# Variation in the Secular Changes in the Teeth and Dental Arches

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## INTRODUCTION

Secular trends in stature and other bodily dimensions have been reported in population samples from Russia,[1] Japan,[2] Sweden,[3] France,[4] North America[5] and England.[6] Although these trends are dependent upon a variety of factors, e.g., sex and socio-economic conditions,[7] Bakwin and McLaughlin[8] have suggested that secular increases in stature may now be reaching a plateau. Indeed, anthropometric measurements of Tristan da Cunha Islanders show no evidence for a secular trend over the past 30 years.[9]

In contrast to the general body dimensions, however, there are relatively little data relating to secular trends in the teeth and jaws. For instance, secular increases over the period between two generations have been noted for the teeth[10] and the palatal arch.[11] Lavelle[12] has reported similar secular trends for the arch and tooth dimensions among Caucasoids, Negroids and Mongoloids.

There is no information on whether the dental arches and teeth are affected as a whole by secular changes or whether only certain specific dimensions vary, e.g., arch length as opposed to arch width. Hence a study was undertaken to examine the secular trends of the teeth and arches in a more or less homogeneous population sample.

## MATERIALS AND METHODS

### *Subjects*

In this study each of 150 families involved comprised two offspring - a son and a daughter - and with both parents living. The subjects included in this study were derived from a four mile radius of Leek in North Staffordshire, England. The community is rural, with a small cotton-mill industry and, from examination of the Parish Records, has a stable population. The maximum age of the offspring was restricted by the number of parents with full dentitions, so that offspring of fourteen years or older were included. (This precluded any assessment of secular trends in overall bodily dimensions.) All subjects were Caucasoids, and from examination of the Parish Records, the family of each parent had remained native to Leek for at least three generations.

The families included in this study were selected on the basis that (a) each member had a full complement of teeth with the exception of the third molars; (b) each had no obvious skeletal abnormality and no history of previous orthodontic treatment; (c) each had approximately the same somatotype;[13] (d) all families had sons older than daughters; (e) no member of any family was related to a member of another family for at least three generations.

### *Measurements*

The dimensions of the dental arches and teeth were measured from alginate base hydrocolloid casts, which were initially inspected to exclude those whose condition precluded detailed measurement, and those that did not have a normal anteroposterior relationship between the maxillary and mandibular first molars.

1. Arch dimensions

Using the technique of Lavelle, Flinn, Foster and Hamilton,[14] the dimensions of the dental arches were determined with dial calipers held vertical to the occlusal plane and reading to the nearest 0.1 mm.

(a) Dental arch width: the dimensions of dental arch width were determined as the minimum distance between the centres of corresponding teeth on each side of the arch. Hence the dimensions of maxillary and mandibular arch width were measured between corresponding second and first molars, second and first premolars, canines, and second and first incisors.

(b) Dental arch length (direct): the dimensions of dental arch length (direct)) were measured as the minimum distances between the centres of adjacent teeth on the left side of the dental arch only. The dimensions measured were between the second and first molars, first molars and second premolars, second and first premolars, first premolars and canines, canines and second incisors, and second and first incisors. Due to the curvature of the anterior region of the dental arch, these dimensions between the canines and incisors were projected measurements.

(c) Dental arch length (chord): the dimensions of dental arch length (chord) were measured as the minimum distances between the most mesial aspect of the anterior tooth crowns to the most distal aspect of the posterior tooth crowns, determined from the left side of the dental arch. Thus the dimensions measured were between the central incisors and canines, central incisors and first molars, and between the canines and first molars.

These dimensions of the dental arch were selected since they provided an adequate metrical profile of the arch which could be readily measured.

2. Tooth dimensions

The following dimensions of the teeth from the left side of the dental arch were measured by means of a measuring microscope:

(a) mesiodistal crown diameter: this was measured as the minimum distance between the most mesial and distal crown convexities, determined parallel to the occlusal plane.

(b) buccolingual crown diameter: this was measured as the minimum distance between the most buccal and lingual crown convexities, determined at right angles to the mesiodistal crown diameter.

*Test of measurement technique*

Initially, ten subjects were selected at random and the measurements of their casts checked with the dimensions recorded from the actual teeth and dental arches, where there was in all cases complete agreement. Subsequently, ten sets of casts were randomly selected, and their arch and tooth dimensions determined five times by three independent observers. Analysis of variance showed that any error introduced as a result of inconsistencies in the measurement technique were less than two per cent and were unlikely to have any material effect on the results of the comparison ($P<0.02$).

## Statistical Analysis

The data were tabulated and examined by plotting pairs of dimensions to locate and rectify aberrant observations due to mistakes in measurement. For the four groups (fathers, mothers, sons and daughters), a programme was used which enabled not only the basic statistical data (means and standard errors for each group) to be printed out, but which plotted for each variate intragroup standard deviations against corresponding means, which showed that for each variate the standard deviations fluctuated randomly irrespective of the value of the mean.

The data were fed back into the computer and later, sections of the same programme were brought into operation to produce, by the general method described by Gower,[15] canonical analyses of:

(a) the maxillary and mandibular arch and tooth dimensions combined,
(b) the maxillary and mandibular arch dimensions combined,
(c) the maxillary arch dimensions combined,
(d) the mandibular arch dimensions combined,
(e) the maxillary and mandibular tooth dimensions combined,
(f) the maxillary tooth dimensions combined,
(g) the mandibular tooth dimensions combined.

*Presentation of results*

In order to reduce the tabular data included in this manuscript, only a summary is provided here.

The programme enabled a print out to be provided not only of the coordinates of each group (centered around an over-all mean of zero) in the various orthogonal dimensions of the canonical space (the number of axes being the total number of measurements), but also loadings by which the mean of each variate in each group must be multiplied, the products summed, and a given constant added or subtracted, to produce the canonical coordinates. It also provided:

1. a table of latent roots of the matrix from which the canonical axes were derived, these giving a measure of the proportion of the total variance contained in each axis,
2. the distance of each group from the centroid of the whole constellation in the multidimensional canonical space,
3. a table of the squared generalised distances between all pairs of groups ($D^2$).

The results of the various analyses were examined by the now standard method[16] of plotting the positions of the various groups in relation to pairs of those canonical axes which provided a marked measure of separation between the groups. By definition, discrimination between the groups decreased progressively, and inspection of the data showed that whether considering the arch or tooth dimensions, only the first two canonical axes affected appreciable discrimination between the groups. Hence the canonical coordinates for the first two axes are included in the tables of results (the degrees of separation between the groups being confirmed from the generalised distance ($D^2$) matrix).

## Results

The data for the dental arches of parents and offspring are summarised in Table 1, which emphasise the considerable variability both between and within the groups. The mean degree of sexual dimorphism was 4.5% for the maxillary and mandibular arch dimensions of parents, and 3.9% for the offspring. Furthermore, the mean degree of dimorphism in the maxillary and mandibular dimensions of arch width was 2.8% for the parents and 2.3% for the offspring, the respective figures for the maxillary and mandibular arch length being 4.9% and 3.7%.

The average over-all secular change in maxillary and mandibular arch dimensions between fathers and sons was a reduction of 1.6%, the reduction in arch width being 2.0% and in arch length 2.3%. Similarly, there was an average reduction of 0.7% in the dimensions of the dental arches of daughters compared with mothers, the

TABLE 1. MAXILLARY AND MANDIBULAR ARCH DIMENSIONS

| | | | MALE | | | | FEMALE | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | PARENT | | OFFSPRING | | PARENT | | OFFSPRING | |
| | | | N=150 x̄ | SE | N=150 x̄ | SE | N=150 x̄ | SE | N=150 x̄ | SE |
| MAXILLA | Arch Width: | 7-7 | 56.4 | 0.43 | 54.1 | 0.51 | 55.3 | 0.51 | 53.7 | 0.62 |
| | | 6-6 | 49.9 | 0.31 | 49.7 | 0.38 | 48.8 | 0.39 | 49.2 | 0.65 |
| | | 5-5 | 43.1 | 0.43 | 43.4 | 0.42 | 42.0 | 0.29 | 42.7 | 0.68 |
| | | 4-4 | 38.1 | 0.22 | 37.4 | 0.39 | 36.9 | 0.39 | 37.2 | 0.51 |
| | | 3-3 | 34.1 | 0.23 | 34.3 | 0.40 | 32.6 | 0.48 | 34.2 | 0.44 |
| | | 2-2 | 22.1 | 0.31 | 22.5 | 0.32 | 21.2 | 0.58 | 22.1 | 0.41 |
| | | 1-1 | 8.8 | 0.24 | 8.5 | 0.15 | 8.7 | 0.31 | 8.4 | 0.25 |
| | Arch Length: | 7-7/6-6 | 12.2 | 0.43 | 11.8 | 0.23 | 12.1 | 0.37 | 11.8 | 0.32 |
| | | 6-6/5-5 | 9.3 | 0.41 | 9.7 | 0.14 | 9.0 | 0.19 | 9.4 | 0.13 |
| | | 5-5/4-4 | 7.6 | 0.38 | 7.3 | 0.14 | 7.3 | 0.38 | 7.3 | 0.21 |
| | | 4-4/3-3 | 8.1 | 0.42 | 8.0 | 0.18 | 7.8 | 0.12 | 7.8 | 0.26 |
| | | 3-3/2-2 | 5.7 | 0.31 | 5.2 | 0.23 | 4.8 | 0.10 | 5.2 | 0.19 |
| | | 2-2/1-1 | 3.1 | 0.21 | 3.4 | 0.22 | 2.8 | 0.08 | 3.4 | 0.23 |
| | | 1-6 | 47.3 | 0.23 | 46.9 | 0.59 | 47.3 | 0.33 | 46.0 | 0.53 |
| | | 1-3 | 24.5 | 0.19 | 24.5 | 0.28 | 24.2 | 0.14 | 24.4 | 0.38 |
| | | 3-6 | 33.9 | 0.58 | 33.8 | 0.35 | 33.3 | 0.10 | 33.7 | 0.38 |
| MANDIBLE | Arch Width: | 7-7 | 50.2 | 0.42 | 48.8 | 0.59 | 48.8 | 0.23 | 47.9 | 0.61 |
| | | 6-6 | 44.5 | 0.39 | 43.3 | 0.48 | 42.9 | 0.32 | 42.7 | 0.57 |
| | | 5-5 | 37.4 | 0.62 | 37.1 | 0.68 | 36.2 | 0.37 | 36.1 | 0.51 |
| | | 4-4 | 32.0 | 0.33 | 32.0 | 0.48 | 31.5 | 0.27 | 30.8 | 0.65 |
| | | 3-3 | 25.8 | 0.24 | 26.1 | 0.51 | 25.4 | 0.11 | 26.0 | 0.41 |
| | | 2-2 | 14.9 | 0.31 | 17.2 | 0.48 | 14.5 | 0.13 | 15.2 | 0.34 |
| | | 1-1 | 5.3 | 0.08 | 6.5 | 0.17 | 5.0 | 0.23 | 6.3 | 0.36 |
| | Arch Length | 7-7/6-6 | 12.2 | 0.31 | 12.6 | 0.25 | 11.9 | 0.18 | 12.1 | 0.26 |
| | | 6-6/5-5 | 9.7 | 0.22 | 9.6 | 0.09 | 9.5 | 0.10 | 9.6 | 0.10 |
| | | 5-5/4-4 | 8.0 | 0.18 | 7.7 | 0.10 | 7.7 | 0.06 | 7.6 | 0.19 |
| | | 4-4/3-3 | 7.0 | 0.18 | 6.9 | 0.16 | 6.4 | 0.30 | 6.6 | 0.34 |
| | | 3-3/2-2 | 3.8 | 0.25 | 4.3 | 0.25 | 3.5 | 0.08 | 3.3 | 0.33 |
| | | 2-2/1-1 | 1.5 | 0.32 | 1.9 | 0.20 | 1.2 | 0.19 | 1.3 | 0.20 |
| | | 1-6 | 42.9 | 0.23 | 42.4 | 0.54 | 41.9 | 0.09 | 42.3 | 0.49 |
| | | 1-3 | 18.9 | 0.29 | 18.9 | 0.31 | 18.3 | 0.35 | 18.8 | 0.22 |
| | | 3-6 | 34.5 | 0.35 | 33.3 | 0.41 | 33.4 | 0.33 | 33.3 | 0.46 |

$\bar{x}$ = Mean dimension (mms); SE = Standard error; N = Number in sample

TABLE 2. MAXILLARY AND MANDIBULAR TOOTH DIMENSIONS

| | | | MALE | | | | FEMALE | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | PARENT | | OFFSPRING | | PARENT | | OFFSPRING | |
| | | | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE |
| MAXILLARY | Incisor 1 | MD | 8.74 | 0.06 | 8.76 | 0.19 | 8.61 | 0.07 | 8.63 | 0.18 |
| | | BL | 7.04 | 0.06 | 7.11 | 0.11 | 6.84 | 0.12 | 6.89 | 0.14 |
| | Incisor 2 | MD | 6.72 | 0.09 | 6.74 | 0.16 | 6.69 | 0.09 | 6.72 | 0.12 |
| | | BL | 6.51 | 0.11 | 6.56 | 0.08 | 6.24 | 0.07 | 6.29 | 0.06 |
| | Canine | MD | 7.98 | 0.11 | 8.04 | 0.21 | 7.75 | 0.08 | 7.84 | 0.11 |
| | | BL | 9.36 | 0.07 | 9.42 | 0.14 | 8.88 | 0.04 | 8.91 | 0.08 |
| | Premolar 1 | MD | 6.95 | 0.05 | 6.99 | 0.11 | 7.04 | 0.08 | 7.12 | 0.23 |
| | | BL | 9.84 | 0.06 | 9.87 | 0.18 | 9.66 | 0.11 | 9.68 | 0.06 |
| | Premolar 2 | MD | 6.63 | 0.04 | 6.72 | 0.11 | 6.57 | 0.06 | 6.63 | 0.14 |
| | | BL | 9.97 | 0.09 | 10.01 | 0.19 | 9.86 | 0.09 | 9.94 | 0.19 |
| | Molar 1 | MD | 10.68 | 0.07 | 10.74 | 0.20 | 10.48 | 0.04 | 10.54 | 0.08 |
| | | BL | 12.18 | 0.09 | 12.23 | 0.16 | 11.76 | 0.04 | 11.94 | 0.27 |
| | Molar 2 | MD | 10.04 | 0.09 | 10.17 | 0.24 | 9.76 | 0.08 | 9.79 | 0.04 |
| | | BL | 12.34 | 0.09 | 12.48 | 0.23 | 11.91 | 0.11 | 11.98 | 0.11 |
| MANDIBULAR | Incisor 1 | MD | 5.52 | 0.08 | 5.64 | 0.16 | 5.47 | 0.03 | 5.52 | 0.30 |
| | | BL | 5.98 | 0.11 | 6.01 | 0.30 | 5.89 | 0.10 | 5.96 | 0.26 |
| | Incisor 2 | MD | 6.07 | 0.07 | 6.12 | 0.11 | 6.04 | 0.07 | 6.13 | 0.24 |
| | | BL | 6.42 | 0.08 | 6.45 | 0.18 | 6.24 | 0.06 | 6.28 | 0.29 |
| | Canine | MD | 7.18 | 0.09 | 7.23 | 0.07 | 6.88 | 0.10 | 6.93 | 0.14 |
| | | BL | 8.96 | 0.05 | 9.04 | 0.12 | 8.44 | 0.11 | 8.47 | 0.18 |
| | Premolar 1 | MD | 7.08 | 0.11 | 7.18 | 0.09 | 7.10 | 0.05 | 7.24 | 0.21 |
| | | BL | 8.82 | 0.09 | 8.91 | 0.08 | 8.64 | 0.08 | 8.81 | 0.16 |
| | Premolar 2 | MD | 7.21 | 0.06 | 7.34 | 0.21 | 7.14 | 0.08 | 7.18 | 0.55 |
| | | BL | 9.25 | 0.06 | 9.32 | 0.14 | 9.11 | 0.04 | 9.26 | 0.19 |
| | Molar 1 | MD | 11.24 | 0.08 | 11.29 | 0.26 | 10.99 | 0.06 | 11.18 | 0.20 |
| | | BL | 11.25 | 0.08 | 11.28 | 0.29 | 11.06 | 0.06 | 11.07 | 0.18 |
| | Molar 2 | MD | 10.74 | 0.08 | 10.93 | 0.14 | 10.50 | 0.09 | 10.64 | 0.11 |
| | | BL | 11.17 | 0.11 | 11.26 | 0.20 | 10.92 | 0.06 | 10.99 | 0.08 |

$\bar{x}$ = Mean dimension (mms); S.E. = Standard error; M.D. = Mesiodistal crown diameter; B.L. = Buccolingual crown diameter

TABLE 3. CANONICAL CO-ORDINATES FOR ANALYSIS OF DENTAL ARCH AND TOOTH DIMENSIONS OF PARENTS AND OFFSPRING

| | FATHER | | SON | | MOTHER | | DAUGHTER | |
|---|---|---|---|---|---|---|---|---|
| | AXIS | | AXIS | | AXIS | | AXIS | |
| | I | II | I | II | I | II | I | II |
| Maxillary and mandibular archand tooth dimensions combined together | 3.24 | -5.01 | 5.84 | -2.34 | 4.19 | 3.74 | -0.08 | 3.97 |
| Maxillary and mandibular arch dimensions combined together | 1.85 | -2.74 | 5.11 | -1.17 | 3.38 | 2.45 | -2.19 | 2.31 |
| Maxillary arch dimensions combined together | 1.78 | -1.60 | 4.04 | -0.65 | 2.71 | 1.63 | -0.27 | 1.65 |
| Mandibular arch dimensions combined together | 1.40 | -2.09 | 3.87 | -1.16 | 2.40 | 1.76 | -0.17 | 2.14 |
| Maxillary and mandibular tooth dimensions combined together | 3.48 | -2.94 | 4.17 | -2.21 | 1.84 | 3.16 | -0.74 | 3.66 |
| Maxillary tooth dimensions combined together | 1.59 | -1.64 | 2.26 | -0.98 | 0.39 | 2.24 | -0.45 | 2.57 |
| Mandibular tooth dimensions combined together | 1.27 | -1.38 | 1.85 | -0.47 | 0.16 | 1.64 | -0.27 | 1.88 |

ALL DIMENSIONS ARE IN STANDARD DEVIATION UNITS reduction in arch width being 2.3% and arch length 0.8%.

The data relating to tooth dimensions of parents and offspring are summarised in Table 2, which shows no apparent difference in the degree of sexual dimorphism between parents and offspring. For instance, the average dimorphism between fathers and mothers for the mesiodistal crown diameters is 1.5% and between sons and daughters 1.4.

In general, the maxillary and mandibular tooth dimensions followed a similar pattern of secular increase between parents and offspring, there being an average over-all increase between mothers and daughters of 1.0% for the mesiodistal crown diameter, and 0.9% for the buccolingual crown diameter, the respective increases between fathers and sons being 1.1% and 0.6%. In addition, the tooth index (the ratio of the sum of the mesiodistal diameters of the mandibular teeth against the sum of the mesiodistal diameters of the maxillary teeth, expressed as a percentage) showed an average increase of 0.2% between fathers and sons, and 1.0% between mothers and daughters.

Tooth crowding or spacing occupy opposite extremes of the relationship between the dimensions of the dental arches and teeth; spacing may be defined as the width of the interdental space, i.e., the distance between the mesial and distal crown convexities of adjacent teeth, whereas crowding may be regarded as the lack of space for the tooth within the arch, and measured from subtracting the space actually available for the tooth from the mesiodistal crown diameter. In order to assess the total degree of crowding or spacing within the dental arch, crowding may be given a negative sign and spacing a positive sign. Thus, from measuring the spacing and crowding by means of a measuring microscope, the effect of the secular changes in the tooth and arch dimensions were determined. In both parents and offspring, tooth crowding predominated over spacing, the average degree of crowding increasing by 73% in the maxillary arch of sons compared with fathers, and 34% for daughters compared with mothers, the respective values for the mandibular arch being 69% and 6%.

From the canonical analyses (summarised in Table 3) based on all the arch and tooth dimensions combined, there was significant discrimination between males and females, although considerable overlap between fathers and sons, and between mothers and daughters. This general pattern of contrast was similar in all the analyses, although the actual degree of discrimination was reduced when considering all the arch or all the tooth dimensions combined, and markedly reduced when considering all the maxillary or mandibular arch, or tooth dimensions combined. Also, the first canonical axes appeared to be related to over-all tooth size, whereas the second axis appeared to be related to sexual dimorphism. Furthermore, the data provided no indication that the teeth as a whole of the dental arches were more affected by the secular changes. This general pattern of discrimination was confirmed by the generalised distance ($D^2$) matrix.

From examination of the loading factors, an indication is provided as to which variate contributes most to the separation between the groups. In the analyses of the present data, however, no one variate or group of variates contributed more significantly than others to the separation between the groups. This would appear to indicate that the secular changes involved the dentition and the arches as a whole, rather than specific tooth or arch dimensions.

## Discussion

The data from this comparison between parents and offspring indicate the complexity of secular changes, in that an increase was noted in the tooth dimensions and a decrease in the arch dimensions. The combination of these two changes possibly contributed to the increase in dental crowding noted over the two generations, although the aetiology of crowding has yet to be fully elucidated.[17-20] Moreover, although there is evidence to support a strong hereditary association between the arch and tooth dimensions,[21-26] the present data are insufficient to ascertain whether genetic or environmental factors were primarily responsible for the observed changes, due to the variation in the ages of the subjects and the lack of detailed genetic data. Nevertheless, the recognition that secular changes do occur in tooth and dental arch dimensions is important for the prediction of future growth changes, a feature previously noted by Hirschfeld and Moyers.[27]

Secular increases in the over-all bodily dimensions have been suggested to result from variation in timing of maturation.[2,5,28] It is, however, difficult to equate the contrasting changes of both tooth and arch size. Nevertheless, stature has been shown to be poorly correlated with both tooth[29] and arch[30] dimensions. Moreover, secular changes have been noted over two generations for tooth and arch dimensions.[10,31] Thus it is possible that different factors determine the secular changes in the teeth and arches compared with the over-all bodily proportions.

Teeth are known to drift from the time the deciduous teeth emerge, throughout the mixed dentition[32] and probably throughout the entire life span.[33] Thus the location of the tooth within the dental arch is in a state of dynamic equilibrium, probably in response to the functional forces and growth changes of the face however minute these might be.[34] This, therefore, further complicates the explanation of the secular changes revealed from the present data.

Models of bone growth are concerned with the effect of function-form relationships, an adaptive capacity that concerns size, shape, structure and position of the bony elements, recognising the degree of individuality of bones or areas thereof within the totality of the organism and discarding a bone as an isolated anatomic specimen.[35,36] This fact was taken into account in the present study where, by virtue of the use of multivariate statistical techniques, it was possible to examine the changes in the teeth and dental arches as a whole, which contrasts with univariate analysis whereby only single variates can be examined at any one time.

It was not possible in the present study to ascertain whether the secular changes resulted from variation in tooth or arch size, shape or both. Indeed, measurements define only certain attributes of an object under investigation, and many more dimensions would be required to obtain a complete metrical profile of a tooth or dental arch. Even with a large number of variates, similarity of results obtained from a multivariate analysis would not necessarily indicate similitude of shape, but only resemblance as far as those variates are concerned. Hence the pattern of discrimination obtained from multivariate analysis depends solely upon the measurements chosen, and not necessarily on the shape of the object under investigation. Thus the present results must be interpreted with caution, since it is possible that the variates included in this study highlighted similarities in shape, so that if other variates had been included in the analysis, then a different pattern of separation between parents and offspring might have emerged. Nevertheless, in the present study, multivariate analyses were useful compared with univariate analyses since they permitted the teeth and dental arches to be considered as biological units, i.e., the secular changes in the dental arches and teeth as a whole were examined, rather than single variates being considered one by one.

## Summary

In a study of 150 Caucasoid families, comparison between parents and offspring showed a secular increase in the dimensions of the teeth, but a secular decrease in the dimensions of the dental arches. This emphasises the complexity of secular trends.

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