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Overall and anterior Bolton ratio in Class I, II, and III orthodontic patients

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SUMMARY The aim of the investigation was to compare overall and anterior Bolton ratios in different malocclusion groups with Bolton's standards. The material comprised 600 pre-treatment study casts (262 males and 338 females, aged 12–25 years), selected from the models of 3088 patients who had applied for orthodontic treatment based on the following criteria: permanent dentition from the first right molar to the first left molar and no interproximal caries or restorations. There were 162 Class I, 144 Class II division 1, 155 Class II division 2, and 139 Class III patients. Statistical analysis of the data was undertaken using a Student's *t*-test.

Statistically significant differences were found for the mean overall ratio when compared with the original Bolton norm for the whole study group, as well as for patients with Class I and III malocclusions when the mean anterior ratio was compared with the original Bolton norm. Significant differences were observed in all malocclusion groups for both genders. Discrepancies exceeding 2 SD were found in 31.2 per cent of the studied population for the anterior ratio when compared with Bolton's norm. The highest mean values for anterior ratio were in males with Class I (79.1) and Class III (80.1) malocclusions.

Introduction

Bolton's analysis is one of the most popular methods for determining tooth size abnormality. It is useful in aiding diagnosis as well as in treatment planning. The overall Bolton ratio is the percentage obtained by summing the widths of the 12 mandibular teeth divided by the sum of the widths of the 12 maxillary teeth and should be 91.3 ± 0.26 per cent. Anterior ratio is the percentage obtained by summing the widths of the six mandibular anterior teeth divided by the sum of the widths of the six maxillary anterior teeth and should be 77.2 ± 0.22 per cent (Bolton, 1958, 1962). The original analysis was performed on 55 patients with excellent occlusion, including 44 orthodontically treated (non-extraction) and 11 untreated subjects.

Similar research was carried out by Lundström (1954), where the medium ratio for the incisors and canines was stated to be equal to 78.5 ± 0.13 and the medium ratio of all the 12 teeth equal to 92.3 ± 0.26. The same values for overall and anterior ratios were found for a group of 57 dental students and eight Navaho Indians with a Class I occlusion (Stifter, 1958).

Later studies of the Bolton ratio concerned mainly patients from different Caucasian populations of the United States (Neff, 1957; Sperry *et al.*, 1977; Doris *et al.*, 1981; Crosby and Alexander, 1989) as well as Europeans (Lundström, 1954; Lavelle, 1972; Ebeling *et al.*,1973; Arya *et al.*, 1974; Manke and Miethke, 1983; Redahan and Lagerström, 2003). All publications are listed in Table 1. Most of the studies were based on patients applying for orthodontic treatment with different malocclusions. The sample sizes varied between 55 and 710.

As Bolton used casts of subjects with an ideal occlusion, it is not possible to clinically determine the size of significant discrepancies. Bolton suggested that a discrepancy greater than 1 SD may create clinical problems. Most authors define a clinically significant ratio as 2 SD outside Bolton's mean (Crosby and Alexander, 1989; Freeman *et al.*, 1996; Santoro *et al.*, 2000). Proffit *et al.* (2007) stated that a tooth width discrepancy larger than 1.5 mm creates problems that should be considered in the treatment plan. Most authors assert that a tooth size discrepancy, compared with Bolton's norm, greater than 1.5 mm, or 2 SD, results in difficulties in tooth alignment in the finishing phase of treatment (Crosby and Alexander, 1989; Freeman *et al.*, 1996; Santoro *et al.*, 2000; Araujo and Souki, 2003; Bernabé *et al.*, 2004; Othman and Harradine, 2007). No evidence has been found for the clinical importance of a discrepancy exceeding 2 SD or 1.5 mm and both values seem to be suggestions.

Numerous authors claim that it is necessary to measure the teeth before initiating orthodontic treatment (Freeman *et al.*, 1996; Alkofide and Hashim, 2002; Othman and Harradine, 2007).

Only one Bolton study of the Polish population has been published (Bielawska, 1994). It comprised 51 patients with malocclusions, 22 with a Class II, 10 with a Class III, and 19 with a crossbite.

The aim of the present investigation therefore was to calculate the overall and anterior Bolton ratios in different malocclusion groups of Polish patients applying for orthodontic treatment and to compare them with Bolton's standards.

Table 1 Previous Bolton studies.

Author	Year of publication	Population	Occlusion	Sample size			Anterior ratio	Overall ratio
Lundström	1954	Swedish schoolchildren	No data	140			78.5	92.3
Bolton	1958 1962	American selected orthodontic	Ideal	55			77.2	91.3
Stifter	1958	American selected students and Navaho Indians	Normal	65			77.55	91.04
Lavelle	1972	British selected dental	Ideal untreated	40	Caucasoid	Male	76.8	91.7
						Female	77.5	90.8
				40	Negroid	Male	79.4	93.5
						Female	78.6	92.9
				40	Mongoloid	Male	78.7	92.6
						Female	78.2	92.1
Manke and Miethke	1983	German orthodontic	No data	100			78.28	No data
Crosby and Alexander	1989	American orthodontic	Class I and II	109			77.5	91.4
Lew and Keng	1991	Chinese selected orthodontic	Ideal	85			77.89	No data
Bielawska	1994	Polish orthodontic	Distal occlusion	22			No data	91.2 92.1
			Mesial occlusion	10				92.1
			Crossbite	19				
Freeman *et al.*	1996	American orthodontic	No data	157			77.8	91.4
Nie and Lin	1999	Chinese orthodontic	Class I, II, and III	300			81.52	93.27
Santoro *et al.*	2000	Dominican orthodontic	No data	54			78.1	91.3
Smith *et al.*	2000	American orthodontic	No data	180		White	79.6	92.3
						Black	79.3	93.4
						Hispanic	80.5	93.1
Ta *et al.*	2001	Chinese selected schoolchildren	Class I, II, and III	110			77.5	90.9
Alkofide and Hashim	2002	Saudi Arabian selected orthodontic	Class I, II, and III	240			78.86	92.61
Araujo and Souki	2003	Brazilian orthodontic	Class I, II, and III	300			78.18	No data
Redahan and Lagerström	2003	Swedish orthodontic	Different malocclusions	137			78.0	No data
Bernabé *et al.*	2004	Peruvian schoolchildren	Different malocclusions	200		Male	78.39	91.33
						Female	77.78	90.79
Baidas and Hashim	2005	Turkish orthodontic	No data	184			79.11	92.03
Al-Tamimi and Hashim	2005	Saudi Arabian orthodontic	Normal	65			77.4	91.4
Nourallah *et al.*	2005	Syrian orthodontic	Class I	55			78.99	92.26
Uysal *et al.*	2005	Turkish orthodontic	Class I, II, and III	710			78.26	89.88
Uysal and Sari	2005	Turkish orthodontic	Normal	150			78.26	89.88
Paredes *et al.*	2006b	Spanish orthodontic	No data	100			78.32	91.97
Akyalcin *et al.*	2006	Turkish orthodontic	Class I, II, and III	152			78.15	91.34
Fattahi *et al.*	2006	Iranian orthodontic	Class I, II, and III	200			79.01	91.68
Endo *et al.*	2007	Japanese orthodontic	Class I	60			78.39	91.6
Freire *et al.*	2007	Brazilian orthodontic	Normal	30			77.83	91.46
Al-Omari *et al.*	2008	Jordanian schoolchildren	No data	367			78.6	92.2

Materials and methods

The study material comprised 600 pre-treatment study casts, selected from models of 3088 patients, who during 2003–2006 applied to the university department of orthodontics and two private orthodontic practices in Szczecin and Kolobrzeg for orthodontic treatment. Each of the patients had a cephalometric radiograph. The diagnosis of a Class I occlusion was based on a Class I molar and canine relationship as well as an ANB angle between 0 and 4 degrees. The diagnosis of a Class II was based on the presence of Class II molar and canine relationship accompanied by an ANB angle greater than 4 degrees. Overjet was a criterion to differentiate between Class II division 1 and 2. Class III was diagnosed based on an inverse overjet, a Class III molar and canine relationship as well as an ANB angle less than 0 degrees.

The inclusion criteria were:

1. between 12 and 25 years of age
2. fully erupted permanent dentition from the first molar to the first molar in both arches
3. diagnostic records, including study casts, panoramic view, and a lateral cephalogram

4. the clinical diagnosis of Class I, II, or III malocclusion exemplified by the presence of its features regarding molar and canine relationship and overjet, as well as cephalometric analysis
5. absence of interproximal caries or restorations as well as prosthetic crowns or bridges

The study group included 162 Class I patients (73 males and 89 females), 144 Class II division 1 patients (60 males and 84 females), 155 Class II division 2 patients (67 males and 88 females), and 139 Class III (62 males and 77 females). All were of Polish nationality and Caucasian. The age distribution of the groups is shown in Table 2.

All measurements on the study models were undertaken by one author (BWS) with sliding callipers (Dentaurum, Pforzheim, Germany), accurate to the nearest 0.1 mm. The following were calculated for each pair of study casts.

S_{12mand}—sum of the widths of the 12 mandibular teeth (mm)
S_{12max}—sum of the widths of the 12 maxillary teeth (mm)
S_{6mand}—sum of the widths of the 6 mandibular teeth (mm)
S_{6max}—sum of the widths of the 6 maxillary teeth (mm)

Overall and anterior Bolton ratios, B_{or} and B_{ar}, were calculated according to the following equations: $B_{or} = S_{12mand}/S_{12max}$ and $B_{ar} = S_{6mand}/S_{6max}$, respectively. Since the reasons for tooth size discrepancies in individual patients were not diagnosed, each discrepancy was described as the relative mandibular or maxillary tooth size excess. The formulae for the relative tooth size excess, E, depends on the relationship between the obtained ratios and Bolton standards:

$$E = S_{12mand} - 91.3\%\ S_{12max} \quad \text{for } B_{or} > 91.3\%,$$

$$E = S_{12max} - S_{12mand}/91.3\% \quad \text{for } B_{or} < 91.3\%,$$

$$E = S_{6mand} - 77.2\%\ S_{6max} \quad \text{for } B_{ar} > 77.2\%,$$

$$E = S_{6max} - S_{6mand}/77.2\% \quad \text{for } B_{ar} < 77.2\%.$$

The relative tooth size excess was calculated for each patient.

Table 2 Age distribution between the groups investigated.

Malocclusion group	Sample size	Range (year.month)	Mean (year.month)
Class I male	73	12.25–25.30	14.67
Class I female	89	12.00–25.00	14.33
Class II division 1 male	60	12.42–25.17	14.25
Class II division 1 female	84	12.08–25.42	14.25
Class II division 2 male	67	12.25–25.17	15.33
Class II division 2 female	88	12.17–25.08	14.33
Class III male	62	12.50–25.58	16.33
Class III female	77	12.33–25.00	16.25

Statistical analysis

The Shapiro–Wilk test showed that the data distribution in all the malocclusion groups was normal. The overall and anterior ratios for a particular malocclusion group was compared with Bolton's standard using the Student's *t*-test.

In order to assess the error of the method, 30 study casts were randomly chosen from the total of 600 and remeasured 3 months later by the same investigator. The standard deviation (SD) of all 360 measurement differences was 0.22 mm, giving a coefficient of variation of 2.74 per cent. The error of the method was calculated using Dahlberg's equation. The average measurement error of tooth widths was 0.17 mm corresponding to a relative error of 2.11 per cent. All measurement errors were found to be less than 10 per cent, which was considered acceptable.

Bolton ratios obtained from both measurements were compared using three approaches. First, according to Dahlberg's equation, the errors of the overall and anterior ratios were equal to 0.74 and 0.96 or 0.80 and 1.21 per cent, respectively. In the second approach, the confidence intervals of Bolton ratios obtained from the two measurements were calculated and compared. The lower confidence bounds differed by 0.09 and 0.45 per cent for the overall and anterior ratios, respectively, and the upper confidence bounds by 0.16 and 0.05 per cent, respectively. This means, that the confidence intervals for both measurements overlapped to a high degree. Finally, conservative intraclass correlation coefficients (2;1) were calculated. The results were 0.886 and 0.872 for overall and anterior ratios, respectively. All these approaches confirmed an acceptable level of measurement error.

Results

The overall Bolton ratio for all the malocclusion groups is shown in Table 3. Statistically significant differences were found for the whole study group as well as for the subgroups of subjects with Class I and III malocclusions.

The results for anterior Bolton ratio in the individual malocclusion groups are presented in Table 4. Comparing anterior ratio in the individual malocclusion groups with Bolton's standards, statistically significant differences were observed for all groups and for both genders; the greatest difference was for males with Class III (80.1 ± 3.0) and Class I (79.1 ± 2.2) malocclusions.

The percentage of patients with a significant discrepancy in overall and anterior Bolton ratios in the various malocclusion groups is shown in Table 5. Comparing anterior ratio with Bolton's norm, discrepancies exceeding 2 SD were found in 31.2 per cent of the population studied. The highest percentage of subjects with an anterior Bolton discrepancy exceeding 2 SD (45.2 per cent) was found in males with a Class III malocclusion.

Table 3 Overall Bolton ratio in the individual malocclusion groups.

	Sample size	Minimum	Maximum	Mean	SD	Coefficient of variation (%)	*P* value
Class I male	73	87.9	97.8	92.3	1.86	2.0	***
Class I female	89	86.5	96.0	91.9	2.09	2.3	NS
Class II division 1 male	60	86.0	95.9	91.2	2.22	2.4	NS
Class II division 1 female	84	83.9	95.9	91.1	2.16	2.4	NS
Class II division 2 male	67	84.7	96.1	91.7	2.21	2.4	NS
Class II division 2 female	88	86.7	99.1	91.5	2.23	2.4	NS
Class III male	62	86.6	98.0	93.0	2.29	2.5	***
Class III female	77	86.4	97.7	92.0	2.46	2.7	**
Total male	262	84.7	98.0	92.1	2.22	2.4	***
Total Female	338	83.9	99.1	91.6	2.25	2.5	**
Total	600	83.9	99.1	91.8	2.24	2.4	***

NS, not significant. **$P<0.01$, ***$P<0.001$.

Table 4 Anterior Bolton ratio in the individual malocclusion groups.

	Sample size	Minimum	Maximum	Mean	SD	Coefficient of variation (%)	*P* value
Class I male	73	74.4	86.2	79.1	2.20	2.8	***
Class I female	89	68.5	86.0	78.4	2.98	3.8	***
Class II division 1 male	60	72.5	84.5	78.1	2.46	3.1	**
Class II division 1 female	84	72.2	84.4	78.8	2.63	3.3	***
Class II division 2 male	67	71.5	83.8	78.4	2.71	3.5	***
Class II division 2 female	88	72.5	87.3	78.4	2.80	3.6	***
Class III male	62	73.2	89.2	80.1	3.00	3.7	***
Class III female	77	70.9	88.5	78.9	2.89	3.7	***
Total male	262	71.5	89.2	78.9	2.70	3.4	***
Total Female	338	68.5	88.5	78.6	2.83	3.6	***
Total	600	68.5	89.2	78.8	2.77	3.5	***

**$P<0.01$, ***$P<0.001$.

Table 5 The frequency of Bolton tooth size discrepancies exceeding 2 SD.

	Sample size	Frequency of overall ratio discrepancy			Frequency of anterior ratio discrepancy		
		Total (%)	Relative maxillary excess (%)	Relative mandibular excess (%)	Total (%)	Relative maxillary excess (%)	Relative mandibular excess (%)
Class I male	73	4.1	0.0	4.1	28.8	0.0	28.8
Class I female	89	7.9	1.1	6.7	31.5	5.6	25.8
Class II division 1 male	60	10.0	6.7	3.3	20.0	6.7	13.3
Class II division 1 female	84	9.5	4.8	4.8	34.5	4.8	29.8
Class II division 2 male	67	7.5	1.5	6.0	34.3	3.0	31.3
Class II division 2 female	88	9.1	2.3	6.8	25.0	2.3	22.7
Class III male	62	22.6	1.6	21.0	45.2	1.6	43.5
Class III female	77	13.0	2.6	10.4	31.2	3.9	27.3
Total male	262	10.7	2.3	8.4	32.1	2.7	29.4
Total female	338	9.8	2.7	7.1	30.5	4.1	26.3
Total	600	10.2	2.5	7.7	31.2	3.5	27.7

Discussion

In the present study, the mean overall Bolton ratio was 91.8 per cent, which is significantly higher than Bolton's standard. Anterior and overall Bolton ratios were found to be higher in the malocclusion groups than in the untreated subjects with normal occlusion (Table 1). The mean anterior Bolton ratio was 78.8 per cent, which was higher when compared with Bolton's standard for all malocclusion groups and for both genders. The size of the maxillary anterior teeth, particularly the lateral incisors, may differ

within populations. A greater percentage of patients with anterior tooth size discrepancy than with discrepancies in overall ratio can be explained by the fact that the size of the anterior teeth has, mathematically, less effect on overall ratio (Othman and Harradine, 2006).

The finding that males with a Class III malocclusion have higher Bolton ratios is in agreement with previous reports (Lavelle, 1972; Nie and Lin, 1999). However, some authors found no differences in gender or type of malocclusion (Arya *et al.*, 1974; Sperry *et al.*, 1977; Crosby and Alexander, 1989; Nourallah *et al.*, 2005; Uysal *et al.*, 2005). The only study concerning the Polish population by Bielawska (1994), performed on 51 orthodontic patients with different malocclusions, also did not find any statistically significant differences. It is likely that in the most studies citied, the sample sizes of particular malocclusions were not sufficiently large to detect differences between the malocclusion groups. Moreover, some investigations did not include Class III subjects.

In the present study, the prevalence of a significant (exceeding 2 SD) discrepancy in overall ratio was 10.2 per cent. Both Bolton (1958, 1962) and Proffit *et al.* (2007) reported less than 5 per cent of cases with an overall Bolton discrepancy exceeding 2 SD, but their studies included populations with excellent occlusion, which may be considered representative of the general population, but not of patients beginning orthodontic treatment.

The frequency of a significant anterior Bolton discrepancy in the present investigation was 31.2 per cent, which supports earlier findings in other populations (Santoro *et al.*, 2000; Smith *et al.*, 2000; Alkofide and Hashim, 2002; Araujo and Souki, 2003; Bernabé *et al.*, 2004; Fattahi *et al.*, 2006; Paredes *et al.*, 2006a,b; Endo *et al.*, 2007).

It has been suggested that it is necessary to determine specific standards, especially for anterior Bolton ratio, for different populations (Ta *et al.*, 2001; Uysal and Sari, 2005; Endo *et al.*, 2007) as well as for different malocclusions (Ta *et al.*, 2001) since the relationships established by Bolton for American whites are not always appropriate. The standard, however, should be the range of the proportion of tooth size that allows alignment of the teeth in perfect occlusion. Thus, it seems to be impractical to produce 'specific particular standards' for the numerous different malocclusions since these should be considered as discrepancies.

Bolton's standards have not been adequately verified on large groups of individuals of different ethnicity with ideal Class I occlusions, perfect alignment, and no crowding. Uysal and Sari (2005) calculated Bolton ratios in a group of 150 subjects with a normal occlusion, but with minor crowding. The obtained mean values and SDs seem to differ from Bolton's means, but the authors did not verify the compatibility with Bolton's norms, so the difference may be statistically insignificant. Nie and Lin (1999) calculated the Bolton ratio for 60 subjects with normal occlusion and found the received mean values to be higher than those of Bolton, but statistical comparisons were made only between normal occlusion and malocclusion groups and the inclusion criteria for the subjects with a normal occlusion were not reported. Lew and Keng (1991), who undertook measurements on 85 study casts with perfect occlusions (32 untreated and 53 post-orthodontic), reported anterior ratios almost identical to Bolton's mean. This finding is also in concordance with the study of Ta *et al.* (2001) who stated that Bolton standard applies to Chinese children with a Class I occlusion.

Based on the fact that Bolton's standards apply to patients with ideal occlusion (Lavelle, 1972; Lew and Keng, 1991), it seems that the standards, e.g. values characterizing individuals with a perfect Class I occlusion, could be similar for different populations, but various ethnic groups may be characterized by a different prevalence of Bolton discrepancy.

The fact that Bolton used casts with ideal occlusion has made it impossible to determine the size of any discrepancy that would make an ideal occlusion unachievable. An attempt to verify the clinical importance of tooth size discrepancy was undertaken by Heusdens *et al.* (2000) who created different amounts of discrepancy in an experimental set-up. By simultaneously altering the curve of Spee, an acceptable occlusion according to the Peer Assessment Rating (PAR) Index was achieved even with 6 mm of anterior stripping in the upper dental arch (PAR Index 2.35). Tooth size discrepancy was not studied as an isolated factor. Thus, the clinical importance of tooth size discrepancy, especially relative to anterior mandibular tooth size excess, has not been adequately verified. It should be remembered that patients treated with fixed appliances expect at the termination of treatment an occlusion, which is ideal, not acceptable according to some index. This may be difficult in Class III malocclusion subjects with an anterior Bolton discrepancy due to a relative mandibular tooth size excess, if not diagnosed before the initiation of treatment.

Conclusions

1. Bolton ratios in patients with malocclusions differ from Bolton's standards.
2. An anterior Bolton discrepancy exceeding 2 SD occurs in 31.2 per cent of Polish orthodontic patients.
3. It is necessary to calculate Bolton's ratios in all orthodontic patients, especially in males with a Class III malocclusion.

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