1909; Howes, 1947; Rees, 1953; Neff, 1957; Lundström, 1981) have been used to assess the relationship that exists between tooth dimensions and supporting bone as well as to predict final tooth positions.

Bolton (1958, 1962) suggested that a ratio greater than 1 standard deviation (SD) from the mean values indicated a need for diagnostic consideration and possible treatment. Other authors (Crosby and Alexander, 1989; Freeman *et al.*, 1996) have defined a significant discrepancy as a value outside 2 SD from Bolton's mean. Araujo and Souki (2003) also found a high proportion of patients with anterior tooth size discrepancies, but they defined a discrepancy as greater than ±1 SD from Bolton's mean ratio. Because different tooth sizes have been associated with ethnicity (Moorrees *et al.*, 1957; Lavelle, 1972; Buschang *et al.*, 1988; Smith *et al.*, 2000), it is logical to expect that differences in tooth widths can directly affect tooth-widths ratios. Since gender tooth size differences are not systematic across all teeth (Garn *et al.*, 1967; Lavelle 1972; Bishara *et al.*, 1989), different interarch relationships might be expected. The relationships between different malocclusion groups and tooth size discrepancy have been reported previously (Lavelle, 1972; Crosby and Alexander, 1989; Freeman *et al.*, 1996; Ta *et al.*, 2001; Fatahi *et al.*, 2006; Puri *et al.*, 2007).

The aims of the current study were to determine (1) whether there is a difference in the incidence of tooth size discrepancies among different malocclusion groups, classified according to Angle, which coincided with skeletal categories (Class I, Class II, and Class III) represented by anterior, overall, and posterior ratio; (2) the percentage of tooth size discrepancies outside 2 SD from Bolton's means for tooth ratios in each malocclusion group and in the overall sample; and (3) whether gender dimorphism exists for tooth size ratios.

Materials and methods

Dental casts and lateral cephalometric radiographs of Croatian subjects aged 13–22 years (mean age 16.86 ± 2.93 years) was collected from the archives of the Department of Orthodontics, University of Zagreb, Croatia. The selection criteria for the dental casts were (1) all permanent teeth erupted and present from right to left first molar to permit measurement of the MD crown dimensions, (2) no severe tooth abrasion or large restorations that could compromise the MD dimension of a tooth and no teeth with anomalous shapes or deformity, and (3) pre-treatment casts of subjects with no previous orthodontic treatment.

A total of 301 casts (127 males and 174 females) met the criteria. The mean age for males was 16.5 ± 3.1 and for females 17.1 ± 2.8 years. Occlusional categories of all subjects, classified according to Angle, coincided with skeletal categories. Skeletal types were assessed by ANB from cephalometric analysis. ANB was set at 0–5 degrees for Class I, greater than 5 degrees for skeletal Class II, and less then 0 degrees for skeletal Class III (Muretić, 1984). One hundred and eleven subjects (36.87 per cent) were Class I, 109 (36.21 per cent) Class II, and 81 (26.91 per cent) Class III (Table 1).

The MD dimensions of all teeth on each cast from first molar to first molar were measured with digital callipers (Levior S.R.O., Kokory, Czech Republic) accurate to 0.1 mm. The MD dimension of each tooth was measured according to the method described by Moorrees *et al.* (1957), from its mesial contact point to its distal contact point at its greatest interproximal distance. All measurements, carried out under natural light, were performed by the same author (MS), who did not exceed more then seven casts per day in order to avoid eye fatigue and to minimize the possibility of subjective error.

Bolton's analysis was performed on each set of models, when the teeth of all 301 subjects had been measured. The 'overall ratio' was determined using the formula:

$$\text{overall ratio} = \frac{\sum(36 \leftrightarrow 46)}{\sum(16 \leftrightarrow 26)} \times 100.$$

For the ratio between the maxillary and mandibular anterior teeth, the same method was used. The ratio between the two is the percentage relationship of mandibular anterior width to maxillary anterior width, referred to as 'anterior ratio':

$$\text{anterior ratio} = \frac{\sum(33 \leftrightarrow 43)}{\sum(13 \leftrightarrow 23)} \times 100.$$

Table 1 Number and percentage distributions of the subjects among the different malocclusion Classes with the mean age of the sample.

	N (males)	*N* (females)	*N* (m + f)	%	Mean age (years)
Class I	42	69	111	36.87	17.02
Class II	49	60	109	36.21	16.70
Class III	36	45	81	26.91	16.81

Furthermore, the posterior ratio and both anterior and posterior discrepancy in the upper arch were calculated from the formula:

$$\text{posterior ratio} = \frac{\sum(36 \leftrightarrow 34, 44 \leftrightarrow 46)}{\sum(16 \leftrightarrow 14, 24 \leftrightarrow 26)} \times 100.$$

Measurement error

Intraexaminer error was determined by one author (MS), who measured 30 pairs of casts after an interval of 24 hours and interexaminer calibration was carried out by another author (SM), who also measured the 30 pairs of casts twice separated by 24 hours. If the difference was less than 0.2 mm, the first measurement was registered. If the second measurement differed by more than 0.2 mm from the first, the tooth was measured again and only the new measurement was registered.

The reproducibility of the measurements was analysed using Dahlberg (1940) formula. The error was calculated from the equation: $\text{ME} = \sqrt{d^2 / 2n}$, where d is the difference between duplicated measurements and n is the number of replications.

The results showed no significant difference between the two measurements. Intraclass correlation coefficients were 0.979 ($P < 0.001$), 95.79 per cent, ME = 0.17 (range 0–1.45) for interexaminer calibration and 0.987 ($P < 0.001$), 97.35 per cent, ME = 0.14 (range 0–0.6) for intraexaminer calibration.

Statistical analysis

The subjects were divided by gender and by skeletal Class. Statistical calculations were carried out using the Statistical Package for Social Sciences version 13.0 (SPSS Inc., Chicago, Illinois, USA). The results are summarized in Tables 1, 2, 3, and 4. After measurement of the MD widths of all maxillary and mandibular teeth (excluding the second and third molars), their distribution was evaluated with the Kolmogorov–Smirnov test to see whether the sample was normally distributed. To determine whether there was gender dimorphism in the incidence of tooth size discrepancies, a Student's *t*-test was performed. For each malocclusion group, the level of significance was set at 0.05. In order to compare intermaxillary tooth size discrepancies among different malocclusion groups, one-way analysis of variance (ANOVA) was performed. To test which means were different, Scheffé's test was used that extends the *post hoc* analysis possibilities to include linear differences as well as comparisons between specific means. In order to determine the percentage of tooth size discrepancies in the different malocclusion groups, each group was compared with the results from Bolton's study. Measurements outside 2 SD were defined as exhibiting a clinically significant tooth size discrepancy sufficient to warrant treatment because this represents a 2–3 mm tooth size discrepancy (Crosby and Alexander, 1989; Freeman *et al.*, 1996). The number of patients with a tooth size ratio outside 2 SD was divided by the total number of patients in the group. To determine the percentage of tooth size discrepancies within each of the malocclusion groups, this number was multiplied by 100 (Figures 1 and 2).

Results

The Kolmogorov–Smirnov test demonstrated that the sample came from a normally distributed population ($P > 0.20$); therefore, parametric tests were used. The numbers and percentage are presented in Table 1. Descriptive statistics for anterior, posterior, and overall ratios between the genders and *t*-test for independent samples for gender are shown in Table 2. Because statistically significant gender differences were found in anterior ratio, ANOVA for the differences regarding Classes was performed separately for each gender. The differences for skeletal Classes were calculated for posterior and overall ratio. ANOVA demonstrated significant differences for posterior and overall ratios (Table 3).

Scheffé's p*ost hoc* test showed significant differences ($P < 0.05$) in posterior ratios. For overall ratio, significant differences were found between Class I and Class II and between Class II and Class III malocclusion groups (Table 4).

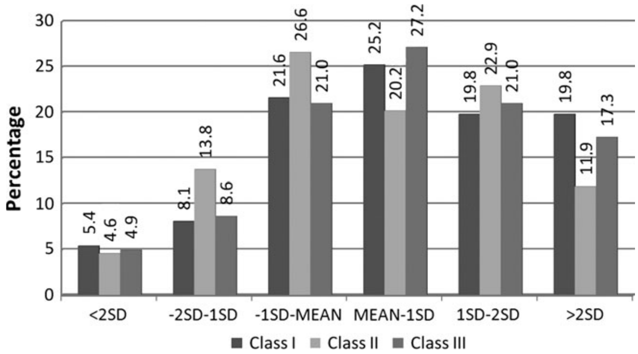

Figure 1 Percentage of subjects with anterior tooth size ratios compared with Bolton's standard.

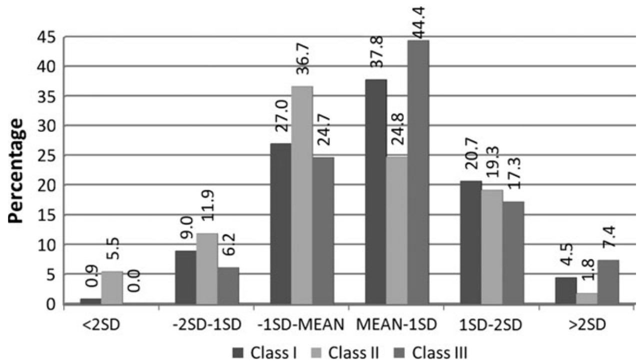

Figure 2 Percentage of subjects overall tooth size ratios compared with Bolton's standard.

Table 2 Mean, standard deviation (SD), standard error (SE), and independent *t*-test for anterior, posterior, and overall ratios for males (M) and females (F).

	Gender	*N*	Mean	SD	SE	*P* value
Anterior ratio	M	127	78.39	2.87	0.25	0.017*
	F	174	77.81	2.36	0.18	
	Total	301	78.06	2.60	0.15	
Posterior ratio	M	127	104.74	3.20	0.28	0.340
	F	174	104.99	2.96	0.22	
	Total	301	104.88	3.06	0.18	
Overall ratio	M	127	91.71	2.00	0.18	0.730
	F	174	91.60	2.06	0.16	
	Total	301	91.64	2.03	0.12	

*$P < 0.05$.

Discussion

The age range of the subjects was 13–22 years. The mean age for males was 16.5 and for females 17.1 years. This young age group was chosen in accordance with the study of Doris *et al.* (1981) to minimize the alteration of the MD dimensions due to attrition, restorations, or caries. Consequently, the effect of these factors on actual MD tooth widths was minimal. The subjects in the current study were all randomly selected Caucasians and thus proportionately representative of malocclusion type.

Comparison with Bolton's sample

The descriptive statistics for anterior, posterior, and overall ratios between genders in each malocclusion group are shown in Table 2. The means of the tooth size ratios of the subjects were similar to Bolton's measurements as well as with those of Crosby and Alexander (1989). The only difference was in the higher SD in the present study as compared with Bolton's standards that could be attributed to the difference in the sample size. The Class I anterior ratio SD was 2.58 compared with Bolton´s SD of 1.65, while the overall ratio SD showed no difference. When comparing other malocclusion groups with Bolton´s measurements, similar trends were found. While the means were very close, the SD were higher in the present study (Table 3). Although Bolton's analysis is useful in a clinical setting, some limitations still exist (Lundström, 1981; Crosby and Alexander, 1989; Freeman *et al.,* 1996). Bolton's sample was obtained from the models of 55 subjects with perfect Class I occlusions (Bolton, 1958; 1962). The population and gender composition of that sample was not specified, the grouping criteria were not explained in detail, and it was unclear as to how many were treated or untreated, which implies potential selection bias. In the present

Table 3 Mean, standard deviation (SD), standard error (SE), and analysis of variance for anterior, posterior, and overall ratios regarding different malocclusion groups.

	Class	*N*	Mean	SD	SE	*P* value
Anterior ratio	I	111	78.25	2.58	0.25	0.252
	II	109	77.73	2.42	0.23	
	III	81	78.23	2.82	0.31	
	Total	301	78.06	2.60	0.15	
Posterior ratio	I	111	104.97	2.66	0.25	0.013*
	II	109	104.28	3.37	0.32	
	III	81	105.58	3.00	0.33	
	Total	301	104.88	3.06	0.18	
Overall ratio	I	111	91.81	1.99	0.19	0.004*
	II	109	91.14	2.14	0.21	
	III	81	92.08	1.82	0.20	
	Total	301	91.64	2.03	0.12	

*$P < 0.05$.

investigation, with a sample size of 301, and pre-treatment casts of patients treated orthodontically, skeletal categories were taken into account, and the subjects were selected by the criteria of occlusal categories coinciding with skeletal categories.

Tooth size discrepancies in different malocclusion classes

The results of the present study showed significant differences for overall and posterior ratios among the different malocclusion groups (Table 3). However, the SDs were larger than expected. The Class I group had the smallest SDs, but only for posterior ratios, when compared with the other malocclusion groups. Tooth size ratios among different malocclusion groups have been compared by Sperry *et al.* (1977) and Crosby and Alexander (1989). Crosby and Alexander (1989) analyzed Bolton ratios and tooth sizes for different occlusal categories, but did not include Class III patients or differentiate between the genders. The relationship between malocclusion and skeletal pattern was not mentioned. No statistically significant differences in the incidence of tooth size discrepancy among different malocclusion groups were found. Sperry *et al.* (1977) analyzed Bolton ratios for groups of Class I, II, and III cases. The subjects were not differentiated by gender and the skeletal patterns were not mentioned. The overall ratios showed that there was mandibular tooth size excess for the Class III patients similar to the findings in the present study. Nie and Lin (1999) reached a similar conclusion; however, they included not only Class III but also Class III surgery patients. Although Class III surgery and non-surgery patients were included in the present study, similar results were found. The overall ratio of Class III patients was highest among the different malocclusion groups, with the largest difference between Class II and Class III subjects (Tables 3 and 4). This statistically significant trend to larger ratios in Class III patients was also reported by Ta *et al.* (2001) in

Table 4 Scheffé's *post hoc* test (the level of significance was $P < 0.05$).

	Class	Class I	Class II	Class III
Posterior ratio	I		0.237	0.384
	II	0.237		0.014
	III	0.384	0.014	
Overall ratio	I		0.035	0.969
	II	0.035		0.031
	III	0.969	0.031	

southern Chinese, Alkofide and Hashim (2002) in Saudis, Araujo and Souki (2003) in Brazilians, and Fatahi *et al.* (2006) in Iranians. While Uysal *et al.* (2005) found no differences between malocclusion types, all malocclusion groups had significantly higher average ratios than the subjects with untreated normal occlusions. Lavelle (1972) showed that the sizes for maxillary teeth in Class III subjects were smallest and mandibular teeth the largest among different malocclusion groups. In that study, only a type of descriptive statistical result was presented, with no comparison of ratios, which stated the mean size of each tooth of male patients for each malocclusion group and mentioned a pattern of contrast.

Tooth size discrepancy and gender

Bishara *et al.* (1989) found that males had larger teeth than females; however, the tooth size discrepancy ratios were not measured. It is important to note that the possibility of gender differences in tooth size discrepancy varies from differences in absolute tooth size (Othman and Harradine, 2006).

No differences in the mean Bolton ratios were found between the genders (Al-Tamimi and Hashim, 2005). In studies where differences have been found, they have been small, with males having slightly larger ratios (Lavelle, 1972, Richardson and Malhotra, 1975; Smith *et al.,* 2000). Gender differences ($P = 0.017$) were found in the present study but only for anterior ratio, similar to findings of Fatahi *et al.* (2006).

Prevalence of tooth size discrepancy

According to Bolton (1958), there is a relatively small range in which tooth size ratios should fall to be able to achieve optimal occlusal relationships. Stifter (1958) reached a similar conclusion, while Crosby and Alexander (1989) found that a large number of orthodontic patients presented with a significant Bolton tooth size discrepancy. When all patients in the current study were combined, 16.28 per cent had an anterior ratio with a significant deviation from Bolton's mean (greater than 2 SD; Figure 1). A significant discrepancy, higher than Bolton's mean, was found in anterior ratio in 21 per cent of Spaniards (Paredes *et al.*,

2006) as well as in the samples of Crosby and Alexander (1989) 22.9 per cent, Freeman *et al.* (1996) 30.6 per cent, Santoro *et al.* (2000) 28 per cent, Bernabé *et al.* (2004) 20.5 per cent, and Othman and Harradine (2007) 17.4 per cent. A discrepancy in overall ratio outside 2 SD from Bolton's mean (Figure 2) was found in 4.32 per cent of the present sample, similar to the findings of 5 per cent by Bernabé *et al.* (2004), Paredes *et al.* (2006), and Othman and Harradine (2007), but lower than that of Freeman *et al.* (1996) of 13.5 per cent and Santoro *et al.* (2000) of 11 per cent. Fernández-Riveiro *et al.* (1995) found greater anterior and overall ratios in their study, but they considered values outside 1 SD to be significant. In the present investigation, a tendency was found to mandibular tooth size excess in Angle Class III malocclusion subjects and maxillary tooth size excess in Angle Class II malocclusion subjects, in agreement with the findings of Nie and Lin (1999).

Regarding studies reporting the MD dimensions of lower teeth to be larger in Class III subjects when compared with Classes I and II (Lavelle, 1972; Sperry *et al.*, 1977), Fatahi *et al.* (2006) speculated that these greater means in Bolton's ratio might be due to aetiological factors that lead to mandibular prognathism and may also be associated with increased MD dimensions of upper anterior teeth in Class II subjects that lead to maxillary prognathism. Further studies are needed to clarify whether a correlation exists between increased growth of the jaws and increased MD dimensions of anterior teeth. A large individual cultural variability might have existed in the growth pattern of the subjects (Akyalçin *et al.*, 2006).

In clinical practice, attention should be paid to tooth size discrepancies between the maxillary and mandibular teeth and that Bolton's analysis is important for orthodontic diagnosis and treatment planning that would improve achieving optimal occlusion, overbite, and overjet, It should also be borne in mind that Bolton tooth size analysis might be of assistance in the finishing phase of orthodontic treatment, especially in increasing the stability of the treatment result (Araujo and Souki, 2003). Although such an analysis in some instances may appear to be time-consuming, the benefits would seem to be significant.

Conclusions

1. Tooth size discrepancy was found to be more frequent in the anterior region with respect to gender.
2. A tendency was found for mandibular tooth size excess in Angle Class III malocclusion subjects and maxillary tooth size excess in those with an Angle Class II malocclusion. Posterior and overall ratios were greater in Class III malocclusion subjects than in other occlusal categories.
3. The percentage of subjects with more than 2 SD from Bolton's means for anterior and overall ratios was16.28 and 4.32, respectively.

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References

Akyalçin S, Doğan S, Dinçer B, Erdinc A M, Oncağ G 2006 Bolton tooth size discrepancies in skeletal Class I individuals presenting with different dental Angle classifications. Angle Orthodontist 76: 637–643

Alkofide E, Hashim H 2002 Intermaxillary tooth-size discrepancy among different malocclusion Classes: a comparative study. Journal of Clinical Pediatric Dentistry 24: 383–387

Al-Tamimi T, Hashim H A 2005 Bolton tooth-size ratio revisted. World Journal of Orthodontics 6: 289–295

Araujo E, Souki M 2003 Bolton anterior tooth size discrepancies among different malocclusion groups. Angle Orthodontist 73: 307–313

Ballard M L 1944 Asymmetry in tooth size: a factor in the ethiology, diagnosis and treatment of malocclusion. Angle Orthodontist 14: 67–71

Bernabé E, Major P W, Flores-Mir C 2004 Tooth-width ratio discrepancies in a sample of Peruvian adolescents. American Journal of Orthodontics and Dentofacial Orthopedics 125: 361–365

Bishara S E, Jacobsen J R, Abdullah E M, Garcia A F 1989 Comparisons of mesiodistal and buccolingual crown dimensions of the permanent teeth in three populations from Egypt, Mexico, and the United States. American Journal of Orthodontics and Dentofacial Orthopedics 96: 416–422

Bolton W A 1958 Disharmonies in tooth size and its relation to the analysis and treatment of malocclusions. Angle Orthodontist 28: 113–130

Bolton W A 1962 The clinical application of a tooth size analysis. American Journal of Orthodontics 48: 504–529

Buschang P H, Demirjian A, Cadotte L 1988 Permanent mesiodistal tooth size of French-Canadians. Journal of the Canadian Dental Association 54: 441–444

Crosby D R, Alexander C G 1989 The occurrence of tooth-size discrepancies among different malocclusion groups. American Journal of Orthodontics and Dentofacial Orthopedics 95: 457–461

Dahlberg G 1940 Statistical methods for medical and biological students. Interscience Publications, New York

Doris J M, Bernard B W, Kuftinec M M, Stom D 1981 A biometric study of tooth size and dental crowding. American Journal of Orthodontics 79: 326–336

Fatahi H R, Pakshir H R, Hedayati Z 2006 Comparison of tooth size discrepancies among different malocclusion groups. European Journal of Orthodontics 28: 491–495

Fernández-Riveiro P, Suárez-Quintanilla D, Otero-Cepeda J L 1995 Análisis odontométrico de una población maloclusiva: índice de Bolton. Revista de Española Ortodoncia 25: 119–126

Freeman J E, Maskeroni A J, Lorton L 1996 Frequency of Bolton tooth-size discrepancies among orthodontic patients. American Journal of Orthodontics and Dentofacial Orthopedics 110: 24–27

Garn S M, Lewis A B, Swindler D R 1967 Genetic control of sexual dimorphism in tooth size. Journal of Dental Research 46: 963–972

Howes A E 1947 Case analysis and treatment planning based upon the relationship of the tooth material to its supporting bone. American Journal of Orthodontics and Oral Surgery 33: 499–533

Lavelle C L B 1972 Maxillary and mandibular tooth size in different racial groups and in different occlusal categories. American Journal of Orthodontics 61: 29–37

Lundström A A 1981 Intermaxillary tooth width ratio analysis. European Journal of Orthodontics 3: 285–287

Moorrees C F A, Thomsen S O, Jensen E, Yen P K 1957 Mesiodistal crown diameter of the deciduous and permanent teeth in individuals. Journal of Dental Research 36: 39–47

Muretić Z 1984 Prijedlog kvalitativnih i kvantitativnih parametara za zagrebačku rendgenkefalometrijsku analizu. Acta Stomatologica Croatica 18: 159–167

Neff C W 1957 The size relationship between the maxillary and mandibular anterior segments of the dental arch. Angle Orthodontist 27: 138–147

Nie Q, Lin J 1999 Comparison of intermaxillary tooth size discrepancies among different malocclusion groups. American Journal of Orthodontics and Dentofacial Orthopedics 116: 539–544

Othman S A, Harradine N W T 2006 Tooth-size discrepancy and Bolton's ratios: a literature review. Journal of Orthodontics 33: 45–51

Othman S A, Harradine N W T 2007 Tooth size discrepancies in an orthodontic population. Angle Orthodontist 77: 668–674

Paredes V, Gandia J L, Cibrian R 2006 Do Bolton's ratios apply to a Spanish population? American Journal of Orthodontics and Dentofacial Orthopedics 129: 428–430

Pont A 1909 Der zahn index. Orthodontic Zeitshrifte der Zahnärtzliche Orthopedie 3: 306–321

Puri N, Pradhan K L, Chandna A, Sehgal V, Gupta R 2007 Biometric study of tooth size in normal, crowded, and spaced permanent dentitions. American Journal of Orthodontics and Dentofacial Orthopedics 132: 279.e7–279.e14

Rees D J 1953 A method for assessing the proportional relation of apical bases and contact diameters of the teeth. American Journal of Orthodontics 39: 695–707

Richardson E R, Malhotra S K 1975 Mesiodistal crown dimension of the permanent dentition of American Negroes. American Journal of Orthodontics 68: 157–164

Santoro M, Ayoub M E, Pardi V A, Cangialosi T J 2000 Mesiodistal crown dimensions and tooth size discrepancy of the permanent dentition of Dominican Americans. American Journal of Orthodontics and Dentofacial Orthopedics 70: 303–307

Smith S S, Buschang P H, Watanabe E 2000 Interarch tooth size relationships of 3 populations: does Bolton's analysis apply? American Journal of Orthodontics and Dentofacial Orthopedics 117: 169–174

Sperry T P, Worms F W, Isaacson R J, Spiedel T M 1977 Tooth-size discrepancy in mandibular prognathism. American Journal of Orthodontics 72: 183–190

Stifter J 1958 A study of Pont's, Howes', Rees', Neff's and Bolton's analyses on Class I adult dentitions. Angle Orthodontist 28: 215–225

Ta T A, Ling J Y K, Hägg U 2001 Tooth-size discrepancies among different occlusion groups of southern Chinese children. American Journal of Orthodontics and Dentofacial Orthopedics 120: 556–558

Uysal T, Sari Z, Bascifiti F A, Memili B 2005 Intermaxillary tooth size discrepancy and malocclusion: is there a relation? Angle Orthodontist 75: 208–213