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# Tooth dimensions in hypodontia patients, their unaffected relatives and a control group measured by a new image analysis system

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SUMMARY Tooth dimensions were compared between index patients with severe hypodontia (six or more congenitally missing teeth), their relatives with a full complement of teeth, and a control group. The groups consisted of 12 index cases (seven females and five males), 21 relatives without hypodontia (13 females and eight males), and a control group of 10 males and 10 females with complete dentitions, and no family history of hypodontia.

All formed teeth were imaged buccally and occlusally from study models, with a digital camera linked to a computer. The images were acquired and measured using Adobe Photoshop and Image Pro Plus, respectively. Mesiodistal, buccolingual, or occlusogingival area and perimeter measurements were determined from each image.

In the index hypodontia group tooth dimensions were significantly smaller ($P < 0.001$, Bonferroni corrected level) for maxillary and mandibular canines, and first premolars for all dimensions from the buccal view, and for maxillary and mandibular canines and first premolars, maxillary central incisors, maxillary first molars, mandibular lateral incisors, and mandibular second premolars for all dimensions from the occlusal view.

In the relatives without hypodontia compared with the control group, mesiodistal dimensions from the buccal view were significantly smaller ($P < 0.001$) for the central incisors and maxillary first and second premolars, and for the maxillary and mandibular first premolars for all dimensions from the occlusal view.

There was a trend for the tooth dimensions of all teeth in the index group to be smaller compared with the control group. The tooth dimensions of the relatives without hypodontia also tended to be smaller than the control group, but were larger than those of the index cases.

## Introduction

The term 'hypodontia' refers to the congenital absence of teeth. Hypodontia is not an isolated trait but occurs with other dental anomalies, including an alteration in tooth dimensions (Brook, 1984).

The prevalence of hypodontia has been estimated between 2.3 per cent (Werther and Rothenberg, 1939) and 10.1 per cent (Hunstadbraten, 1973) in the permanent dentition. Many factors account for the variation in estimated prevalence of dental anomalies, including the criteria and technique for establishing the anomaly, and variations in potentially important characteristics such as age, gender, inclusion of affected siblings, ethnic, and racial background (Brook, 1975).

Tooth size is important in planning orthodontic treatment. The size of the teeth in relation to the jaws will determine whether the dentition is spaced, well aligned, or crowded. Discrepancies between the amount of tooth tissue in different arches will determine buccal interdigitation, overjet, overbite, and centreline discrepancies. Thus, the dental anomalies associated with hypodontia have implications for orthodontic treatment. These anomalies include smaller dimensions of the remaining teeth, abnormal

tooth morphology involving both crowns and roots, delayed tooth formation, delayed, or ectopic eruption, alteration of the eruption sequence, and tooth malposition.

Various genetic and environmental factors have been implicated in the aetiology of hypodontia. Studies have shown that hypodontia fulfils the criteria for a genetic trait (Graber, 1978; Jorgenson, 1980; Schalk-van der Weide, 1992). Concerning the mode of inheritance, single gene defects (usually autosomal dominant with incomplete penetration and variable expression) have been proposed (Grahnén, 1956; Woolf, 1971; Philip and Caudry, 1985; Ranta, 1985; Svinhufvud *et al*., 1988). It is possible, however, that the data used in the various studies fit different patterns for the mode of inheritance. This was shown by Brook (1974a), and by Suarez and Spence (1974), who determined that Grahnén's (1956) data would also fulfil the criteria for a polygenic model of inheritance. Polygenic inheritance is caused by a number of genes each with a relatively small effect and is commonly found in continuous traits. Many authors have suggested polygenic models (Brook, 1974b; Suarez and Spence, 1974; Bailit, 1975; Chosack *et al*., 1975; Schalk-van der Weide *et al*., 1992), and a quasi-continuous trait, based on an underlying continuous distribution of tooth size, has been proposed as an extension of this reasoning (Brook, 1974a; Bailit, 1975). Evidence for this model has come from twin and family studies. Subsequently, Brook (1984) described a multi-factorial model in which genetic factors play a major part, but environmental factors are also included (Figure 1). This model has a continuous scale related to tooth number and size, with separate curves for males and females. At each end of the distribution there are two anomalies: one tail displays hypodontia and microdontia, and the other supernumeraries and megadontia. Hypodontia and supernumeraries occur at the threshold points. The genetic component of this model includes both single gene defects of major and polygenic effects. The possible environmental influences include infections, such as rubella, irradiation, and drugs.

Recent studies have begun to elucidate which genes may be involved in hypodontia. Various homeobox genes, e.g. Msx-1, Msx-2, Dlx-1, Dlx-2, and Barx-1 have been found to be expressed in various regions of future tooth development in experiments in mice (Cobourne, 1999). It has therefore been suggested that homeobox genes may be implicated in human dental development and possibly patterning of the dentition. Vastardis (2000) recommended the use of human molecular genetics and the 'family study' method to identify the genes involved in hypodontia. Nieminen *et al*. (1995) studied the relationship of the Msx-1 and Msx-2 homeobox genes in five families and linkage analysis excluded these genes as a cause

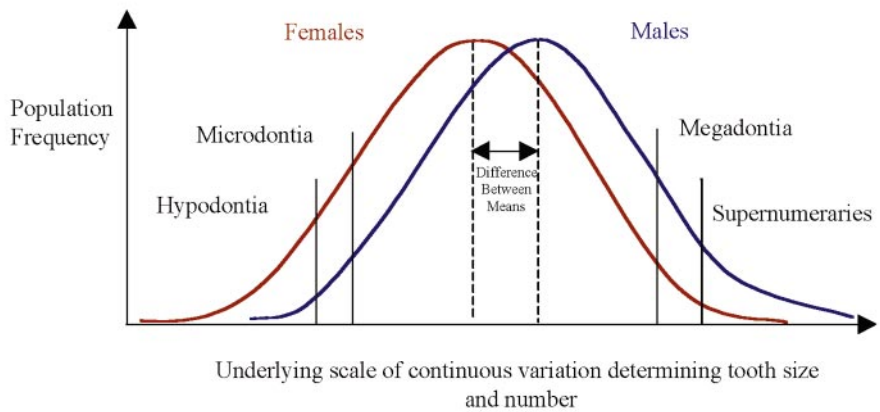


**Figure 1** Brook's multi-factorial model (1984) proposing the aetiology of dental anomalies of tooth number and size. Reprinted from Brook (1984) with permission from Elsevier Science.

of hypodontia in those families. However, Vastardis *et al*. (1996) used genetic linkage analysis in a family with agenesis of second premolars and third molars, and identified a locus on chromosome 4p, where the Msx-1 gene resides. Further sequence analyses demonstrated an Arg31Pro mis-sense mutation in the homeodomain of Msx-1 in all the affected family members. Arte *et al*. (1996) performed genetic mapping of hypodontia in 77 individuals from seven families, 31 of whom had incisor–premolar hypodontia. They studied the possibility of linkage between hypodontia and some candidate genes, previously suggested to have important functions during tooth development. Their results excluded epidermal growth factor, epidermal growth factor receptor, and fibroblast growth factor-3 loci as possible sites for gene mutation in these cases.

Peters *et al*. (1998) showed that Pax-9 is essential for the formation of teeth and that it is required for tooth development to proceed beyond the bud stage in mice. In patients with isolated hypodontia sequence variations in candidate genes Msx-1, Pax-9, and Pitx-2 may be associated with isolated tooth agenesis (Milton *et al*., 2000). Stockton *et al*. (2000), in a family study of autosomal dominant hypodontia, demonstrated that a mutation in Pax-9 is associated with tooth agenesis, and the phenotypic and segregation analyses have been described in this family (Goldenberg *et al*., 2000).

Lyngstadaas *et al*. (1996) reported an increase in the number of congenitally missing teeth along with some of the minor symptoms of ectodermal dysplasia, following the mating of affected individuals from two unrelated families. They concluded that this may have resulted due to allelic mutations at a single gene locus, or may have been due to a synergistic effect, as expected for a multi-factorial trait with interacting gene products.

One study has revealed a reduction in tooth size in male and female relatives of patients with severe hypodontia (Schalk-van der Weide and Bosman, 1996). However, limited tooth dimensions were measured and non-independence of data needs to be addressed.

The aims of the present study were to determine whether individuals with hypodontia and a group of their relatives without hypodontia have teeth of smaller dimensions than a control group. These findings will contribute to the developing understanding of the aetiology of hypodontia.

## Materials and methods

Following ethical approval by the South Sheffield Research Ethics Committee, a prospective study of relatives of individuals affected with severe hypodontia (i.e. six or more congenitally absent teeth), their first degree relatives and a control group was carried out measuring tooth dimensions in all formed teeth. All individuals were patients in the Departments of Orthodontics and Child Dental Health at the Charles Clifford Dental Hospital, Sheffield. All were white Caucasians and older than 9 years of age. The index hypodontia patients did not have any associated syndrome and had no unexplained previous loss of teeth due to trauma, caries, periodontal disease, or orthodontic extractions. All index cases completed medical questionnaires and were directly questioned regarding sparse hair and absence of sweating. Twelve families gave informed consent to the study, providing 12 index cases (seven females and five males) and 21 relatives without hypodontia (13 females and eight males). The control group consisted of 10 males and 10 females patients referred at the same time as the index cases with complete permanent dentitions and no family history of hypodontia.

A single operator, according to the manufacturer's instructions, took upper and lower alginate impressions (Fidelity alginate, Davis Schottlander and Davis Ltd, Letchworth, UK) of each individual. The impressions were cast in yellow dental stone (Kaffir D, British Gypsum, Newark, UK) the same day. The study models were mounted on an adjustable stand and buccal and occlusal tooth surfaces were individually imaged using a 32-bit digital camera (Kodak/Nikon DCS 410, KJP, Manchester, UK) with a 90 mm macro lens (Elicar, KJP, Manchester, UK), linked to a computer (Pentium II-266 MMX, Viglen Ltd, Middlesex, UK).

The camera was mounted horizontally above the model on an adjustable rod (Figure 2). The

**Figure 2** The image analysis equipment including a 32-bit digital camera mounted on a stand, positioned over a study model, and linked to a computer.

lens was focused parallel to the tooth surface and parallel to the long axis of the clinical crown for buccal views, or perpendicular to the long axis of the clinical crown for occlusal views. A calibration scale was included in each image. Two multi-directional white strip lights provided standardized illumination.

All permanent teeth were imaged (Table 1), except teeth that were partially erupted (i.e. those teeth that had not reached the occlusal level of adjacent teeth and were not in function), had restorations, excessive wear involving the mesial, distal, buccal, or lingual surfaces, or were severely crowded or rotated.

The images were acquired using Adobe Photoshop (V 4.0, Adobe Systems Ltd, KJP, Manchester, UK), and Image Pro Plus (V 3.01, Datacell, Finchampsted, UK) was used for measurement after image calibration.

The perimeter, area, maximum mesiodistal, buccolingual, and occlusogingival measurements were then determined (Figure 3). The reproducibility of the measurements using this system has been reported (Brook *et al.*, 1998), and intra- and inter-operator agreement was assessed prior to imaging and measuring the study groups.

### *Error of the method*

The error study was performed using a mixture of second molars, canines, and lateral and central

**Table 1** The number of individuals in the control, index, and relatives groups.

| Tooth | Control | Index | Relatives |
|---|---|---|---|
| 11,21 | 20 | 12 | 18 |
| 12,22 | 19 | 3 | 20 |
| 13,23 | 15 | 10 | 18 |
| 14,24 | 18 | 4 | 19 |
| 15,25 | 20 | 2 | 19 |
| 16,26 | 20 | 12 | 17 |
| 17,27 | 11 | 5 | 19 |
| 31,41 | 19 | 5 | 19 |
| 32,42 | 19 | 9 | 20 |
| 33,43 | 19 | 10 | 19 |
| 34,44 | 19 | 10 | 20 |
| 35,45 | 16 | 2 | 18 |
| 36,46 | 20 | 12 | 15 |
| 37,47 | 13 | 2 | 16 |

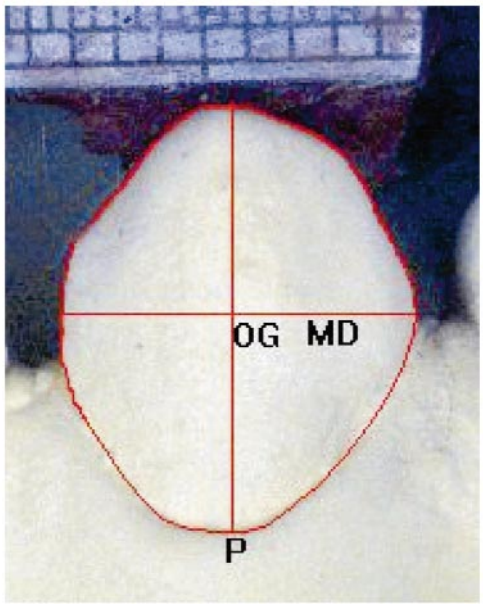


**Figure 3** A digital image of the labial surface of a maxillary canine tooth on a study model, showing the measurements made, i.e. the mesiodistal dimension (MD), the occlusogingival dimension (OG), and the perimeter (P).

incisors from hypodontia and control cases. Twenty-one teeth were included in the intra-operator error study and 29 teeth in the inter-operator error study. All teeth were imaged and measured on two separate occasions approximately two weeks apart.

*Statistical analysis*

*Method error*. Using the mean and standard deviation of the differences between each pair of measurements, limits of agreement (Bland and Altman, 1986) were constructed to provide ranges within which 95 per cent of measurement differences lie.

*Bilateral averaging*. Prior to analysis an assessment was made to evaluate the information lost by averaging bilateral measurements from opposite sides of the mouth. If considered separately, the same characteristic may be tested twice if bilateral measurements are essentially the same in value, and also at a lower level of significance to allow for multiple testing. Variance components from a one-way ANOVA were used to compare the variation in measurements within individuals (between left and right) with the variation in the average of these measurements between individuals. If the variation within an individual was small compared with that between individuals, then the measurements may be thought of as essentially measuring the same characteristic and so little information will be lost by averaging.

*Comparison between index group and control group*. For each dimension variable considered, a test for a difference in mean value was made between the index and control patients, whilst controlling for any influence that may be due to gender. This was achieved using linear modelling and testing the model parameter for between groups in a model, which already includes a parameter for between genders.

*Comparison between relatives without hypodontia and the control group*. The 21 relatives without hypodontia related to the 12 index cases could not be regarded as independent due to shared family membership. Consequently, an analysis of form above (or a standard *t*-test) would be inappropriate. For each variable considered the data formed an unbalanced, mixed effects multilevel design with three levels; each individual fell within a family, and within either the control or 'relatives without hypodontia' group. The design was unbalanced since the family sizes and group numbers varied.

Each variable was modelled as below:

$$\text{Tooth dimension} = \beta_0 + \beta_1 + \mu_{\text{fam}} + \varepsilon_{\text{individ (within fam)}} + \beta_2$$

where $\beta_1 = 0$ if the individual was from the control group; $\beta_0$ represents the mean score in the control group; $\beta_0 + \beta_1$ the mean score in the relatives without hypodontia; $\beta_1$ the difference in means between the two groups; $\mu_{\text{fam}}$ the random variation in family means (between families); $\varepsilon_{\text{individ (within fam)}}$ the variation of individuals within families; and $\beta_2$ a parameter controlling for differences in tooth dimension due to sex differences

Analysis was performed using the package 'MlwiN' version 1.0 (Multilevel Models Project,

Institute of Education, University of London). Testing the term $\beta_1 = 0$ above, tests whether there is no difference in means between the two groups.

*Corrected significance levels*. Since multiple variables were compared, the nominal significance level of each test had to be adjusted using a Bonferonni correction. Approximately 100 tests were performed and so an overall level of 5 per cent was achieved by using a level of 0.05 per cent for each test. However, as many of the variables tested were likely to be correlated, this adjustment was somewhat conservative, so a level of 0.1 per cent (10 per cent overall) has also been indicated in the tables.

## Results

### *Method error*

The results of the error study are presented in Tables 2 and 3.

For example, if the mesiodistal dimension was measured from the buccal view by two examiners, 95 per cent of the measurements would be expected to lie within –0.42 to 0.32 mm of each other. If the same examiner were to measure the mesiodistal dimension again this range of agreement would be ± 0.18 mm.

### *Bilateral averaging*

The results indicate that there was much greater variation in right and left tooth dimensions between than within individuals. The mean intraclass correlation coefficient, which expresses between individual variation as a proportion of total (between and within individuals)

**Table 2** Intra-operator error assessment for mesiodistal (MD), occlusogingival (OG), buccolingual (BL), area, and perimeter tooth dimensions taken from the buccal or occlusal views on a selection of 21 teeth. The table displays the mean difference between pairs of measurements and the limits of agreement, calculated as twice the standard deviation of the differences about 0. None of the mean differences was significantly different to zero (5 per cent level), indicating no bias in measurement between occasions.

| | Mean difference | Limits of agreement |
|---|---|---|
| Buccal view | | |
| MD | 0.01 | 0.36 mm |
| OG | –0.12 | 0.64 mm |
| Area | –0.57 | 4.48 $mm^2$ |
| Perimeter | –0.21 | 1.23 mm |
| Occlusal view | | |
| MD | 0.03 | 0.34 mm |
| BL | 0.03 | 0.36 mm |
| Area | –0.61 | 4.67 $mm^2$ |
| Perimeter | –0.14 | 1.21 mm |

**Table 3** Inter-operator error assessment for mesiodistal (MD), occlusogingival (OG), buccolingual (BL), area, and perimeter tooth dimensions taken from the buccal or occlusal views on a selection of 29 teeth. The table displays the mean difference between pairs of measurements, the standard deviation of the differences, and the lower and upper limits of agreement calculated as mean difference ± 2 SD of the differences. None of the mean differences was significantly different to zero, indicating no bias in measurement between occasions.

| | Mean difference | SD of difference | Lower limit | Upper limit |
|---|---|---|---|---|
| Buccal view | | | | |
| MD | –0.05 | 0.18 | –0.42 mm | 0.32 mm |
| OG | –0.10 | 0.37 | –0.84 mm | 0.64 mm |
| Area | –0.70 | 2.88 | –6.36 $mm^2$ | 5.05 $mm^2$ |
| Perimeter | –0.19 | 0.68 | –1.55 mm | 1.17 mm |
| Occlusal view | | | | |
| MD | –0.03 | 0.21 | –0.44 mm | 0.39 mm |
| BL | –0.12 | 0.43 | –0.98 mm | 0.75 mm |
| Area | –1.08 | 3.43 | –7.94 $mm^2$ | 5.78 $mm^2$ |
| Perimeter | –0.14 | 1.00 | –2.13 mm | 1.85 mm |

variation was 86.37 per cent for mandibular teeth (range 64.41–98.72 per cent) and 86.9 per cent (range 65.22–97.47 per cent) for maxillary teeth. Therefore, the teeth from both right and left sides were averaged in subsequent analyses.

*Index group compared with the control group*

The results are presented in Tables 4 and 5. Tooth dimensions were significantly smaller in the index group compared with the control group ($P < 0.001$, Bonferroni corrected level) for maxillary and mandibular canines, and first premolars for all dimensions from the buccal view, and for maxillary and mandibular canines and first premolars, maxillary central incisors, maxillary first molars, mandibular lateral incisors, and mandibular second premolars for all dimensions from the occlusal view. Area measurements produced the same significant differences as the perimeter measurements so are not reported here.

*Relatives without hypodontia compared with the control group*

Tooth dimensions were significantly smaller in the relatives without hypodontia compared with the control group ($P < 0.001$) for the mesiodistal dimension from the buccal view for the central incisors, and maxillary first and second premolars, and for all dimensions from the occlusal view

**Table 4** Tooth dimensions in hypodontia patients, their relatives, and the control group. O, MD, and BL indicate the occlusal view, the mesiodistal dimension, and the buccolingual dimension, respectively.

| Tooth | Control | | Index | | Relatives | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| MD (O) | | | | | | |
| 11,21 | 9.44 | 0.56 | 7.80[a] | 0.67 | 8.47[a] | 0.56 |
| 12,22 | 7.35 | 0.51 | 5.92[a] | 0.29 | 6.56[a] | 0.51 |
| 13,23 | 8.35 | 0.42 | 7.29[a] | 0.54 | 7.80 | 0.31 |
| 14,24 | 7.49 | 0.31 | 6.73[a] | 0.49 | 6.98[a] | 0.27 |
| 15,25 | 7.09 | 0.34 | 6.34 | 0.07 | 6.75 | 0.39 |
| 16,26 | 10.95 | 0.47 | 9.85[a] | 1.04 | 10.47 | 0.42 |
| 17,27 | 10.33 | 0.65 | 9.64 | 0.56 | 10.09 | 0.52 |
| 31,41 | 5.98 | 0.35 | 5.26[b] | 0.31 | 5.44 | 0.26 |
| 32,42 | 6.49 | 0.38 | 5.60[a] | 0.35 | 6.02[b] | 0.37 |
| 33,43 | 7.41 | 0.50 | 6.52[a] | 0.57 | 6.84 | 0.33 |
| 34,44 | 7.67 | 0.37 | 6.51[a] | 0.50 | 7.13[a] | 0.39 |
| 35,45 | 7.64 | 0.38 | 6.17[a] | 0.19 | 7.19 | 0.36 |
| 36,46 | 11.62 | 0.59 | 10.82 | 1.01 | 11.12 | 0.55 |
| 37,47 | 11.09 | 0.64 | 11.00 | 0.04 | 11.02 | 0.60 |
| BL (O) | | | | | | |
| 11,21 | 7.98 | 0.63 | 6.34[a] | 0.87 | 7.41 | 0.56 |
| 12,22 | 7.26 | 0.86 | 5.70 | 0.16 | 6.56 | 0.44 |
| 13,23 | 8.84 | 0.88 | 6.92[a] | 0.89 | 7.98 | 0.33 |
| 14,24 | 10.11 | 0.49 | 8.33[a] | 0.80 | 8.62[a] | 0.48 |
| 15,25 | 10.15 | 0.54 | 8.22[a] | 0.50 | 8.91[a] | 0.56 |
| 16,26 | 12.02 | 0.69 | 10.20[a] | 0.83 | 11.06[a] | 0.24 |
| 17,27 | 11.77 | 0.75 | 10.49[b] | 0.45 | 10.87 | 0.63 |
| 31,41 | 6.98 | 0.58 | 6.05[b] | 0.59 | 6.41 | 0.36 |
| 32,42 | 7.31 | 0.64 | 5.90[a] | 0.49 | 6.68 | 0.52 |
| 33,43 | 8.09 | 0.79 | 6.79[a] | 0.69 | 7.56 | 0.28 |
| 34,44 | 8.59 | 0.59 | 6.95[a] | 0.55 | 7.55[a] | 0.38 |
| 35,45 | 9.24 | 0.59 | 7.33[a] | 0.22 | 8.18[a] | 0.45 |
| 36,46 | 11.23 | 0.79 | 9.83[a] | 0.61 | 10.20[b] | 0.49 |
| 37,47 | 10.92 | 0.76 | 10.36 | 1.48 | 10.11 | 0.64 |

[a]$P < 0.05$, [b]$P < 0.001$, when mean dimension was compared with control group.

**Table 5** Tooth perimeter measurements in hypodontia patients, their relatives, and the control group from the occlusal (O) and buccal (B) views.

| Tooth | Control | | Index | | Relatives | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| Perimeter (O) | | | | | | |
| 11,21 | 27.83 | 1.84 | 22.65[a] | 2.04 | 25.44 | 1.71 |
| 12,22 | 23.20 | 1.92 | 18.45[b] | 0.43 | 20.88 | 1.42 |
| 13,23 | 27.39 | 1.38 | 22.33[a] | 1.82 | 24.77[b] | 0.96 |
| 14,24 | 28.56 | 1.26 | 24.16[a] | 2.18 | 25.29[b] | 1.28 |
| 15,25 | 28.09 | 1.37 | 23.17[a] | 1.31 | 25.35[b] | 1.35 |
| 16,26 | 38.54 | 1.54 | 33.53[a] | 3.03 | 36.23[a] | 1.80 |
| 17,27 | 36.78 | 2.10 | 33.50 | 1.78 | 34.69 | 1.13 |
| 31,41 | 20.34 | 1.44 | 17.89 | 0.95 | 18.84[b] | 0.75 |
| 32,42 | 21.59 | 1.67 | 18.18[a] | 0.86 | 20.24 | 1.47 |
| 33,43 | 24.79 | 2.13 | 20.87[a] | 1.98 | 22.84 | 0.68 |
| 34,44 | 26.03 | 1.48 | 21.31[a] | 1.54 | 23.33[b] | 0.97 |
| 35,45 | 27.44 | 1.67 | 21.42[a] | 0.61 | 24.82[a] | 1.01 |
| 36,46 | 38.12 | 2.03 | 34.14[a] | 2.38 | 35.69[b] | 1.28 |
| 37,47 | 36.98 | 1.85 | 35.54 | 2.96 | 35.34 | 2.10 |
| Perimeter (B) | | | | | | |
| 11,21 | 33.28 | 1.78 | 28.39[a] | 3.35 | 30.93 | 2.31 |
| 12,22 | 25.68 | 2.24 | 21.34 | 1.62 | 25.20 | 2.24 |
| 13,23 | 28.20 | 1.46 | 24.27[a] | 2.63 | 27.98 | 1.38 |
| 14,24 | 23.58 | 0.93 | 19.43[a] | 1.99 | 23.68 | 1.55 |
| 15,25 | 21.16 | 1.46 | 17.71 | 0.83 | 21.66 | 2.38 |
| 16,26 | 28.87 | 1.23 | 25.71[a] | 2.97 | 29.77 | 3.17 |
| 17,27 | 27.96 | 1.33 | 27.41 | 4.54 | 28.62 | 1.91 |
| 31,41 | 24.86 | 1.59 | 22.48 | 2.36 | 23.10 | 1.93 |
| 32,42 | 24.96 | 1.56 | 21.29[a] | 2.41 | 24.66 | 2.16 |
| 33,43 | 27.61 | 2.13 | 22.90[a] | 3.60 | 27.72 | 1.56 |
| 34,44 | 25.03 | 1.27 | 21.38[a] | 1.50 | 25.13 | 1.02 |
| 35,45 | 23.30 | 1.53 | 19.91 | 0.85 | 24.10 | 1.76 |
| 36,46 | 31.56 | 1.71 | 29.05 | 3.29 | 31.17 | 2.37 |
| 37,47 | 29.22 | 1.79 | 26.55 | 1.74 | 30.36 | 2.30 |

[a]$P < 0.05$, [b]$P < 0.001$, when mean dimension was compared with control group.

for the maxillary and mandibular first premolars (Tables 4 and 5). Again, area measurements produced the same significant differences as the perimeter measurements and so are not reported.

## Discussion

The purpose of this study was to contribute to the understanding of the aetiology of hypodontia. Brook (1984) described a multi-factorial model for hypodontia, based on an underlying continuous distribution of tooth number and size. Schalk-van der Weide and Bosman (1996) also investigated mesiodistal tooth size in relatives of individuals with hypodontia, and concluded that, in determining the mode of inheritance, measurements of the size of teeth of relatives are important. Minor signs, such as smaller tooth dimensions, should be included or the genetic pattern may be missed. Accurate recordings of tooth dimensions are therefore required. This study used an image analysis system developed for this purpose (Brook *et al*., 1998). This has advantages over manual methods in that multiple measurements can be made from a single image and automation of procedures during measurement reduces subjectivity in identifying landmarks.

*Data obtained*

The data collected for this study fit some of the criteria for a multi-factorial trait (Brook, 1984). The proportion of affected relatives is consistent with the expected frequency. In this study six out of 27 relatives (22 per cent) also had hypodontia. With a population frequency of 4.4 per cent for British white Caucasians (Brook, 1974b) the expected value in first-degree relatives is 21 per cent for a multi-factorial inheritance (Emery, 1976). In the study of Grahnén (1956) the population prevalence in Swedish white Caucasians was 6.1 per cent and the observed affected relatives frequency was 31 per cent, compared with the expected frequency of 25 per cent for a multi-factorial trait (Emery, 1976).

*Index group*

Several studies have shown smaller tooth dimensions of the formed teeth in patients with hypodontia (Garn *et al*., 1963; Keene, 1964; Garn and Lewis, 1970; Baum and Cohen, 1971; Rune and Sarnäs, 1974; Schalk-van der Weide *et al*., 1994). Often only mesiodistal dimensions have been measured, but Schalk-van der Weide *et al*. (1994) manually measured maximal labiolingual dimensions in hypodontia patients. Their results showed a similar and slightly greater reduction in labiolingual dimensions compared with mesiodistal dimensions.

The present study also demonstrated smaller mesiodistal and labiolingual dimensions in individuals with hypodontia, with nine out of 14 tooth types significantly reduced in the mesiodistal dimension from both views, and 10 out of 14 tooth types significantly smaller in the labiolingual dimension from the occlusal view. These proportions may have been higher if larger sample sizes had been available, increasing the power of the statistical tests, but due to the frequency of missing tooth types in hypodontia, only low numbers of some teeth were available. An example of this concerns maxillary lateral incisors. Clinically, such teeth often appear diminutive, but only three teeth were available for measurement and, consequently, the ability to reject the hypothesis of no difference in each mean tooth dimension was limited. However, the lack of significant differences in these teeth is not evidence that the dimensions are equivalent (i.e. that no differences exist.)

Occlusogingival, area, and perimeter measurements, not previously recorded in other studies, follow the same trend for tooth size reduction exhibited by other dimensions in the hypodontia patients (Tables 4 and 5).

*Relatives of index cases*

This study involved detailed measurements of tooth dimensions in relatives of individuals with hypodontia as recommended by Brook (1984) and Schalk-van der Weide and Bosman (1996). Significantly smaller dimensions from the buccal view were recorded for the mesiodistal dimension of the central incisors and the maxillary first premolars. Results from the occlusal view demonstrated statistically significant differences in all four dimensions, which varied in magnitude between tooth types (Tables 4 and 5).

One other study investigated the mesiodistal dimensions in 59 first and second-degree relatives of individuals with hypodontia (Schalk-van der Weide and Bosman, 1996). The relatives were divided into two groups, those with hypodontia and those with a full complement of teeth, with male and female data reported separately. It was found that the relatives who had hypodontia and those with complete dentitions had smaller mesiodistal diameters than a control group.

Six relatives with missing teeth were also measured in the present study. They had an average of five missing teeth. Although it was not possible to perform any statistical analysis on these data, there would appear to be a trend for patients with fewer missing teeth to also have smaller teeth, although they were affected to a lesser extent than individuals with larger numbers of missing teeth. This is an area that warrants further investigation.

## Conclusions

The data are compatible with a multi-factorial model for hypodontia. Future work on enlarged samples would enhance consideration of penetration, expression, and dosage effects.

Tooth dimensions of all teeth in the index group were smaller compared with the control group, with the relatives without hypodontia group intermediate. There were statistically significant reductions in tooth dimensions between the index and control groups. There were also statistically significant reductions in tooth dimensions between the relatives without hypodontia and the control group.

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