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The effect of heritability on Bolton tooth-size discrepancy

Bülent Baydaş, Hüsamettin Oktay and İlhan Metin Dağsuyu
Department of Orthodontics, Faculty of Dentistry, Atatürk University, Erzurum, Turkey

SUMMARY The purpose of this study was to determine the possible effect of genetic factors on Bolton tooth-size discrepancy. Subjects who applied for orthodontic treatment and their siblings (106 females and 78 males) were included in the study. The ages of the subjects ranged from 13 to 21 years. The siblings were grouped according to gender: male–male (24 pairs), female–female (38 pairs) and male–female (30 pairs). Mesio-distal tooth size was measured using a pair of dividers with fine tips, and Bolton anterior and overall ratios were calculated. The effect of heritability on Bolton ratios was studied by means of Harvey's mixed model least-squared and maximum likelihood computer program (LSMLMW) model type II.

Statistical analysis showed that heritability was effective on Bolton tooth-size discrepancy in all groups except the male–female group. Siblings of the same gender showed high heritability for anterior and overall ratios, but no statistically significant difference was observed in the siblings of different gender.

Introduction

Malocclusion is a major developmental problem in industrialized countries, and a high prevalence is a major health care concern. Most malocclusions are combinations of bone- and tooth-based disharmonies, which are multifactorial in origin. Contemporary clinical opinion emphasizes the role of heredity as a cause of malocclusion. In craniometric and cephalometric studies of familial similarities, the majority of the evidence supports the hypothesis that facial form is largely a product of the person's genotype (Harris and Johnson, 1991) and the shape and size of teeth are also genetically determined (Lavelle, 1972; Doris *et al.*, 1981; Boraas *et al.*, 1988; Harris and Johnson, 1991; Dempsey *et al.*, 1995).

Andrews (1972) indicated the importance of the 'six keys' of occlusion. The absence of any one or more of the keys results in an occlusion that deviates from normal. Another important factor affecting normal occlusion is tooth-size discrepancy, which is often the cause of spacing, crowding, and incorrect intercuspation (Rakosi *et al.*, 1993). It is well known that the mesio-distal tooth size of the maxillary and mandibular arch must relate to each other in order to obtain an occlusion with good alignment, ideal overjet and overbite, and a Class I molar relationship at the completion of orthodontic treatment (Claridge, 1973; Sperry *et al.*, 1977; Crosby and Alexander, 1989; Harris and Johnson, 1991; Tayer, 1992; Shellhart *et al.*, 1995; Freeman *et al.*, 1996; Rudolph *et al.*, 1998; Heusdens *et al.*, 2000; Smith *et al.*, 2000). It can be said, therefore, that it is difficult for a clinician to make an adequate diagnosis and plan and carry out treatment without information on the size of individual teeth and groups of teeth (Richardson and Malhotra, 1975).

Disproportionately sized teeth are, in some cases, easily recognizable. However, significant discrepancies can occur between the overall sizes of the maxillary and mandibular teeth that are difficult to identify by inspection alone (Shellhart *et al.*, 1995). It has been observed that approximately 5 per cent of the population have some degree of disproportion among the sizes of individual teeth (Proffit and Ackerman, 1986). Tooth-size discrepancies are seen more frequently in subjects with orthodontic malocclusions. In an epidemiological study on potential orthodontic patients in the US Army, Freeman *et al.* (1996) found that a number of the subjects showed overall (13.4 per cent) and anterior (30.6 per cent) tooth-size discrepancy. Crosby and Alexander (1989) found a relatively large number of tooth-size discrepancies in subjects with malocclusions. These results show that tooth-size discrepancy must be taken into consideration in diagnosis, treatment planning, and treatment of malocclusions.

Very few studies on tooth-size discrepancy have been published, and are as clinically useful or as well accepted as that of Bolton (1958) on the relationship of tooth-size disharmony to the treatment of malocclusion (Crosby and Alexander, 1989; Shellhart *et al.*, 1995; Freeman *et al.*, 1996; Smith *et al.*, 2000). Bolton (1958, 1962) evaluated 55 subjects with excellent occlusions; 44 had been treated orthodontically without extractions and 11 were untreated. The mesio-distal dimensions of the maxillary and mandibular teeth, except second and third molars, were measured. The ratios were calculated to produce a percentage relationship of mandibular size to maxillary size. This calculation was carried out for the anterior teeth (canine to canine) and for the whole dentition (first molar to first molar). By comparing the results of the two ratios, deficient or excessive areas were found. Although there are some limitations to this analysis it has been widely used by orthodontists (Shellhart *et al.*, 1995; Smith *et al.*, 2000).

Size differences and asymmetries of teeth are factors that affect Bolton's tooth-size analysis. As a result of secular changes and changes in nutrition, the mesio-distal tooth width has increased in more recent generations (Ebeling *et al.*, 1973; Lavelle, 1973; Heusdens *et al.*, 2000). It is well known that tooth size is under a high degree of genetic control, although there have been difficulties in separating the various genetic and environmental effects (Boraas *et al.*, 1988; Dempsey *et al.*, 1995). Thus, it is likely that genetic factors are also effective on tooth-size discrepancy. The purpose of this study was to evaluate the possible effects of genetic factors on the results of Bolton's analysis.

Subjects and methods

Subjects who applied for orthodontic treatment and their siblings were included in the study. There were 106 females and 78 males, whose ages ranged from 13 to 21 years. All were in the permanent dentition stage, with no bilateral tooth loss other than second and/or third molars, no tooth-size abnormality, and no evidence of attrition or interproximal caries and restorations. Alginate impressions of the dentitions were taken from each subject, and stone casts were prepared. Impressions of the subjects with an orthodontic malocclusion were taken before their treatment.

A pair of dividers with fine tips (029-361 Dentaurum, Ispringen, Germany) was used to measure the maximum mesio-distal widths of the teeth. Using the dividers, the measurements of each dental arch were recorded by punching along a straight line on a card. When punching adjacent measurements, one leg of the dividers was inserted into the previous pinhole so as to reduce the measurement error to a minimum. Anterior arch lengths (canine to canine) and total arch lengths (first molar to first molar) were then measured using a finely calibrated millimetre ruler. All the measurements were carried out by the same investigator.

The Bolton anterior ratio (the ratio between the mesio-distal widths of the six anterior mandibular teeth and the mesio-distal widths of the six anterior maxillary teeth) and the Bolton overall ratio (the ratio between the mesio-distal widths of the 12 mandibular teeth and the mesio-distal widths of the 12 maxillary teeth) were calculated as explained by Bolton (1958, 1962).

For method error evaluation, 20 casts were selected at random, 40 days after the original measurements. The teeth were remeasured on these casts and the ratios were recalculated. The first and second calculated ratios were compared (Houston, 1983). No error associated with the measurements and calculations was found.

The sibling pairs were divided into three groups according to gender: male–male (24 pairs), female–female (38 pairs), and male–female (30 pairs). Means, standard deviations (SD), ranges, and heritability values of Bolton anterior and overall ratios were computed for each group. Anterior and overall ratios of the male and female subjects were compared, but no statistically significant difference was found ($F = 0.566$; $P > 0.05$). Based on this result, the sibling pairs in each group were pooled, and another group was formed. For the pooled group, heritability estimate values (h^2) were computed after the variation related to sex was eliminated, although there was no gender difference.

The heritability assessments of anterior and overall ratios were undertaken according to narrow sense heritability. The narrow sense heritability estimate value (h^2) was computed according to the formula:

$$h^2 = \frac{\sigma_g^2}{\sigma_g^2 + \sigma_e^2}$$

where σ_e is the environmental variance and σ_g is the genetic variance.

When siblings of the same parents are used, genetic variance is doubled, and the formula is converted to the following:

$$h^2 = \frac{2\sigma_g^2}{\sigma_g^2 + \sigma_e^2}$$

For the calculation and evaluation of heritability estimate values (h^2), Harvey's mixed model least-squared and maximum likelihood computer program (LSMLMW) model type II was used for the statistical analysis (Harvey, 1987).

Results

The means, SDs, and ranges of Bolton anterior and overall ratios and the results regarding the heritability estimate coefficients (h^2) are shown in Table 1. As can be seen, heritability estimate values (h^2) of overall and anterior ratios were statistically significant in all groups, except for the male–female group. Heritability coefficients (h^2) of overall ratios in the male–male and pooled groups were less than those of the female–female group. Bolton anterior and overall ratios had high heritability (especially in the anterior ratios) in siblings of the same gender (Table 1). In siblings of different gender, anterior and overall ratios did not show any heritability.

Table 1 Ranges, means, and standard deviations (SD) of Bolton ratios and the results of Harvey's heritability analysis.

Group	*n* (pair)	Variable	Bolton ratios				Heritability values		
			Minimum	Maximum	Mean	SD	h^2	SE	*P*
Male–male	24	Anterior ratio	71.57	85.16	79.03	2.95	>1*	0.269	0.000
		Overall ratio	86.97	96.33	92.32	2.17	0.641	0.370	0.048
Female–female	38	Anterior ratio	70.87	88.88	79.09	3.22	0.764	0.279	0.005
		Overall ratio	84.31	96.80	91.77	2.12	0.813	0.273	0.003
Male–female	30	Anterior ratio	73.20	88.38	79.65	3.24	0.334	0.316	0.150†
		Overall ratio	85.10	97.30	92.40	2.35	0.240	0.317	0.228†
Pooled group	92	Anterior ratio	70.87	88.88	79.11	3.03	0.586	0.191	0.001
		Overall ratio	84.31	97.30	92.03	2.20	0.442	0.198	0.014

*Genetic variance invalidated by environmental covariance.
†Not significant.
SE, standard error.

Discussion

Information on family members can be useful in predicting the effects of facial growth on occlusion. However, despite the fact that there have been many studies of craniofacial dimensions in families and that anthropologists have long been interested in the inheritance of tooth size, little is known about the genetic effects on features most relevant to the treatment of malocclusions, such as anterior crowding, buccal segment relationships, overjet and overbite (Harris and Smith, 1980). The present study aimed to determine the possible effects of genetic factors on Bolton ratios.

In genetic studies, twins, siblings, and parents are the most commonly used subjects. However, tooth loss, restorative and orthodontic treatment of older generations make such investigations difficult. The researcher is, then, generally restricted to the study of similarities between siblings rather than between parent and child (Harris and Smith, 1980). Siblings resemble each other not only because they share approximately half their genes, but also because they experience very similar pre-, peri-, and post-natal environments. In other words, there are two general factors that could contribute to familial resemblances: the sharing of common genes and the sharing of common environments (Harris and Smith, 1980, 1982; Harris and Johnson, 1991). Sibling pairs of the same and different gender in the permanent dentition were included in this study. Their ages were not taken into consideration, as the final sizes of dental crowns were determined before emergence of the teeth into the oral cavity.

Phenotypic variance consists of genetic and environmental variances. When genetic and environmental contributions are partitioned, the total genotypic contribution to the phenotypic variation is termed 'heritability' in the broad sense. This variance can, in turn, be partitioned into contributions from individual alleles (dominance variance), from pairs of homologous alleles at a locus (dominance variance), from combinations of non-homologous loci (epistatic variance), and so forth. In contrast, the potentially smaller proportion of phenotypic variance that can be attributed to additive genetic variance is called 'heritability' in the narrow sense (Harris and Johnson, 1991). In the present study, narrow sense heritability assessments were used.

The mechanics of measuring tooth size may be carried out with a sliding calliper with a vernier scale, a pair of dividers (Doris *et al.*, 1981; Santoro *et al.*, 2000), or computerized methods (Tomasetti *et al.*, 2001). Measurements from dental casts are more consistent and therefore more accurate than direct measurements taken from the oral environment, particularly in the posterior segments (Doris *et al.*, 1981). In the present study, mesio-distal dimensions of the teeth were measured from dental casts using a pair of engineer dividers with fine tips, as described by Bolton (1958, 1962), and special attention was paid to the measurement procedures.

Tooth size may play an important role in the aetiology of malocclusions, and thus it should be taken into consideration in orthodontic examination and therapy (Lavelle, 1972). Doris *et al.* (1981) pointed out that the total mesio-distal tooth size was uniformly larger in crowded arches. It has been shown that tooth size is essentially dependent upon genetic factors (Lavelle, 1972; Harris and Smith, 1980; Doris *et al.*, 1981; Sharma *et al.*, 1985; Boraas *et al.*, 1988; Harris and Johnson, 1991). Variations in tooth positions and occlusal similarities, such as overjet, overbite, molar relationship, crowding, spacing, and arch length and shape, within families may be more related to common environmental effects than to heredity. Because siblings share the same maternal environment, including a number of issues relevant to skeletal development (e.g. dietary preferences, manner of food preparation, socio-economic status, patterns of energy expenditure, and childhood illnesses)

(Harris and Smith, 1980, 1982; Harris and Johnson, 1991), they may show similar occlusal traits. This resemblance between siblings may be helpful in orthodontic examination and treatment planning.

Many investigators have attempted to quantify interarch tooth-size discrepancies (Freeman *et al.*, 1996), but none is as useful or as well accepted as the study published in 1958 by Bolton (White, 1982; Crosby and Alexander, 1989; Shellhart *et al.*, 1995; Freeman *et al.*, 1996; Smith *et al.*, 2000). According to Sheridan (2000), the vast majority of orthodontists (91 per cent) use Bolton's tooth-size analysis.

Lavelle (1972) reported that the overall and anterior ratios were consistently larger in males than in females, regardless of race. Smith *et al.* (2000) found significant gender differences for overall and posterior ratios, but not for the anterior ratio. In the present investigation, no gender differences were observed in either overall or anterior ratios, and thus, in addition to the studies in the three sibling pairs, heritability estimate values were computed for the pooled group.

A number of articles have been published concerning Bolton's tooth-size analysis, with the majority refuting the effects of tooth-size discrepancy on occlusion (Bolton, 1958, 1962; Richardson and Malhotra, 1975; Sperry *et al.*, 1977; Crosby and Alexander, 1989; Shellhart *et al.*, 1995; Freeman *et al.*, 1996; Rudolph *et al.*, 1998; Heusdens *et al.*, 2000; Santoro *et al.*, 2000). No study investigating the heritability of tooth-size discrepancy could be found and, therefore, it was not possible to compare the results with those of other studies.

It was found that heritability estimate values were statistically significant in all groups, except in the male–female group (Table 1). Heritability estimate coefficients (h^2) of the anterior ratio were higher than those of the overall ratio in the male–male and pooled groups. The reason for this finding cannot be explained. That the heritability estimate coefficients (h^2) of overall and anterior ratios were not statistically significant in the group with different genders could be explained by the fact that the teeth of males were larger than those of females for each type of tooth in both arches.

Harris and Smith (1982) reported that sibling correlations include the effects of a shared environment, so this estimate of h^2 is almost invariably inflated. In the present study, an invariably inflated h^2 value ($h^2 > 1$) was only seen in the anterior ratio of the male–male group (Table 1). The other h^2 values did not show any inflation.

Conclusion

If a patient has a tooth-size discrepancy, the same problem may also be seen in siblings of the same gender. For orthodontic diagnosis and treatment planning, it should be remembered that it is not the aetiology of the resemblance between siblings, but the resemblance itself that should be taken into consideration.

Address for correspondence

Hüsamettin Oktay
Atatürk Üniversitesi
Diş Hekimliği Fakültesi
Ortodonti Anabilim Dalı
25240-Erzurum
Turkey
Email: hoktay@atauni.edu.tr

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