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A Geometric Morphometric Analysis of the Crown Form of the Maxillary Central Incisor in Humans

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ABSTRACT Dental traits have been studied over a long period and grossly evaluated using standard reference plaques. However, grading by subjective observation may result in inter-observer measurement errors. We aimed to analyze crown models three-dimensionally to assess the morphology of the lingual surface termed shovel shape. Micro-CT scanned data of 38 maxillary central incisors stored at two different laboratories were used to create crown models of the outer enamel surface (OES) and the dentinoenamel junction (DEJ). Original crown data were evaluated according to the grade of shoveling into weak and strong groups. Homologous models consisting of the same number of data points were created and the distance matrices between tooth models of OES and DEJ were respectively analyzed by using multidimensional scaling analysis (MDS) and principal component analysis. Student's t-test was used to compare corresponding scores between the two groups based on shovel-shape. The results of a t-test in the OES model indicated significant differences between the two groups. In contrast, the result in the DEJ model did not reveal a statistically significant difference. Our results indicate that geometric morphometric analysis of micro-CT scanned tooth crowns represents a powerful solution for the objective shape assessment of human teeth. *Dental Anthropology* 2011;24(1):1-10.

Studies of tooth crown morphology are essential in human biology and phylogeny. In particular, dental morphological traits have been recognized for their importance as a phenotypic expression of genetic differences between groups (Ohno, 1986; Irish, 1998). Traditional standard morphological analysis for comparing dental traits is performed by visual morphological observations (Hanihara, 1954, 1955; Suzuki and Sakai, 1966; Mizoguchi, 1977, 1978), which has a long history of making significant contributions to dental science. The approach is generally based on quantifying the relative expressions and frequencies of discrete traits by a standard reference plaque.

On the other hand, it has been reported that grading by standardized plaque is susceptible to inter- and intra-observer measurement errors (Mizoguchi, 1977; Turner and Hanihara, 1977; Nichol and Turner II, 1986; Haydenblit, 1996). Haydenblit (1996) reported that the percentage of intra-observer error greater than a one-grade scoring difference was 5.4% for 20 maxillary dental traits and 4.7% for 20 mandibular dental traits. Additionally, inter-observer error in the >1-grade variant-scoring percentage for a total of 47 traits ranged from 0.0% to 40.0%. Mizoguchi (1978) estimated percent discordances between duplicated observations on the same sample; he reported a value of 10.7% for shoveling in the central incisor, though he emphasized that discordances are negligible in most cases unless there is obvious misjudgement. Although the difficulty associated with discrimination among tooth crown grades depends on type of tooth character and degree of expression, in some instances observational estimation can influence the consequential outcome. Therefore, objective approaches to classify tooth crown characteristics are desirable.

The aims of the present study were (1) to explore the differences between subjectively discriminated grading with standard plaque and objectively distinguished grading with geometric morphometrics, and (2) to determine whether the outer enamel surface (OES) or dentinoenamel junction (DEJ) form in tooth crown distinguishes the existence of shovel shape among a variety of maxillary central incisor morphologies. From the perspective of dental anthropology, tooth crown morphology is consequential for taxonomy as the grouping variable. As a preliminary investigation, we

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focused on shovel shape as the tooth crown character, which was first described by Hrdlička (1920). We adopted the Arizona State University (ASU) Dental Anthropology System (Turner *et al*., 1991) for visual discrimination. This is a frequently-used standard for evaluating dental traits (Irish, 1998; Irish and Guatelli-Steinberg, 2003; Manabe *et al*., 2003, 2008; Nwe Aung *et al*., 2005; Suzuki, 2005; Sasaki *et al*., 2005). We also performed morphometric analysis with three-dimensional (3D) tooth data from various populations for objective discrimination.

For objective evaluation of 3D data, the database of anthropometry of human data is globally available and can be commercially applied (Kouchi and Mochimaru, 2004, 2010; Mochimaru and Kouchi, 2000). Unlike the 2D data, 3D data have significance in detecting group average form. A homologous modeling method was developed to classify 3D body forms (Mochimaru *et al*., 1999; Mochimaru and Kouchi, 2000; Kouchi and Mochimaru, 2006), which is applied for designing products that fit to human body shape. The basic modeling technology based on subdivisions of the surface has been developed and applied to foot shape and body shape (Mochimaru *et al*., 1999; Kouchi and Mochimaru, 2010). This method allows computation of the average and variability of 3D body shapes in a sample. In the present study, we applied homologous modeling and compared the tooth crown shape related to OES and DEJ. A homologous model can represent the tooth as shape data with the same number of data points of the same topology. Finally, we discuss the differences between the results of grading with an ordinal-scale plaque and those obtained from morphometric analysis, exploring the possibility of geometric morphometrics to evaluate 3D tooth crown shape.

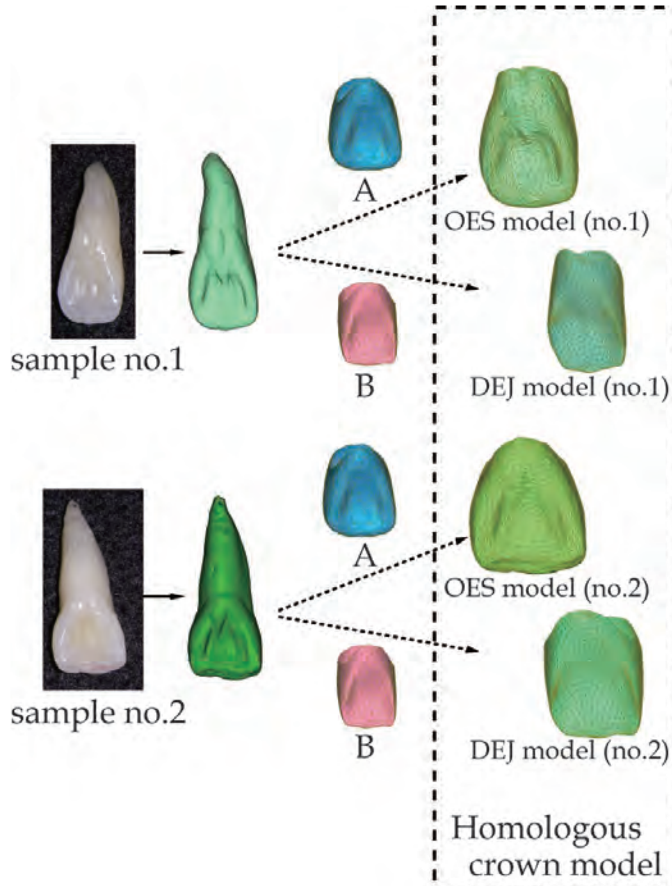

Fig. 1. Diagram of homologous crown model creation. Lingual surfaces of two examples (sample no. 1 and 2 are shown). Template crown models of the OES (A) and the DEJ (B) were used to construct homologous models.

TABLE 1. Maxillary central incisor data used in this study

Ethnic Group	n[a]	WS[b]	SS[c]	Data	Source
Japanese	23 (22)	9 (12)	14 (10)	original	AGU
Indians	2 (2)	2 (2)	0	original	AGU
Burmese	2 (2)	2 (2)	0	original	AGU
Nepalese	1 (1)	1 (1)	0	original	AGU
Caucasian	6 (3)	6 (3)	0	CT	B&H
Pacific-Islander	1 (0)	1 (0)	0	CT	B&H
African-American	3 (2)	3 (2)	0	CT	B&H
Totals	38 (32)	24 (22)	14 (10)		

[a]n, sample size
[b]WS, weak shoveling (ASU: 0-2)
[c]SS, strong shoveling (ASU: 3-6)
[d]AGU, Aichi-Gakuin University, Japan; B&H, Brown and Herbranson Imaging, Inc., CA, USA
Numbers indicate dentinoenamel junction (DEJ) data
Numbers in parenthese show outer enamel surface (OES) data

MATERIALS AND METHODS

Study sample

Micro-CT scanned data of 38 permanent upper left central incisors were obtained for geometric morphometric analysis of OES and DEJ of tooth crown. Table 1 lists the human populations from which the incisors used in this study were obtained. Japanese, Indians from India, Burmese and Nepalese incisors stored at Aichi-gakuin University (AGU) were scanned by micro-CT (SMX-225CT, Shimadzu, Kyoto, Japan) at an isometric voxel resolution of 60 microns (70 kV, 50μA, 512/512 matrix, 600 views, 360 degrees of rotation, 10 frame averaging). CT scan data of Caucasian, Pacific-Islander and African-American teeth were provided by Brown and Herbranson Imaging, Inc. (B&H, Palo Alto, CA, USA). The details of the B&H CT scan data were as follows: raw projection data of 16 bit, image size of 580/579/989 matrix and resolution of 20-60 microns isotropic cube.

Incisors were grouped into two classes based on the shoveling grade of the ASU Dental Anthropology System. Observations of the shovel shape for B&H data were necessarily made from 3D models. As analyses based on the sum of shovel and semi-shovel grade were more appropriate to reduce the observational error (Suzuki and Sakai, 1966), the data were grouped into ASU grades 0-through-2 as the Weak Shoveling group (WS) and ASU grades 3-through-6 as the Strong Shoveling group (SS). Six incisors that had enamel defects or caries were excluded from OES analysis in this study. The total numbers of teeth in WS and SS for OES analysis were 22 and 10, while those in WS and SS for DEJ analysis were 24 and 14, respectively. Right incisor data were mirror-imaged during 3D image reconstruction processing (described in the next section) in order to maximize the sample size. To reduce the size of the resulting files, image stacks were downsampled to 60 microns.

Homologous Model Creation

Figure 1 shows a diagram of homologous model creation. An image stack was imported into reconstruction software (VGStudio Max 2.0, Volume Graphics, GmbH, Heidelberg, Germany). During 3D image reconstruction, right incisor data were mirror-imaged to the left incisor. After calibration to define material and background, enamel and dentine tissues were segmented using

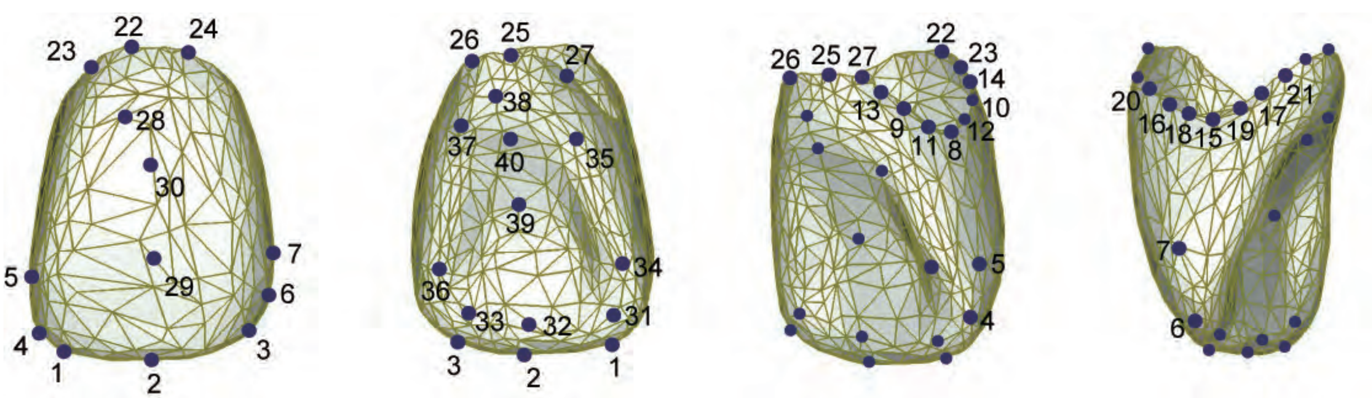

Fig. 2A. Depiction of the 40 landmarks used for OES surface model in this study.

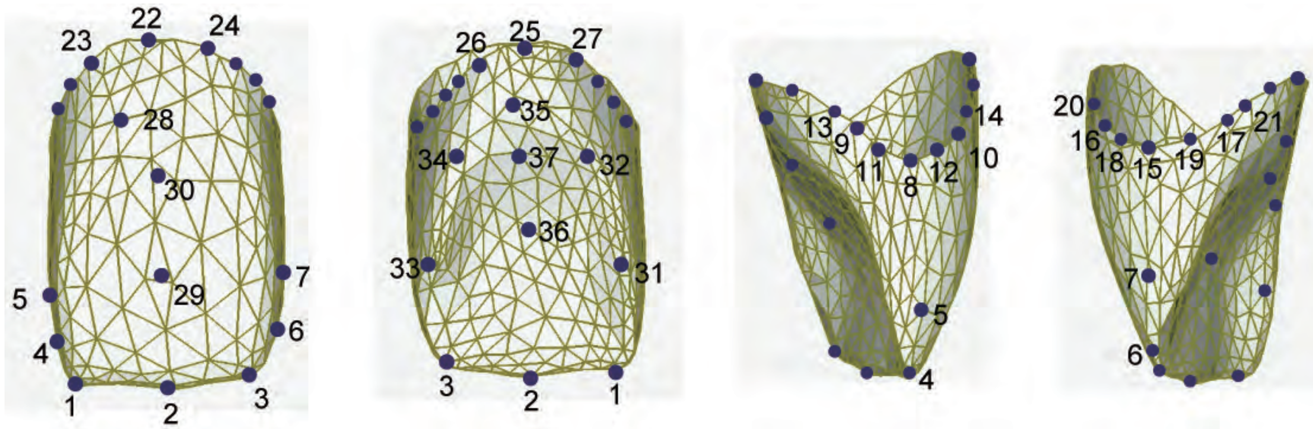

Fig. 2A. 40 landmarks used for OES surface model in this study.

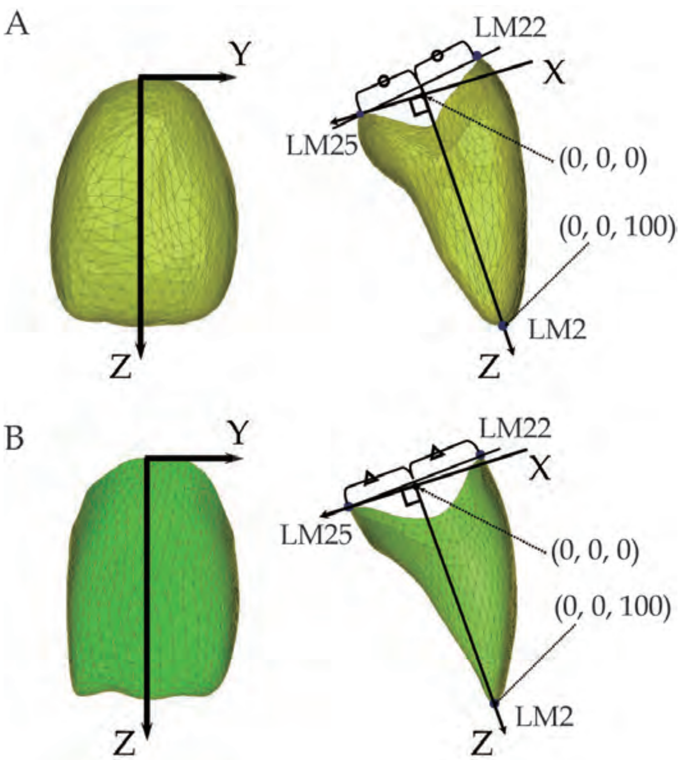

Fig. 3. Orientation of the OES model (A) and DEJ model (B). LM 2, LM 22, and LM 25 stand for the central point on the incisal edge, the center of the horizontal cross section of the highest point on the labial cervical line, and the highest point on the lingual cervical line, respectively.

the distribution of grayscale threshold values on its histogram, which arises from differences of mineralization of enamel and dentine. Then, the OES and DEJ form were respectively reconstructed as a triangulated surface model.

Before constructing a homologous model, we produced template crown models of the OES or the DEJ crown shape consisting of about 700 polygons using Geomagic studio 9 (Geomagic, Inc., Durham, NC, USA). A template crown model exhibiting the shape of the enamel surface was produced from a segmented tooth crown enamel cap. In addition, the template crown model of the dentinoenamel junction shape was produced by substituting with the inner surface of the enamel cap model. That way, template models of the OES and DEJ were constructed and landmarks were applied on the model (Fig. 2A,B). 40 vertices for the OES model and 37 vertices for the DEJ model were manually assigned to anatomical landmarks. The template OES model had three more landmarks than the DEJ, and these were related to the thickness of the incisal edge. The template model automatically fits into the individual scanned point cloud of the maxillary central incisors by minimizing external and internal energy functions. The external energy function is based on the Euclidian distance between data points of the template model and those of the scanned data. The internal energy function is based on the local deformation of the template model. The vertices of the template model specified as landmarks were fit into the landmarks, and vertices generated by the subdivision surface were fit into measured point clouds with minimal deformation of the initial template model. As described above, the OES and DEJ homologous models were created for each sample by using Homologous Body Modeling software (HBM, Digital Human Technology Inc., Tokyo, Japan) and HBM-Rugle (Medic Engineering Corporation, Kyoto, Japan).

Coordinate system

Figure 3 illustrates the coordinate system used for crown model orientation. The Z-axis was the crown axis direction passing through the center of the horizontal cross-section of the highest point on the labial cervical line (landmark 22) and the highest point on the lingual cervical line (landmark 25), through the central point on the incisal edge (landmark 2). The X-axis was in the labiolingual direction passing the landmark 25 orthogonal

TABLE 2. Means, standard deviations and differences for measurements of Z- Y- X- directional length of polygon models obtained from CT scanned data

		AGU Mean (mm)	sd	B&H Mean (mm)	sd	Differences AGU:B&H (mm)	Percentage error
A	Z	22.13	0.8	22.58	0.9	0.45	2.0
	Y	8.59	0.5	8.65	0.5	0.04	0.5
	X	6.86	0.2	7.23	0.6	0.38	5.5
B After Standardization							
	Z	20.00	0.0	20.00	0.0	0.00	0.0
	Y	7.77	0.5	7.69	0.5	0.08	1.0
	X	6.20	0.3	6.42	0.7	0.22	3.5

n = 6

TABLE 3. Significance probability (P value) from student t-test between MDS scores of WS group and those of SS group for all dimensions

Dimension	OES[a]	DEJ[b]
1	0.49	0.10
2	0.27	0.14
3	0.43	0.21
4	0.44	0.77
5	0.001**	0.07

[a]outer enamel surface
[b]dentinoenamel junction
**P < 0.01

to the Z-axis. The Y-axis was in the mesiodistal direction. The origin (0, 0, 0) was the intersection point of the X-axis and the Z-axis. Landmark 2 was made to lie at (0, 0, 100) in each specimen in order to remove differences in crown height.

Inter-System Comparison

To assess the comparability of CT systems, we examined the possible measurement error of CT scanned data from two institutes. Six maxillary central incisors were scanned by both CT systems (AGU and B&H). External surface models of the whole teeth were created by VGStudio Max 2.0. For inter-system comparison, the coordinate system used for crown model orientation was used and the length from central point on incisal edge to apical point of the root was scaled to be 20 mm.

The size of polygon models was measured using the software. The shape errors between two polygon models were calculated.

Statistical Analysis

The distance between the two models was defined as the sum of the Euclidean distances between corresponding data points. The distance matrix between 32 models for OES and that between 38 models for DEJ was analyzed by the multidimensional scaling (MDS) method and principal component analysis (PCA). MDS is one of the factor analyses used to determine the spatial configuration of objects (Wickelmaier, 2003). MDS detects meaningful underlying dimensions that allow us to explain observed similarities or dissimilarities between objects. It generally attempts to arrange objects in a space with a particular number of dimensions, explaining the distance matrix in terms of fewer underlying dimensions to reduce the observed complexity of nature (Borg and Groenen, 2005; Bronstein *et al*., 2006). On the other hand, PCA, which is used in many studies (Stefan and Trinkaus, 1998; Hlusko and Mahaney, 2007; Bastier *et al*., 2008; Morimoto *et al*., 2008), summarizes data variation into fewer principal components corresponding to axes that account for the largest, second largest, and successively smaller proportion of the total sample variance. Kouchi and Mochimaru (2006) assessed the usefulness of PCA and MDS in analyzing variations in intra-individual shape change patterns and compared them. They reported that MDS is more efficient in information compression, so we assessed homologous models with MDS in addition to PCA to compare the information obtained from each analysis using Human Body Statistica (HBS, Digital Human Technologies Inc., Tokyo, Japan).

MDS and PCA scores in the WS and SS groups were compared by Student's t-test for OES or DEJ analyses. Statistical analysis was performed using statistical software (SPSS 15.0J for windows, SPSS Japan Inc., Tokyo, Japan). In order to interpret the obtained dimensions by MDS and PCA, virtual shapes with scores of ±3 S.D. for each of the three axes showing significant differences were calculated by using HBS (Mochimaru and Kouchi, 2000).

RESULTS

Inter-System Comparison

Six polygon models constructed by the authors from data acquired at AGU and B&H were measured. Table 2A provides averages and standard deviations of tooth length, labiolingual diameter, and mesiodistal diameter substituted by the length along the Z-axis, X-axis, and

TABLE 4. Significance probability (P value) from student t-test between PCA scores of WS group and those of SS group for all PCs.

PC[a]	OES[b]	DEJ[c]
01	0.82	0.84
02	0.22	0.02*
03	0.55	0.58
04	0.08	0.18
05	0.09	0.25
06	0.31	0.36
07	0.21	0.72
08	0.03*	0.17
09	0.59	0.09
10	0.01**	0.06
11	0.20	0.27
12	0.74	0.54
13	0.74	0.17
14	0.71	___
15	0.26	___
16	0.67	___

[a]principal component
[b]outer enamel surface
[c]dentinoenamel junction
*0.05 > P > 0.01
**P < 0.01

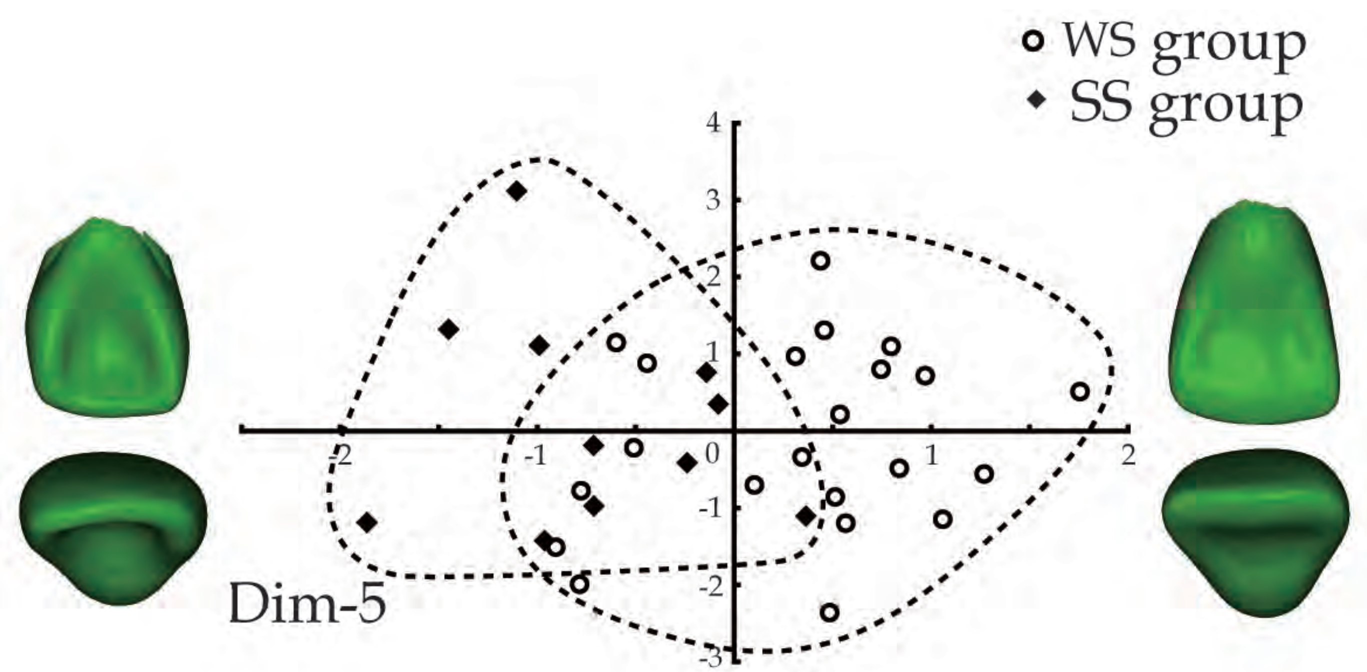

Fig. 4. Scatter plot of MDS scores in dimension-5 (Dim-5) for the OES model of WS and SS groups. +3 SD and -3 SD virtual shape models across dimension-5 axis are indicated at the both end of the axis.

Y-axis, respectively. The percent errors between the two systems ranged from 0.5% to 5.5%. Based on these results, the length of the present model was standardized. Table 2B shows the measured values after standardization. The percent errors between the two systems ranged from 0.0% to 3.5%.

MDS Scores

A five-dimension solution was adopted for both the OES and DEJ analyses because R^2 (squared correlation coefficient) was high (OES, 0.84; DEJ, 0.94). Table 3 shows the level of significance (P value) of the Student's t-test between MDS scores of the WS group and SS group for all dimensions. As MDS calculates spatial configuration of objects, the calculated factor of differences is called "dimension." The first dimension has the highest variance and each succeeding dimension in turn has the higher variance that is uncorrelated with the preceding dimension. Significant differences were found in only dimension-5 ($P < 0.01$) between the WS and SS groups in the OES model. However, no significant difference in the DEJ model was observed.

Based on the calculated MDS score in dimension-5 for the OES model, virtual shape models within -3 SD to +3 SD of the average were created. Figure 4 shows a scatter plot of MDS scores in dimension-5 for the OES model of the WS and SS groups. Virtual shape models with +3 SD and -3 SD across dimension-5 axis are indicated at the ends of the axis. By observing the virtual shapes, MDS space can be interpreted over the axes. It was found that dimension-5 related to thickness of the incisal edge and size of the mesial and distal marginal ridges in addition to the relative depth of the lingual surface.

PCA Scores

Almost 100% of total variance was explained by 16 PCs for the OES and 13 PCs for the DEJ. Table 4 shows the P values of the Student's t-test between PCA scores of the WS and SS group for all principal components. In PCA, significant differences in the OES model between the WS and SS groups were found in PC8 ($P < 0.05$) and PC10 ($P < 0.01$). The first 10 PCs explain 82.3% of total variance. On the other hand, significant differences in DEJ were seen in PC2 ($p < 0.05$). The first two PCs explain 41.9% of total variance. However, it is difficult to explain this component seen in the DEJ model. This is because the virtual shape expressed labiolingual thickness and mesiodistal length in addition to the depth of the lingual hollow. This means that the PC2 axis was not directly related to the shovel shape despite significant differences between PCA scores of the WS and SS groups. Thus, this component of DEJ model could be ignored.

Figure 5 shows a scatter plot of PCA scores in PC8 and PC10 for the OES model of the WS and SS groups. Virtual shape models within the +3 SD and -3 SD interval across each axis are indicated at the end of these axes. PC8 axis for the OES model was related to thickness of the incisal edge and size of the marginal ridge in parallel

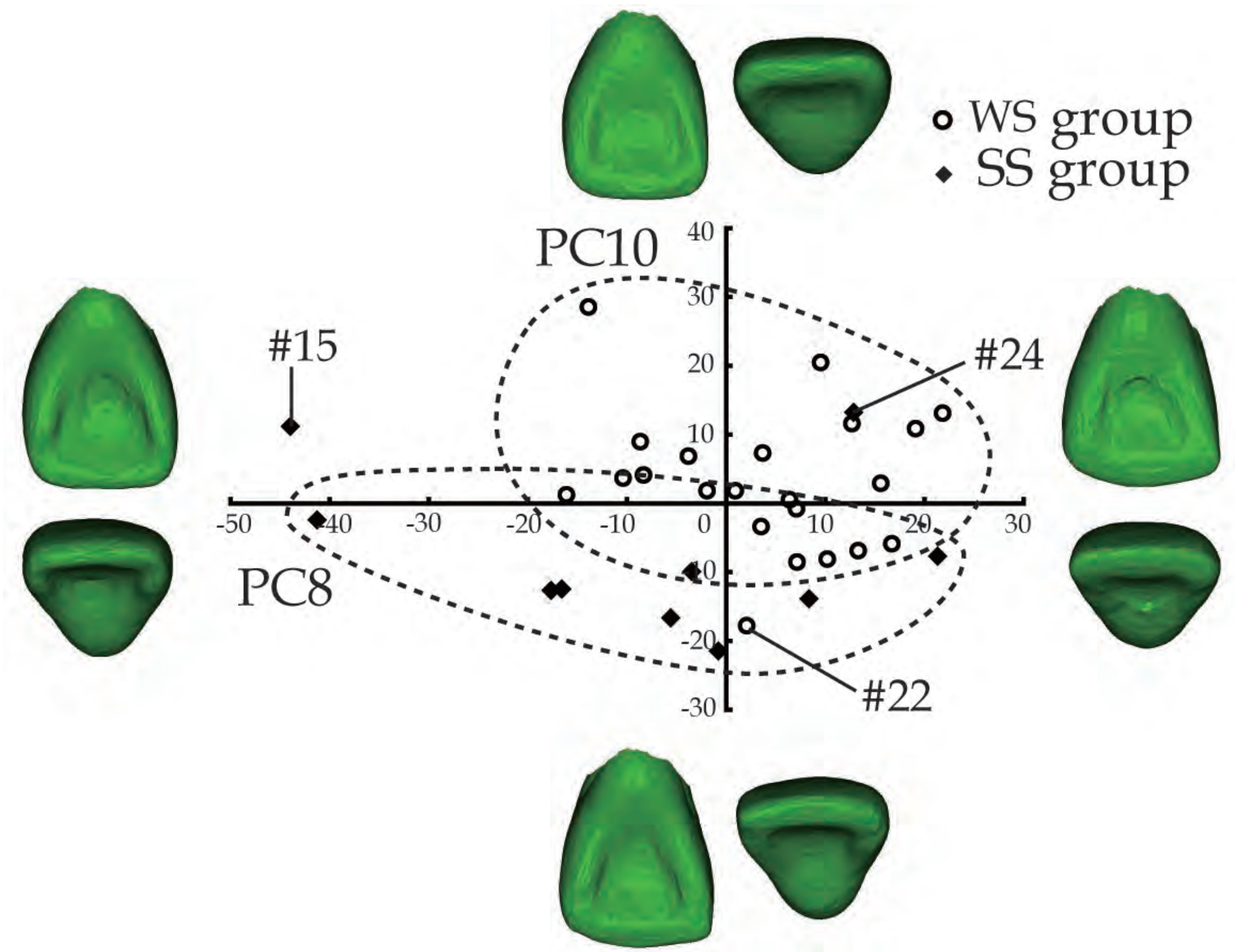

Fig. 5. Scatter plot of PCA scores in PC 8 and PC 10 for OES model of WS and SS groups. +3 SD and -3 SD virtual shape models across each axis are indicated at the end of these axes.

with shovel depth. PC10 for the OES model was related to the presence of the slope face (incline) following the lingual cingulum.

DISCUSSION

In the present study, the shoveling group subjectively discriminated with standard plaque corresponded to those groups objectively discriminated with 3D homologous crown models of outer enamel surface shape. In this section, we discuss some of the major issues and approaches involved in the acquisition of CT scanned data from different systems, and then we discuss the results of the present study.

Recent studies using micro-CT have contributed to our knowledge by evaluating a non-invasive method to analyze objects (Kono *et al*., 2002; Suwa and Kono, 2005; Smith and Tafforeau, 2008; Olejniczak *et al*., 2008). Olejniczak and Grine (2006) compared physical sections to computer-generated micro-CT sections of recent primate teeth, and a difference of 3% to 5% was indicated between them. Their report revealed that measurement with the greatest care under proper conditions makes micro-CT useful. Furthermore, Olejniczak *et al*. (2007) compared different micro-CT systems to ensure that results are comparable and not machine-dependent and found that the measurements were comparable between systems (within 3%).

In the present study, we analyzed human teeth, in which the degree of mineralization of enamel and dentine are similar among objects. Images acquired both at AGU and B&H appeared to be comparatively sharp and with few artifacts. Olejniczak and Grine (2006) reported that the ability of segmentation software to distinguish enamel and dentine differs in some cases from the ability of the human eye to detect the same two tissues. In general, data acquisition is performed by one operator under strictly controlled techniques. In addition, laboratory conditions are regulated to minimize inter-operator error. However, assessment of tooth morphology requires a large sample of certain taxa. Collections of required sample number may be limited in each laboratory. In particular, isolated teeth with a clear background are difficult to collect. Bailey *et al*. (2004) suggest that clear images with certain prescribed standards can be pooled together. In addition, data that are acquired under proper conditions, even if they were originally scanned for different purposes, can be gathered together and be analyzed as a large sample. In the present study, samples of different origin were combined and scanned under different conditions and techniques. To compensate for inter-system differences, segmentation differences used to distinguish enamel and dentine and the subsequent construction of homologous models were carried out by the first author. Nevertheless, an error ranging from 0.5% to 5.5% was revealed from the results of error verification in the present study. In order to compensate for these inter-system errors and account for differences in size, we standardized all the tooth length with the same value. As a result, shape data were standardized with acceptable accuracy (0.0% to 3.5%). These results suggested that tooth models acquired from different systems could be used as valid data after some compensation. At the same time, it must be mentioned that this method is applied to a comparative study and not a measurement field. Collective data would benefit a wide range of researchers who engage in dental morphometric assessment (Kato and Ohno, 2008).

The expression of dental traits at the DEJ junction has been applied to extant and fossil hominoid taxa (Skinner *et al*., 2008, 2010). Statistically significant taxon-specific patterns at the DEJ that are not evident at the OES have also been reported (Skinner *et al*., 2009). Furthermore, if DEJ images can be obtained, the character retains its taxonomic value even in worn teeth. In the present study, we could not find any differences between the DEJ patterns of human teeth. This result was expected, since analysis for the OES shape should reflect the outcome of observations. Sakai and Hanamura (1973) describes the small component seen on the lingual surfaces of incisor as follows: “marginal ridges at the DEJ are less wide than at the OES, while thickness of marginal ridges is mostly the same”. It is presumed that the morphometric differences found by examination of human teeth shape at the DEJ were too minor to be detected by the statistical analysis. For these reasons, we suggest that the present methodology using OES crown model could be appropriate for objective evaluation.

Shovel shape is characterized by “a peculiar, pronounced hollow of the lingual surface of the teeth, bounded laterally or surrounded by a well-defined elevated enamel border” (Hrdlička, 1920). Mizoguchi (1978) reported that the correlation coefficients between the shoveling and marginal ridges are positive and considerably high, ranging from 0.55 to 0.82, in the maxillary central incisor. In the present result of MDS analysis on the OES model, the dimension-5 axis showed a shovel-shaped character. Virtual shape of +3 SD revealed thick incisal edge, and buccolingual midsection was also thick due to existence of the central ridge. Also, it showed narrower and thinner marginal ridges, and consequently a less deep hollow. On the other hand, virtual shape of -3 SD revealed thin incisal edge, and buccolingual midsection was not thick. Also, it showed wider and thicker marginal ridges, and consequently a deep hollow.

On the other hand, PCA resulted in the following PC8 axis: virtual shape with +3 SD showed that the marginal ridges are not prominent, the incisal edge is relatively thick, and consequently a less deep hollow. Virtual shape of -3 SD at the PC8 axis revealed that the marginal ridges are prominent, the incisal edge is not thick, and consequently a deep hollow. Furthermore, PCA resulted in the following PC10 axis: virtual shape of +3 SD showed a wide slope face from lingual cingulum, which was gradually flattening up to the lingual hollow. Virtual shape of -3 SD at PC10 revealed no slope from the lingual cingulum. Here, as the sample is not large enough, we cannot discuss the influences of mesial and distal marginal ridges with shovel shape. However, it is interesting for PCA analysis to extract a factor of the slope from lingual cingulum. As Mizoguchi (1978) reported, the central ridges decrease the extent of the shoveling. The present virtual shape showed weak shoveling with the slope face from the lingual cingulum and strong shoveling without the slope. This is interesting in terms of the small component on the lingual surface, which was related to the shoveling shape. Also, this component was extracted by PCA, not by MDS. That is, as Kouchi and Mochimaru (2006) suggested, MDS analysis is efficient for information compression. The present results revealed by MDS seemed to be the compressed shape factors compared to the results showed by PCA. Considering the differences between WS and SS groups combined with the result of calculated virtual forms of +3 SD and -3 SD here, these extracted results coincide with the characteristics of the shovel shape. Also, concerning the reason why the first few PCs do not exhibit significant differences between the WS and SS groups, it is attributed to the fact that the individual differences of crown form such as labiolingual width, mesiodistal length, and these mixed elements are relatively larger compared to differences of the shoveling.

As Figure 5 shows, there are three tooth crowns, #24, #22 and #15, that are apart from each group, and these outliers should be discussed here. First, #24 was located in the area of the WS group, although it was classified as the SS group by observation, probably due to the existence of the incline. On the lingual surface of #24, the lingual cingulum had a steep incline to the hollow of the incisal half area. Therefore, on observation, the focus was on the deep hollow and prominent lateral ridges and it was judged as having a strong shovel shape, whereas geometric analysis grouped #24 into the WS group based on the presence of the slope. Second, #22 was located in the area of the SS group, although it was classified as the WS group on observation. This may be due to the small pit and hollow above the lingual cingulum. It is considered that it was judged as having a weak shovel shape on observation due to less prominent lateral ridges. However, geometric analysis grouped #22 in the strong shovel group based on the presence of the small pit and hollow above the lingual cingulum. Finally, in terms of #15, we could see no apparent reason why it was apart from the group; it had a well-developed mesial marginal ridge and strong shoveling. In spite of the deep hollow in the lingual surface, #15 was located in the upper area along with PC8 axis. Thus, all factors that influence the results are unknown at this time and require further investigation.

Objective evaluation of dental morphology has several advantages: 1) it does not involve man-made errors that accompany observation; 2) it enables analysis of data collected from around the world by 3D morphological data; and 3) it enables calculations of average tooth form in a group. There also are disadvantages, including 1) 3D morphological calculation could result in incompatible shape factor with conventional definition of dental traits; and 2) conditions in terms of landmark positioning or geometric algorithm of homologous model may affect the outcome of analysis. Nevertheless, potential contributions of these 3D morphometric data to dental science can be expected by overcoming these problems.

CONCLUSION

The study proposed geometric morphometric analysis of the maxillary central incisor crown form to assess degrees of lingual shoveling. The greatest merit of an objective methodology lies in the fact that a vast amount of data from all over the world could be analyzed all together. Although there are many technical challenges to overcome, we conclude that geometric morphometric analysis of micro-CT scanned tooth crowns represents a powerful solution for objective shape assessment of human teeth.

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Prevalence of Short Dental Roots in Four Ethnic Groups in an Orthodontic Population

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ABSTRACT The purpose of the current study was to investigate if a significant relationship exists between ethnicity, sex, and short dental roots. The hypotheses are: 1. Hispanics have a higher prevalence of short dental roots than Caucasians, African Americans, and Asians; and 2. Females have a higher prevalence of short dental roots than males. The experimental groups consisted of 30 Caucasians, 30 Hispanics, 30 African Americans, and 26 Asian subjects who presented to University of Illinois Department of Orthodontics for treatment. Actual root length (mm) and relative root length were measured on periapical radiographs, for the maxillary and mandibular central and lateral incisors, and second premolars. The results showed that Asians had the shortest dental root lengths for all teeth measured, except the maxillary second premolar. Significant differences in relative root length values between the ethnic groups were found for the maxillary central incisor and second premolar. Females had shorter roots than their male counterparts within each ethnic group. *Dental Anthropology* 2011;24 (1):11-15.

Root resorption is the most frequent unwanted side-effect of orthodontic treatment discussed with new patients, and occurs in all orthodontic patients to various degrees (Weiland, 2006). The risk of root resorption during treatment has been found to be related to a number of factors, including dental anomalies, syndromes, variations in dental anatomy, sex, mechanics of orthodontic treatment, and disturbances during development, among others. Developmentally short dental roots have been observed to experience a higher incidence of root resorption during orthodontic treatment. Thongudomporn and Freer (1998) found that teeth with one or more dental anomalies, such as invaginations, pipette-shaped roots, or short and blunted roots undergo a significant amount of root resorption during orthodontic treatment as opposed to teeth without these anomalies. Lind (1972) was the first to suggest the connection between developmentally short dental roots and root resorption. He defined short root anomaly as involvement of bilateral maxillary incisors and less commonly canines and premolars. Lind measured the crown-to-root ratios of short-rooted and normal teeth on intraoral radiographs and found that the control group had an average of 5.5 mm longer maxillary incisor roots than the experimental group. Developmentally short roots have been found in 1.2-10.0% of pretreatment orthodontic patients (Uslu *et al.*, 2009). These teeth have an unfavorable crown-to-root ratios as compared to teeth with normal root length (Höltta *et al.*, 2004). The ratio of crown-to-root length in these shortened teeth is at least 1.0:1.6 (Desai *et al.*, 2006). Developmentally short roots have been found to be associated with syndromes such as dentin dysplasia, scleroderma, Steven's-Johnson syndrome, Laurence-Moon-Bardet-Biedl syndrome, Thalassemia, Down syndrome, Aarskog syndrome, dwarfism, and Rothmund-Thomson syndrome (Desai *et al.*, 2006). They may also occur simultaneously with other dental anomalies, such as tooth agenesis, dens invaginatus, supernumerary teeth, generalized microdontia, obliterated pulp chambers, increased tooth mobility, and spontaneous exfoliation (Apajalahti *et al.*, 1999). Short dental roots may develop from three mechanisms: disturbances during development, resorption of previously well-formed roots, or genetics. Disturbances during root development can result from radiation or chemotherapy exposure during childhood, or systemic illness such as hypoparathyroidism. Resorption of originally well-formed roots may follow trauma or occur during orthodontic treatment. Short roots may have a genetic origin, such as short root anomaly (Höltta *et al.*, 2004). Teeth with short roots pose difficulties in orthodontic and prosthodontic treatment planning as a result of their unfavorable crown-to-root ratio. Anchorage methods and occlusal loading need to be considered carefully in teeth with short roots (Höltta *et al.*, 2004). The purpose of the current study is to

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investigate the relationship between ethnicity and the prevalence of developmentally short dental roots.

Two hypotheses were tested in this study, namely 1)Hispanics have a statistically significant higher prevalence of developmentally short dental roots than Caucasians, African Americans, and Asians, and 2) females have a higher prevalence of short dental roots than males. If one or more ethnic groups show an increased prevalence of short roots, it may be assumed that they would be at increased risk for root resorption during orthodontic treatment as stated in previous research. This information would be helpful to orthodontists in treatment planning mechanics for their patients.

MATERIALS AND METHODS

The experimental groups consisted of Caucasians, African Americans, Hispanics, and Asians with 30 subjects in each ethnic group except the Asian group which had 26 subjects due to a lack of cases that met the inclusion criteria for this study. The subjects were at least 14 years of age and both male and female. The subjects' dental records came from the University of Illinois College of Dentistry Orthodontic Clinic patient pool. Subjects satisfied all inclusion criteria, including no history of dental trauma, orthodontics, endodontics, or oral surgery to the teeth being measured. The teeth could not have large caries or restorations of half or more of the crown, significant attrition, significant dilaceration of the root, or be rotated such that their facial and palatal surface were not parallel to the x-ray film. Subjects with craniofacial malformations, such as cleft lip and palate, were excluded. All permanent teeth were fully erupted, except third molars, and all apices of the teeth were closed. All subjects must have had their pretreatment periapical radiographs taken at the University of Illinois College of Dentistry Radiology clinic between the dates of January 1, 2000, and April 14, 2010.

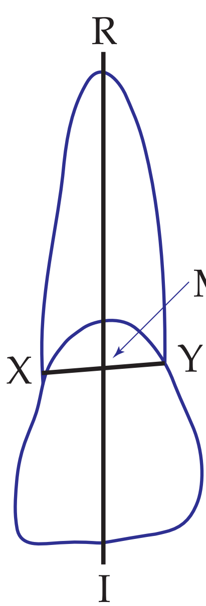

Fig. 1. Reference lines used to measure root length (M to R) and relative root length (M to R divided by I to M).

RADIOGRAPHIC MEASUREMENT TECHNIQUE

Maxillary and mandibular central and lateral incisors, and second premolar root lengths were measured from the apex to the cervical constriction of the anatomic crown on periapical radiographs. These teeth were chosen because they were single-rooted teeth and their root structures were more clearly identified on radiographs than multi-rooted teeth. As shown in Figure 1, the XY line represents the anatomic cementoenamel junction and was found on the radiographs by connecting the mesial and distal cervical constrictions with a line. Point M is defined as the intersection of the XY line and a straight line connecting the root apex (R) and the midpoint of the incisal edge (I). The length of the root was measured in millimeters from point M to R. The relative root length was measured by dividing the root length (MR) by the crown length (IM) and expressed as a ratio.

The statistical analysis was done using SPSS version 16 (SPSS, Chicago IL). The data measurements gathered were first tested for normality. Two-way analysis of variance tests were done using ethnic group and sex as factors for all teeth measured. P-values of less than or equal to 0.05 were considered statistically significant (two tail). If the overall ANOVA showed significance, Scheffé tests were used to isolate pairwise differences among the means.

RESULTS

The descriptive statistics for maxillary central incisor root length and relative root length are shown in Table 1. African American males had the longest mean root length (17.12 mm) and Asian females had the shortest mean root length (13.73 mm), and this difference between the groups ($F = 3.30$, $P = 0.02$) and sexes ($F = 22.0$, $P = 0.000$) was statistically significant. Caucasian males had the highest relative root length values (1.66) and Asian females had the smallest (1.40), but this difference was not statistically significant ($F = 2.87$, $P = 0.09$).

The descriptive statistics for maxillary lateral incisor root length can be seen in Table 2. A significant difference between sexes was found in the two-way ANOVA, with males having longer mean root length than females by 0.99 mm ($F = 8.34$, $P = 0.005$). African American males had the longest mean root length (16.63 mm) and Asian females had the shortest mean root length (14.67 mm).

The descriptive statistics for the maxillary second premolar relative root length are shown in Table 3. African American males had the highest relative root length value (1.70) and Caucasian males had the lowest (1.61), but this difference was not statistically significant between groups (F = 0.58, P = 0.63) or sexes (F = 0.02, P = 0.88). Caucasian females had relative root length values 0.6 higher than Caucasian males. Hispanic males had a relative root length value 0.3 higher than Hispanic females. African American males had a relative root length value 0.8 higher than African American females. Finally, Asian females had a relative root length value 0.3 higher than Asian males.

The descriptive statistics for the mandibular central incisor are shown in Table 4. Statistically significant differences were found between Caucasians and Asians, and between African Americans and Asians (F = 4.46, P = 0.005). Statistically significant differences were also found between sexes (F = 4.27, P = 0.04). The males in each ethnic group had between 0.21 mm and 0.77 mm longer roots than the females within their ethnic group.

The descriptive statistics for the mandibular lateral incisor root length are seen in Table 5. Statistically significant differences were found between Caucasians and Asians, Hispanics and Asians, and African Americans and Asians (F = 7.78, P = 0.00). The mean root length for Asians was found to be statistically significantly shorter than the other three ethnic groups.

The descriptive statistics for the mandibular second premolar root length are shown in Table 6. Statistically significant differences in mean root length were found between Hispanics and African Americans, and African Americans and Asians, and between sexes in each group (F = 6.9, P = 0.000). Males in each ethnic group had between 0.30 mm and 0.87 mm longer roots than the females. The largest difference was found between African American males and females.

DISCUSSION

The results of the current study indicate that there is a statistically significant relationship between ethnicity and developmentally short dental roots for the maxillary central incisor, mandibular central and lateral incisors, and mandibular second premolars. This finding is in agreement with Lind (1972). Overall, Asians were found to have the shortest roots for all teeth except the maxillary second premolar as compared to Caucasians, Hispanics, and African Americans. Statistically significant differences in relative root length between ethnic groups were found for the maxillary central incisor and second premolar. In the present study, Asians and African American females showed a relative root length value less than 1.6 for the maxillary central incisor which indicates a predisposition to developmentally short dental roots for these teeth as previously stated by Desai *et al*. (2006). It is possible that Asians and African Americans have tall maxillary central incisor crown heights as compared to their root lengths for this tooth

TABLE 1. Descriptive statistics for the maxillary central incisor

Group	Sex	Mean root length	sd	Mean relative length	sd	n
Caucasians						
	Males	16.81	2.05	1.66	0.27	16
	Females	14.75	1.95	1.62	0.29	14
	Total	15.85	2.23	1.64	0.27	30
Hispanics						
	Males	15.96	2.71	1.65	0.34	11
	Females	14.55	2.38	1.61	0.21	19
	Total	15.07	2.55	1.63	0.26	30
African Americans						
	Males	17.12	1.55	1.62	0.13	16
	Females	15.21	1.76	1.52	0.24	14
	Total	16.23	1.89	1.57	0.19	30
Asians						
	Males	15.41	1.71	1.52	0.19	11
	Females	13.73	1.59	1.40	0.21	15
	Total	16.23	1.82	1.45	0.21	26
Total						
	Males	16.44	2.06	1.62	0.24	54
	Females	14.55	2.00	1.54	0.25	62
	Total	15.43	2.23	1.58	0.25	116

TABLE 2. Descriptive statistics for the maxillary lateral incisor

Group	Sex	Mean Root Length	sd	n
Caucasians				
	Males	16.28	2.15	16
	Females	15.04	1.94	14
	Total	15.70	2.12	30
Hispanics				
	Males	15.86	1.23	11
	Females	15.34	1.64	19
	Total	15.53	1.50	30
African Americans				
	Males	16.63	1.73	16
	Females	15.64	1.90	14
	Total	16.17	1.84	30
Asians				
	Males	15.64	1.64	11
	Females	14.67	1.01	15
	Total	15.08	1.38	26
Total				
	Males	16.17	1.76	54
	Females	15.18	1.65	62
	Total	15.64	1.77	116

TABLE 3. Descriptive statistics for the maxillary second premolar

Group	Sex	Mean Root Length	sd	n
Caucasians				
	Males	1.61	0.27	16
	Females	1.67	0.31	14
	Total	1.63	0.29	30
Hispanics				
	Males	1.68	0.23	11
	Females	1.71	0.29	19
	Total	1.70	0.27	30
African Americans				
	Males	1.79	0.52	16
	Females	1.71	0.25	14
	Total	1.75	0.41	30
Asians				
	Males	1.70	0.37	11
	Females	1.73	0.39	15
	Total	1.72	0.37	26
Total				
	Males	1.70	0.37	54
	Females	1.70	0.31	62
	Total	1.70	0.34	116

TABLE 4. Descriptive statistics for the mandibular central incisor

Group	Sex	Mean Root Length	sd	n
Caucasians				
	Males	14.84	1.33	16
	Females	14.07	1.09	14
	Total	14.48	1.26	30
Hispanics				
	Males	14.18	2.04	11
	Females	13.50	1.47	19
	Total	13.75	1.70	30
African Americans				
	Males	14.25	1.99	16
	Females	14.04	1.43	14
	Total	14.15	1.73	30
Asians				
	Males	13.36	1.83	11
	Females	12.60	1.21	15
	Total	12.92	1.52	26
Total				
	Males	14.23	1.82	54
	Females	13.53	1.42	62
	Total	13.86	1.65	116

TABLE 5. Descriptive statistics for the mandibular lateral incisor

Group	Sex	Mean Root Length	sd	n
Caucasians				
	Males	15.22	1.99	16
	Females	15.50	1.53	14
	Total	15.35	1.77	30
Hispanics				
	Males	15.64	1.58	11
	Females	14.68	1.60	19
	Total	15.03	1.63	30
African Americans				
	Males	15.84	1.50	16
	Females	15.64	1.57	14
	Total	15.75	1.51	30
Asians				
	Males	13.91	1.55	11
	Females	13.67	1.11	15
	Total	13.77	1.29	26
Total				
	Males	15.22	1.79	54
	Females	14.84	1.63	62
	Total	15.02	1.71	116

TABLE 6. Descriptive statistics for the mandibular second premolar

Group	Sex	Mean Root Length	sd	n
Caucasians				
	Males	15.59	2.10	16
	Females	15.29	2.53	14
	Total	15.45	2.28	30
Hispanics				
	Males	14.73	1.03	11
	Females	14.42	1.59	19
	Total	14.53	1.40	30
African Americans				
	Males	16.94	2.50	16
	Females	16.07	1.81	14
	Total	16.53	2.21	30
Asians				
	Males	14.73	1.69	11
	Females	14.13	1.64	15
	Total	14.39	1.66	26
Total				
	Males	15.64	2.15	54
	Females	14.92	2.00	62
	Total	15.25	2.09	116

and results in smaller relative root length values. Asians may be particularly vulnerable to developmentally short maxillary incisor roots because they also had the shortest mean root length for this tooth. All four ethnic groups had relative root length values greater than 1.6 for the maxillary second premolar which indicates that this tooth does not appear to be predisposed to being developmentally short.

Statistically significant differences in mean root length were found between sexes for the maxillary central and lateral incisors, mandibular central incisors and second premolars. Furthermore, statistically significant differences were found for relative root length values between sexes for the maxillary central incisors. In the majority of teeth, females had shorter roots than their male counterparts within their ethnic group. This finding was in agreement with Kjaer (1995) and Lind (1972).

There were several limitations to the current study. First, the mesial and distal cervical constrictions and the apices of the teeth were not always clear on the radiographs. This could have introduced measurement error into the results. A second limitation was that although the periapical radiographs were taken using the long cone paralleling technique they were taken by different operators and some magnification, elongation, or foreshortening distortions could have been introduced into the images due to operator variability. However, according to Sameshima and Asgarifar (2001) the magnification factor associated with periapical films is less than 5%, and intraoral films are accurate within 0.3 mm. A third limitation of the current study is that it could not be confirmed that the subjects were not of mixed ethnic background. The ethnicity of the subjects was identified from their electronic record. A more accurate way to ensure that the subjects were of a homogenous ethnic background would be to question family members, but this was not realistic since the current study was retrospective in nature.

CONCLUSIONS

The current study found that Asians had the shortest dental root lengths for all teeth measured, except for the maxillary second premolar, as compared to Caucasians, Hispanics, and African Americans. Statistically significant differences in root length were found between ethnic groups for the maxillary central incisor, mandibular central and lateral incisors, and mandibular second premolar. Significant differences in relative root length values among the ethnic groups were found for the maxillary central incisors. Statistically significant differences between sexes were found for the maxillary central and lateral incisors, and the mandibular central incisor mean root lengths, plus the maxillary central incisor relative root lengths. Females had shorter roots than their male counterparts within each ethnic group for the teeth measured.

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Fluctuating Asymmetry in Root Number and Morphology of Permanent Premolars and Molars—Case Reports

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ABSTRACT Aim of this article is to report cases with fluctuating asymmetry in root morphology and root number in permanent premolars and molars and to survey the literature about reporting for fluctuating asymmetry in roots of teeth. Fluctuating asymmetry is a left-right asymmetry of a paired structure that is usually symmetrical. Teeth in corresponding quadrants of the upper and lower jaws are normally symmetrical structures that exhibit mirror imagery. Fluctuating asymmetry does occur at varying levels for all root traits. Fluctuating asymmetry for root morphology and number has been poorly studied. In this article, 21 cases with fluctuating asymmetry in root number and morphology of permanent premolars and molars are reported. Key points are: (1) Fluctuating asymmetry seems to be occurring in Tamil speaking population of Madurai South India more frequently than reported for Caucasian populations. (2) More detailed study of variation in root morphology with greater emphasis on fluctuating asymmetry for root morphology is warranted. 3) Fluctuating asymmetry is of importance to clinical dentists, dental morphologists, and dental anthropologists. *Dental Anthropology* 2011;24(1):16-24.

Van Valen (1962) grouped deviations from perfect symmetry in an organism into three categories: (1) directional asymmetry; (2) antisymmetry; and (3) fluctuating asymmetry (an asymmetry involving a paired structure that is usually symmetrical). Fluctuating asymmetry may be either quantitative or qualitative (Lundström 1961). Bilateral asymmetry in root number is quantitative variation and root morphology asymmetry is qualitative variation.

Fluctuating asymmetry has been associated with congenital abnormalities, genetic syndromes, and elevated levels of inbreeding, and it is also thought to be a general indicator of stress caused by nutritional and/ or disease during development (Scott and Turner 2000). Teeth in corresponding quadrants of the upper and lower jaws are normally symmetrical structures that exhibit mirror imagery. Asymmetry does occur, at varying levels, for all crown and root traits, including overall tooth size, cuspal dimensions, hypodontia and hyperdontia. Numerous studies have explored both the quantitative and qualitative nature of fluctuating asymmetry in crowns of the teeth (both size and morphological variation) among various populations (Lundström 1963; Garn *et al*. 1966; Dibennardo and Bailit 1978; Baume 1979; Townsend 1981; Noss *et al*. 1983; Kieser *et al*. 1986; Kieser and Groeneveld 1988; Scott and Turner 2000; Wetherell *et al*. 2004). But, with regard to fluctuating asymmetry for root number and morphology, studies are very limited (Sabala *et al*. 1994).

The present cases highlight the importance of the clinician and researcher to understand this phenotypic variation. A total of 21 cases are described exhibiting macroscopic fluctuating asymmetry in root number and morphology of permanent premolars and molars. This report describes four mandibular second premolars with extra roots, seven mandibular first molars with extra roots, four mandibular second molars with C-shaped roots, two mandibular second molars with extra roots, three mandibular third molars with extra roots, and one maxillary second molar with extra root configurations.

The subjects reported here were treated in the Department of Conservative Dentistry and Endodontics in the CSI College of Dental Sciences, Madurai, India, or a private referral clinic in Madurai, India, during the period between year June 2007 and December 2010 and were from the local indigenous Tamil speaking population. The bilateral eccentric periapical radiographs of patients who visited for treatment of either pain or caries were obtained (30-degree mesial angulation using a protractor). All the periapical radiographs were taken using an X-Mind® AC X-ray generator (Satelec Acteon Group, Gustave Eiffel, France) operated at 70 kVp and 8

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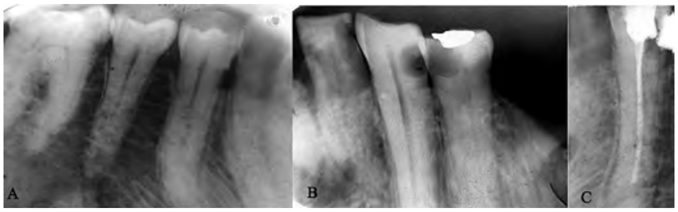

Fig. 1. (*Left*) Mandibular left second premolar. (*Center*) Mandibular right second premolar of the same case (diagnostic radiograph). (*Right*) Postoperative mandibular right second premolar showing two roots. Case is a 45 year old female.

mA. Size 2 periapical Kodak dental films (Eastman Kodak Co., Rochester, NY) were used. Periapical radiographs were taken using paralleling cone technique and films were held using film holders. Panoramic radiographs used in this report were taken using Planmeca x-ray unit (Proline EC, Helsinki, Finland). Films were developed using manual X-ray developer and fixer (Eastman Kodak Co., Rochester, NY) by the time and temperature method. The radiographs were placed on a viewing box, and the light surrounding the radiograph was blocked. Each radiograph was independently studied by two independent reviewers by using magnifying lens (3X). Disagreement in the interpretation of images was discussed with two endodontists, and a consensus was reached (Tu *et al*. 2007, Schafer *et al*. 2009). The criteria for the indication of an extra root were justified by crossing the translucent lines, defining the pulp space and the periodontal ligaments (Walker and Quackenbush 1985).

Mandibular Second Premolars

Report 1

A 45 year old female reported to the department with the complaint of pain in the mandibular right first and second premolars, a diagnosis of irreversible pulpitis was made. On examination, the periapical radiograph (Fig. 1B) of the mandibular right second premolar showed that the tooth had two separate roots in mesiodistal orientation.

Fig. 2. (*Left*) Mandibular left second premolar. (*Right*) Postoperative mandibular right second premolar showing two roots. Case is a 35 year od male.

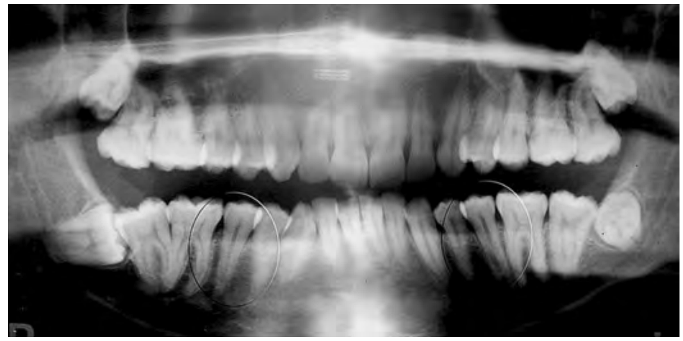

Fig. 3. Panoramic radiograph showing mandibular left second premolar with two roots and mandibular right second premolar with only one root. Case is a 21 year old female.

This was confirmed during root canal treatment (Fig. 1C). A contralateral radiograph (Fig. 1A) was taken for the mandibular left second premolar, and it had only one root.

Report 2

A 35 year old male was referred with the complaint of pain in both right and left mandibular second premolars. A diagnosis of irreversible pulpitis due to carious pulp exposure was made. On examination of radiographs (Fig. 2B) the mandibular right second premolar had two separate roots in mesiodistal orientation while the mandibular left second premolar (Fig. 2A) had only one root.

Report 3

A 21 year old female reported with a complaint of pain in the mandibular right third molar region, and a panoramic radiograph was advised. On examination, pain was diagnosed as being due to a mandibular right third molar impaction. It was noted on the panoramic radiograph (Fig. 3) that the mandibular left second premolar had two separate roots in mesiodistal orientation, whereas the mandibular right second premolar had only one root.

Fig. 4. Panoramic radiograph showing mandibular left second premolar with two roots and mandibular right second premolar with only one root. Case is a 16 year old female.

Fig. 5. (*Left*) Preoperative diagnostic radiograph showing presence of radix paramolaris on mandibular left first molar. (*Center*) Post-obturation radiograph confirming the presence of a radix paramolaris on mandibular left first molar. (*Right*) Radiograph of mandibular right first molar shows no presence of an extra root. Case is a 34 year old male.

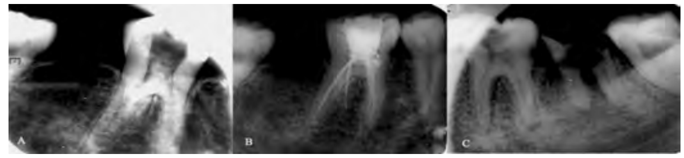

Fig. 7. (*Left*) Preoperative diagnostic radiograph showing the presence of a radix entomolaris on the mandibular left first molar. (*Center*) Post-obturation radiograph confirming the presence of a radix entomolaris on the mandibular left first molar. (*Right*) Radiograph of the mandibular right first molar showing no extra root. Case is a 27 year old female.

Report 4

A 16 year old female was referred by an orthodontist for restoration and management of dental caries in the mandibular right and left first molars. It was noted that the patient had dentinal occlusal surface caries on the mandibular right and left second first molars, and they were managed with class I composite restorations. On examination of a panoramic radiograph (Fig. 4) taken for orthodontic purposes, it was noted that the mandibular left second premolar had two separate roots in mesiodistal orientation, whereas the mandibular right second premolar had only one root.

All the mandibular second premolars with extra root configuration in this report had Vertucci Type IV canal configuration (Vertucci 1984).

Mandibular First Molars

Report 5

A 34 year old male reported with a complaint of pain in the mandibular left first molar. It was noted on the radiograph that a class I amalgam restoration was impinging on the mesial pulp horn; a diagnosis of irreversible pulpititis was made and root canal treatment was undertaken. The periapical radiograph (Fig. 5A) showed that the mandibular left first molar had an extra root, a radix paramolaris (Carlsen and Alexandersen 1991). The contralateral periapical radiograph (Fig. 5C) showed that that tooth had only two roots. Presence of a radix paramolaris was confirmed during root canal treatment of the mandibular left first molar (Fig. 5B).

Report 6

A 15 year old male was referred with pain in the mandibular right first molar and was diagnosed with irreversible pulpitis and root canal treatment was undertaken. The periapical radiograph of the mandibular right first molar (Fig. 6A) showed that the tooth had an extra root, a radix entomolaris (Carlsen and Alexandersen 1990). But the contralateral tooth (Fig. 6C) had only two roots. Presence of a radix entomolaris in mandibular right first molar was confirmed during the root canal treatment (Fig. 6B).

Report 7

A 27 year old female reported to the department with the chief compliant of pain in the mandibular left first molar. She was diagnosed with irreversible pulpitis and root canal treatment was undertaken. The periapical radiograph (Fig. 7A) disclosed that the mandibular left first molar had an extra root, a radix entomolaris. The contralateral periapical radiograph (Fig. 7C) showed that that tooth had only two roots. Presence of a radix entomolaris on the mandibular left first molar was confirmed during root canal treatment (Fig. 7B).

Fig. 6. (*Left*) Preoperative diagnostic radiograph of a mandibular right first molar showing the presence of a radix entomolaris. (*Center*) Post-obturation radiograph confirming the presence of a radix entomolaris on the mandibular right first molar. (*Right*) Radiograph of the mandibular left first molar showing the absence of anyextra root. Case is a 15 year old male.

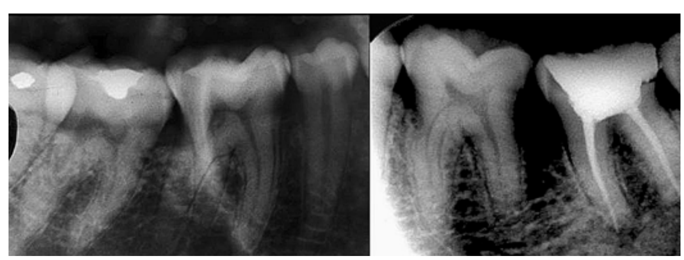

Fig. 8. (*Left*) Radiograph showing the presence of a radix entomolaris on the mandibular right first molar. (*Right*) Radiograph of the mandibular left first molar showing no extra root. Case is a 36 year old male.

Fig. 9. Radiograph showing the presence of a radix entomolaris on the mandibular right first molar, but not on the mandibular left first molar. Case is a 19 year old male.

Report 8

A 36 year old male reported for full crown restoration of the mandibular right second molar, and he also had sensitivity in the mandibular left second molar. A diagnostic periapical radiograph was taken for both mandibular right and left second molar. It was concluded that root canal treatment in the mandibular right second molar was indicated, and a full crown restoration was undertaken. For the mandibular left second molar, sensitivity was due to cervical abrasion and a conservative treatment of desensitizing toothpaste was prescribed followed by evaluation at three months. From the periapical radiograph (Fig. 8A), it was noted that the mandibular right first molar had an extra root , a radix entomolaris, whereas the contralateral tooth (Fig. 8B) had only two roots.

Report 9

A 19 year old male was referred for root canal treatment of the mandibular right first molar. On clinical and radiographic examination a diagnosis of irreversible pulpitis was made and the subject was advised to have root canal treatment. It was noted on the periapical radiograph that the mandibular right first molar had an extra root radix entomolaris (Fig. 9A). On the contralateral tooth (Fig. 9.B) there were only two roots.

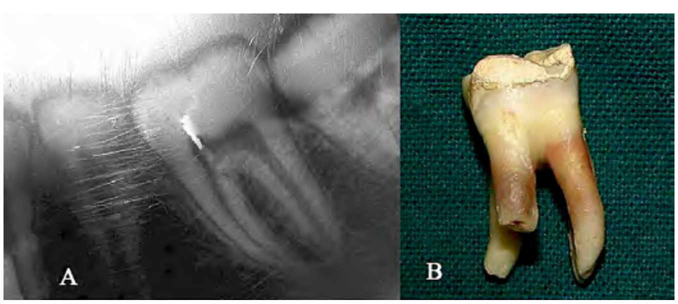

Fig. 10. (*Left*) Periapical radiograph of a mandibular left first molar showing no extra root. (*Right*) Extracted mandibular right first molar having an extra root radix entomolaris. Case is a 32 year old male.

Fig. 11. (*Left*) An extracted mandibular left first molar having an extra root radix entomolaris. (*Right*) Radiograph of mandibular right first molar showing no extra root radix entomolaris. Case is a 50 year old male.

Report 10

A 32 year old male was referred with pain and deep caries on the mandibular right first molar; he was advised for root canal treatment. He rejected this, and the tooth was extracted. It was noted after extraction that the tooth had an extra root, a radix entomolaris (Fig. 10B). The contralateral periapical radiograph showed that that tooth had only two roots (Fig. 10.A).

Report 11

A 50 year old male was referred for root canal treatment of the mandibular left first molar, but the man wanted the tooth extracted. After extraction, it was noted that the tooth had an extra root, a radix entomolaris (Fig. 11A). The contralateral periapical radiograph was taken, and it showed that there were only two roots (Fig. 11B).

Based on Ribeiro and Consolaro's (1997) classification of radix entomolaris curvature, cases 5, 6, 7, 8, 9 had Type I curve, case 10 and 11 had Type II curve.

Mandibular Second Molars

C-shaped root configuration

Report 12

A 22 year old female with a complaint of pain in the mandibular left first molar was diagnosed with irreversible pulpitis, and root canal treatment was undertaken. The periapical radiograph disclosed that the

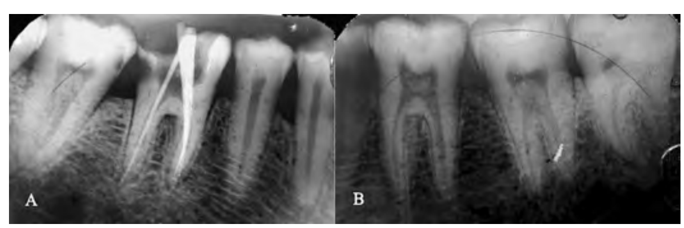

Fig. 12. (*Left*) Periapical radiograph showing the presence of C-shaped root on the mandibular left second molar. (*Right*) Radiograph of the mandibular right second molar showing two separate roots. Case is 22 year old female.

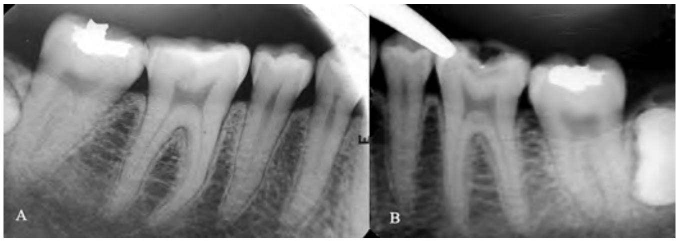

Fig. 13. (*Left*) Radiograph showing the presence of a C-shaped root on the mandibular right second molar. (*Right*) Radiograph of the mandibular left second molar showing two separate roots. Case is 43 year old male.

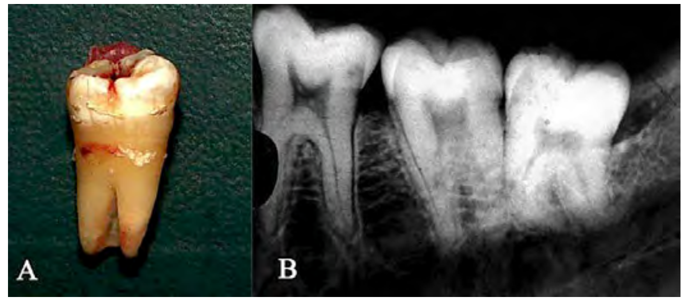

Fig. 15. (*Left*) Extracted mandibular left second molar having a C-shaped root. (*Right*) Radiograph of the mandibular right second molar having two separate roots. Case is a 37 year old male.

mandibular left second molar (Fig. 12A) had a C-shaped root configuration. According to the classification of Fan *et al*. (2004), it was a Type I. The contralateral tooth (Fig. 12B) had two separate roots.

Report 13

A 43 year old male reported to the department with a complaint of postoperative pain after a class I amalgam restoration on the mandibular right second molar. A periapical radiograph was taken, and it was concluded that pain was due to occlusal interference which was relieved. It was noted on the periapical radiograph that this tooth (Fig. 13A) had a C-shaped root configuration. According to Fan *et al*. (2004), the root was Type I. A contralateral radiograph (Fig. 13B.) was taken, and that tooth had two separate roots.

Report 14

A 34 year old female with a complaint of pain in the mandibular right first molar was referred for root canal treatment. This tooth had two separate roots (Fig. 14B). The contralateral tooth had a C-shaped root configuration (Fig. 14A). According to Fan *et al*. (2004), the root was of Type I.

Report 15

A 37 year old male reported with a complaint of pain in the mandibular left second molar. He was advised for root canal treatment, but he was not willing, and elected to have the tooth extracted. It was fond that this tooth had a C-shaped configuration (Fig. 15A). According to Fan *et al*. (2004), the root was of Type II. A contralateral periapical radiograph (Fig. 15B.) showed that the antimere had two separate roots. Presence of a C-shaped root was diagnosed from the radiograph according to the criteria of Fan *et al.* (2004) of having a fused root, presence of a longitudinal groove on the root, and our assessment of the coronal, middle and apical third of root canal indicated the presence of C-shaped root.

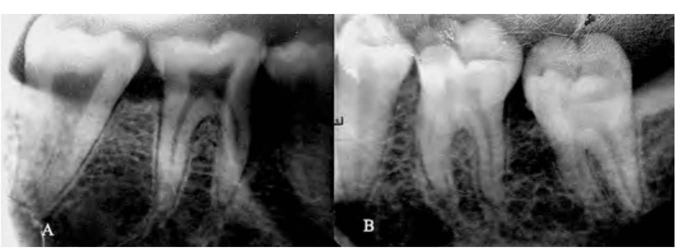

Fig. 14. (*Left*) Radiograph showing the presence of a C-shaped root on the mandibular left second molar. (*Right*) Radiograph of the mandibular right second molar showing two separate roots. Case is a 34 year old female.

Mandibular Second Molars

Presence of an extra root (Radix entomolaris and Radix paramolaris)

Report 16

A 23 year old female was referred for root canal treatment on the mandibular right second molar. The tooth was diagnosed with irreversible pulpitis, and root canal treatment was undertaken. Based on the diagnostic periapical radiograph that this tooth had an extra root, a radix entomolaris (Fig. 16A), which was confirmed during root canal treatment (Fig. 16B). A contralateral radiograph showed that that tooth had two separate roots (Fig. 16C).

Report 17

A 45 year old male reported with the complaints of pain in mandibular left second molar, and he was diagnosed with irreversible pulpitis and root canal treatment was undertaken. The periapical radiograph showed that this molar had an extra root radix entomolaris (Fig. 17A) and this was confirmed during root canal treatment (Fig. 17B). The radiograph of the contralateral tooth showed that it had a fused root (Fig. 17C). Based on the classification by Ribeiro and Consolaro (1997), cases 16, 17 had type I curvature.

Fig. 16. (*Left*) Preoperative diagnostic radiograph showing presence of a radix entomolaris on the mandibular right second molar. (*Center*) Post-obturation radiograph confirming the presence of a radix entomolaris on the mandibular right second molar. (*Right*) Radiograph of mandibular left second molar showing only two roots. Case is a 23 year old female.

Mandibular Third Molars

Report 18
A 46 year old male was referred for root canal treatment of the mandibular right third molar, but because of inadequate mouth opening after consulting with the referring doctor it was decided to extract the tooth. Inspection showed that the molar had three roots with an extra root, a radix paramolaris (Fig. 18A). The contralateral tooth (Fig. 18B) had only two separate roots.

Report 19
A 54 year old male reported with a complaint of pain in the mandibular left third molar. On examination the subject was diagnosed with irreversible pulpitis, and root canal treatment was recommended. But the patient was unwilling, and this third molar was extracted. This third molar had an extra root, a radix entomolaris (Fig. 19A). The contralateral radiograph disclosed that the tooth had two separate roots (Fig. 19B).

Report 20
A 21 year old male was referred with a complaint of pain in the mandibular left third molar. On examination, a diagnosis of irreversible pulpitis due to carious pulp exposure was made, and root canal treatment was recommended. From the panoramic radiograph (Fig. 20) the mandibular right third molar had an extra root radix paramolaris. The contralateral tooth had only two separate roots. Based on Ribeiro and Consolaro's (1997) classification of radix entomolaris curvature, cases 18, 20 had type III curve and case 19 had type I curve.

Fig. 17. (*Left*) Preoperative diagnostic radiograph showing presence of acradix entomolaris on the mandibular left second molar. (*Center*) Post-obturation radiograph confirming the presence of a radix entomolaris on the mandibular left second molar. (*Right*) Radiograph of the mandibular right second molar showing fused roots. Case is a 45 year old male.

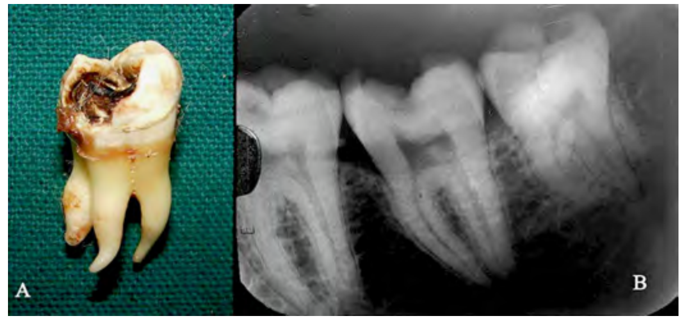

Fig. 18. (*Left*) An extracted mandibular right third molar with a radix paramolaris. (*Right*) Radiograph of the mandibular left third molar showing only presence of two roots.

Maxillary Second Molars

Report 21
A 22 year old female was referred with a complaint of pain in both maxillary right and left second molars. On examination, a diagnosis of irreversible pulpitis with carious pulp exposure was made for both teeth. It was noted from the periapical radiograph of the maxillary left tooth (Fig. 21A) that its palatal root outline was blurred and an extra palatal root canal was suspected. An extra palatal root canal in the maxillary left second molar was confirmed during treatment (Fig. 21B). The contra lateral radiograph revealed that that tooth had only one palatal root canal (Fig. 21C). Based on Vertucci 's (1984) root canal classification, it was a Type IV canal configuration.

DISCUSSION

The variability of root canal morphology and root numbers represents a challenge to both endodontic

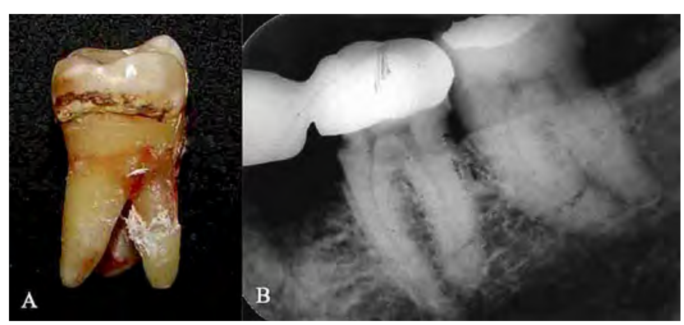

Fig. 19. (*Left*) An extracted mandibular left third molar with a radix entomolaris. (*Right*) Radiograph of the mandibular right third molar showing only presence of two roots. Case is a 54 year old male.

Fig. 20. A panoramic radiograph showing mandibular right third molar having extra root radix paramolaris and a mandibular left third molar showing two separate roots. Case is a 21 year old male.

diagnosis and treatment. Besides the root canal variability, the fluctuating asymmetry presented in these cases reiterates the need for the observer to have a greater understanding of root morphology. Fluctuating asymmetry in root form has been reported and studied exclusively in very limited ways. Bilateral asymmetry has been reported for each group of teeth from different populations, rather than reporting from one group and studying bilateral asymmetry in that population for various tooth types. This is the first time that a case report is presented with fluctuating asymmetry in root aberrations being highlighted.

Review of literature by Cleghorn *et al*. (2007) reports that incidence of mandibular second premolars with two separate roots is very low and it has been put at an average of 0.4%. In a study by Iyer *et al*. (2006) among a South Indian group it was concluded that mandibular second premolars with two roots had an incidence of 6.2%, but the study failed to mention how the radiographs were interpreted for root variations. Also, in the same study, bilateral occurrence of root variation was put at 3.2% but there is no mention which type of root aberrations

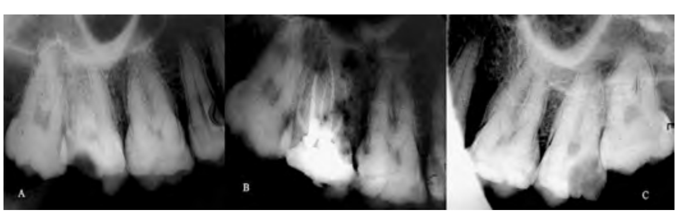

Fig. 21. (*Left*) Pre-operative diagnostic radiograph suggesting the presence of extra palatal root canal on the maxillary left second molar. (*Center*) Post-obturation radiograph confirming the presence of the extra palatal root canal on the maxillary left second molar. (*Right*) Radiograph of the maxillary right second molar showing only one palatal root canal. Case is a 22 year old female.

were encountered or for on which mandibular premolar was affected. This bilateral incidence of 3.2% is much lower than reported by Sabala *et al*. (1994) for bifurcated mandibular second premolar root, which he reported it at 54.5% in a Caucasian population.

In contrast to the study by Iyer *et al*. (2006), the extra-rooted mandibular second premolars in the present study occurred only unilaterally. In agreement with Iyer *et al*. (2006) where it was reported that after Vertucci Type I, the Type IV canal had the highest incidence, in the present cases all the mandibular second premolars with an extra root had Vertucci Type IV canals.

The incidence of three-rooted mandibular first molars in an Indian group has been reported at 5.97%, and bilateral occurrence of this aberration only at 37.14% (Garg *et al*. 2010). In agreement with the present study, cases presented here only occurred unilaterally.

The C-shaped mandibular root configuration in an Indian group has been reported at 7.5% of all extracted teeth examined; bilateral incidence of this root aberration has not been mentioned in that study (Neelakantan *et al*. 2010). Sabala *et al*. (1994) reported that, in a Caucasian group, the bilateral occurrence of a C-shaped root in mandibular second molars is 72.7%. In contrast to this study, we found four cases of mandibular second molars with a C-shaped root occurring only unilaterally.

A mandibular second molar with three roots has been reported for an Indian group at 8.98% of all the extracted teeth examined, and bilateral occurrence of this root aberration has not been mentioned (Neelakantan *et al*. 2010). In the Neelakantan study, presence of an extra root was in the mesiolingual position; however, in the case presented here, the extra root was in the distolingual position (radix entomolaris). This extra-rooted mandibular second molar occurred only unilaterally.

A mandibular third molar with three roots has been reported with an incidence of about 5% in Turkish and Caucasian populations; bilateral occurrence of this aberration has not been mentioned (Sidow *et al*. 2000; Sert *et al*. 2010). The cases presented here occurred only unilaterally, and two cases had the extra root present lingually (radix entomolaris), and one case had the extra root present buccally (radix paramolaris). A study of variation in mandibular third molar root morphology is lacking for the Indian population.

Maxillary second molars with two palatal canals have a low incidence at 1.4% for a Caucasian group, and bilateral occurrence of this aberration has not been reported (Peikoff *et al*. 1996). The one case reported here with two palatal canals occurred only unilaterally. Maxillary second molar root canal variation for Indian populations is lacking.

Very few cases of root aberrations record the bilateral occurrence of root number (De Moor 2002). To our knowledge, the only study that exclusively recorded bilateral occurrence of root variations from a Caucasian population is the study by Sabala *et al*. (1994), and this study concluded that root aberrations occur bilaterally approximately 60% of the time. This is in contradiction to the present case reports where all of the root aberrations were present unilaterally. This variation in unilateral occurrence of the root aberration may be due to differences in the populations reported.

Ethnic differences in root phenotypes are an established phenomenon (Scott and Turner 2008). Root number and morphological studies for indigenous subgroups in India are very limited. Except for one study about the incidence of three-rooted mandibular first permanent molars, others do not mention the bilateral occurrence of root aberrations or fluctuating asymmetry (Garg *et al*. 2010). Human diversity in India is defined by 4,693 different, documented population groups that include 2,205 major communities, 589 segments and, 1,900 territorial units spread across the country (Singh 1988). Structuring of the subgroups has been reported in a genetic study (Kashyap *et al*. 2006). Since tooth and root development is strongly controlled by genetic factors, a more detailed study of root variations in different subgroups in India is warranted. A detailed study about root variations in maxillary and mandibular premolars and molars and their bilateral occurrence in a Tamil speaking population in Madurai, South India; is being undertaken by the authors through the Department of Anthropology, University of Madras.

CONCLUSIONS

1. From the case reports presented here it is seen that for the Tamil speaking population group in Madurai, South India, fluctuating asymmetry is occurring for various types of root aberrations in permanent premolars and molars.
2. Fluctuating asymmetry in root aberrations will be of importance to clinical dentists, dental anthropologists and dental morphologists.
3. A more detailed study on the incidence of root aberrations in permanent premolars and molars of local population group is necessary with greater emphasis on occurrence of fluctuating asymmetry for root aberrations.

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The Phenetic Distances of Jordanian Arabs from Other Human Populations Suggest a Major Genetic Drift from the Caucasoid Race

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ABSTRACT The objectives were to determine the expression frequency and sexual dimorphism of 16 non-metric crown traits on the permanent dentitions of the living Jordanians, and to assess the biological affinity of this sample to 21 high-order groups based on these traits. 360 Jordanian school children (176 males, 184 females; mean ages 15.5, sd = 0.4 years) were studied in 2009. The traits were classified using the Arizona State University dental anthropology system, counted with the individual count method, and dichotomized according to Scott and Turner criteria for the purpose of group comparisons. Z-value test was used to assess sexual dimorphism in these traits. Smith's Mean Measure of Divergence was used to measure all pairwise distance values among the groups. Sexual dimorphism was found in only three traits (*i.e.*, Carabelli's tubercle/cusp, metaconule and hypoconulid absence). This study revealed that the dental pattern of living Jordanians is sufficiently distinct from the Caucasoid pattern and all other known dental patterns to warrant a unique dental pattern for this population. Moreover, the relatively large distance values between the living Jordanians and all other world groups considered including the Western Eurasian groups suggest a major genetic drift for this population from the Caucasoid race. *Dental Anthroology* 2011;24:23-30.

The study of dental morphological traits has been used extensively by dental morphologists, anthropologist and paleontologists for characterization and assessment of the biological relationships within and among ancestral, recent and living major subdivisions of humankind, and to a lesser extent for racial diagnosis in the field of forensic odontology (Dahlberg 1965b, 1986; Turner, 1987a; Scott and Turner, 1988, 1997; Irish, 1993; and others).

Dental morphological traits have been shown to be largely under the control of genes and minimally affected by environmental factors (Scott and Dahlberg, 1982; Corruccini *et al*., 1986; Sofaer *et al*., 1986), and have also been described to be genetically conservative, exhibiting minimal modification over many generations (Scott and Turner, 1988). However, the general evolutionary trend in the modern human dentition has been described to be toward morphologic simplification and tooth size reduction (Scott and Turner, 1988).

The utility of inter-population variation in the frequencies of dental non-metric (morphological) traits for measuring the biological distance between human populations has been well-demonstrated (Scott and Turner, 1997). Such biological distance values provide summary values that encapsulate the overall difference in the expression frequencies of these traits between two groups (Scott and Turner, 1997). Morphological or phenetic distances based on inter-population variation in the frequencies of dental morphological traits have been shown to be powerful in assessing biological affinity between population groups, since these traits have a strong heritable component (Scott and Turner, 1997). In general, small inter-group distances indicate that these groups are biologically similar and have a recent common ancestor, while large values are associated with biological dissimilarity and remote common ancestry (Scott and Turner, 1997). However, significant admixture (gene flow) between groups leads to convergence which can change the original biological distance between these groups (Scott and Turner, 1997).

The dental pattern of living Jordanian Arabs has not been comprehensively studied before, and the biological affinity of this population for other geographic races has not been assessed.

Sexual dimorphism for dental morphological traits has been investigated by many workers, and the reported results are not always consistent and appear to show geographic variation among various world groups. An exception of this is the distal accessory ridge

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of the upper and lower canines which exhibits consistent dimorphism between males and females across diverse groups (Scott, 1977a; Kaul and Prakash, 1981; Kieser and Preston, 1981; Scott *et al*., 1983). Apart from this variable, some researchers have found statistically significant male-female differences in the expression of some dental morphological traits such as Carabelli's trait (Goose and Lee, 1971; Kaul and Prakash, 1981; Kieser and Preston, 1981; Townsend and Brown, 1981b, Scott *et al*., 1983; Mizoguchi, 1985) and upper central incisor shoveling (Rothhammer *et al*., 1968; Harris, 1980) while others found no sex difference for Carabelli's trait (Garn *et al*., 1966d; Turner, 1969; Scott, 1980; Townsend *et al*., 1992) and the shoveling trait (Aas and Risnes, 1979a; Mizoguchi, 1985).

The aims of the present study were, first, to investigate the frequencies and sexual dimorphism of 16 dental morphological traits, that are observable on dental stone casts on the permanent dentition of the living Jordanian Arabs, and, second, to assess the biological affinity of the living Jordanians in a global context by measuring all of the pairwise biological distances among this group and 21 other high-order regional groups from the five major subdivisions of humankind based on the variation of frequencies of the dental traits.

MATERIALS AND METHODS

Sample and Inclusion Criteria

A random stratified sample was obtained in 2009 by selecting 370 tenth grade school children (180 males and 190 females), from 12 schools representing the six regional directories of the capital city of Jordan, Amman. Informed consents were obtained from the parents of all children who chose to participate in the study before the children were subjected to dental examination or impression taking. The average age of the selected subjects was 15 years (sd = 0.4). They were selected according to the following criteria: all subjects were apparently healthy with no history of serious childhood illnesses, have erupted second molars, showing well aligned arches with no supernumerary teeth and no history of orthodontic treatment, with normal appearing teeth, no large restorations or fixed replacements, and minimal marks of caries or attrition.

Alginate impressions for the upper and lower dental arches were taken (Lascod S.p.A, Firenze, Italy). Impressions were poured with type IV dental stone (Elite stone, Zhermack S.p.A, Badia Polesine, Italy) within one hour of impression taking. Casts of ten subjects were excluded due to technical errors such as air bubbles. The remaining casts were of 176 male and 184 female students.

Observation Method

Sixteen morphological tooth crown traits were observed and classified according to the standard plaques of the Arizona State University dental anthropology system (Turner *et al*., 1991). All observations were carried out by under good lighting and using 10X hand lenses. The individual count method was used here to estimate the frequency of expression of the dental morphological traits. According to this method, the antimere exhibiting the highest grade of trait expression is used for statistical analysis (Scott and Turner, 1997). This method was chosen because it assigns each individual a phenotypic value that is thought to best represent the individual genotype and it does not artificially inflate the sample size like the total side (tooth) count method (Scott and Turner, 1997). Such increase in sample size would affect most statistical analyses (Scott and Turner, 1997).

Intraobserver Error

All observations for these morphological traits were carried out by one well-trained observer. Intra-observer reliability for scoring these traits was assessed according to Nichol and Turner criteria (1986). 30 dental casts out of the present sample were selected, to be scored by the single observer, and rescored by the same observer three months later. Care was taken to reproduce the percentages of males and females in this sample as in the original sample of 360 casts. Percentages of disagreements that are of two grades or more between the two scoring sessions (>1 Grade Variant Scoring %) were calculated for the traits considered here and found to be less than the critical value of 10% as set by Nichol and Turner (1986) who justified that traits generating greater than 10% disagreement of two or more grades between two scoring sessions are difficult to reliably score since they reflect either recording error, inaccurate observational method, or difficulties with standard plaque itself rather than the natural difficulty in the ability to consistently classify individuals exhibiting intermediate trait expression between two grade standards on a ranked scale. In addition, the Net Mean Grade Difference (NMGD) between the two scoring sessions was calculated for these traits using the formula

$$NMGD = (\Sigma (X_2 - X_1)/n) \times 100$$

where X_1 = the grade number assigned to a cast for a trait in the first scoring session; X_2 = the grade number assigned to the same cast for the same trait in the second scoring session; and n is the number of casts that were observed in both of the scoring sessions.

The calculated NMGD value for each trait considered here was found below the critical level of NMGD for that trait, which is > 5% multiplied by the number of the highest grade on the grading standard for that trait.

Furthermore, the differences between the mean scores of the two scoring sessions for these traits were estimated using the paired sample t-test and the t-values were found to be below the critical 0.05 probability level adjusted by Bonferroni's method (Miller, 1966; Nichol and Turner, 1986). It should be noted that dental morphological traits are ordinal scale variables and the t-test is an interval scale statistics, however, since the graded scales for scoring these traits were designed so that the variation in expression of these traits is divided into equal intervals from the least to greatest expression (Scott, 1973), it is justifiable, according to Nichol and Turner (1986), to use the t-test with non-metric dental traits based on the assumption that the classification grades are equally spaced on the ranked scales for these traits.

Given the foregoing values (the values of the >1 Grade Variant Scoring %, of NMGD and the t-values), it can be concluded that the scoring of these traits is reliable and that the intra-observer error in scoring these traits can be considered random and statistically insignificant.

Statistical Analysis and Visual Depiction

Social Science Statistical Package Software (SPSS, Version 17.0, Inc., Chicago, IL) was used to analyze the data. Frequencies were calculated for crown traits and dichotomized according to Scott and Turner criteria (1997) for the purpose of group comparisons to quantify their relative prevalence among the living Jordanian sample. Z-value test was used to test any significant difference in trait expression between males and females using software available on the following website:

(http://www.dimensionresearch.com/resources/calculators/ztest.html).

For the purpose of affinity assessment, the biological distances among the living Jordanians and 21 high-order regional groups from the five major subdivision of humankind were measured using CAB Smith's Mean Measure of Divergence (MMD) based on the variation in the frequencies of expression of 16 non-metric tooth crown traits among these groups (Constandse-Westermann, 1972; Harris and Sjøvold, 2004). This analysis was based on our own data for the frequencies of these traits among the living Jordanians and on the data available in Scott and Turner (1997) regarding the frequencies of the same traits among the other 21 regional groups and the corresponding sample sizes. Anscombe's angular transformation formula was adopted here to transform frequencies into angles for calculating the Smith's MMD in order to stabilize sampling variances of binomial variables, since this formula is the recommended angular transformation method by Rao (1952) for moderately large samples (Harris and Sjøvold, 2004). It should be noted that the MMD value between any two groups being compared was measured as recommended by Harris and Sjøvold (2004) by calculating the differences between the two groups in angularly transformed frequencies of each trait, then this difference is squared so that positive and negative differences do not cancel one another, then the correction term $((1/n_{1k} + 0.5)+(1/n_{2k} + 0.5))$ is subtracted from this squared difference for each trait (hence the subscript k) in order to adjust for the overestimation of divergence between corresponding groups generated by the squared difference between two angular values, then the resultant values for all traits used in the equation are summed and then the sum is divided by the number of these traits (Harris and Sjøvold, 2004). The resultant matrix of distance values corresponding to all pairwise comparisons among the 22 groups was used to derive two coordinates (two-dimensional ordination) for each group through multidimensional scaling using SPSS statistics 17.0 in order to reduce the complexities of the distance matrix to two dimensions and to provide graphical representation for the biological distances among the 22 groups considered.

RESULTS

Crown Trait Frequencies

Table 1 summarizes the frequencies of 16 non-metric dental crown traits, on the permanent dentition in both sexes among the living Jordanian sample. By comparing the frequencies of the 16 traits among the living Jordanians with the world ranges of these traits, it is apparent that the dental pattern of the living Jordanians shows distinctly high frequencies of double shoveling on UI1, Carabelli's trait and cusp 5 (metaconule) on UM1; high frequencies of interruption grooves on UI2, hypocone absence (3-cusped form) on UM2 and Bushmen canine trait on UC; intermediate frequencies of shoveling on UI1, hypoconulid absence on LM2, deflecting wrinkle, cusp 6 and 7 on LM1; low frequencies of bilateral winging of UI1s, Y pattern on LM2, hypoconulid absence and distal trigonid crest on LM1, and absence of premolar odontomes (Table 1).

Sexual Dimorphism

Statistically significant male-female differences were found in only three of the 16 dental morphological traits. These include the Carabelli's trait (tubercle and cusp forms only) and cusp 5 (distal accessory tubercle, metaconule) on UM1, and hypoconulid absence (4-cusped form) on LM1. In the first two traits the difference is in favor of males while in the third one it is in favor of females (Table 1).

Phenetic Distances Among 22 Regional Groupings

Table 2 shows a matrix of all the pairwise biological distances among 22 high-order regional groupings including the living Jordanian Arabs based on inter-group variation in the frequencies of the 16 crown traits.

TABLE 1. Frequencies of 16 dental morphological traits among the living Jordanians (individual count, affected individuals/ total number of subjects in parentheses)

Trait name	Tooth	Breakpoint	World range	Percent Males	Percent Females	Z-value	Percent (sexes pooled)
Winging	UI1	Grade 1 (bilateral winging)	4.2-50.0%	8.0% (14/176)	8.7% (16/184)	0.067	8.3% (30/360
Shoveling	UI1	Grades 3-6 (Hrdlicka's semi- and full-shovel)	0.0-91.9%	55.7% (98/176)	56.0% (103/184)	-0.049	55.8% (201/360)
Double Shoveling	UI1	Grades 2-6	0.0-70.5%	98.3% (173/176)	94.6% (174/184)	1.614	96.4% (347/360)
Interruption Grooves	UI2	Grade 1 (total frequency)	10.4-65.0%	63.6% (112/176)	61.4% (113/184)	0.328	62.5% (225/360)
Bushmen Canine	UC	Grades 1-3 (total frequency)	0.0-35.1%	30.7% (54/176)	27.2% (50/184)	0.618	28.9% (104/360)
Odontomes	UPMs and LPMs	Grade 1 (total frequency)	0.0-6.5%	0.0% (0/176)	0.0% (0/184)	—	0.0% (0/360)
3-Cusped	UM2	Grades 0-1 (equivalent to 3 on Dahlberg scale)	3.3-30.6%	26.7% (47/176)	19.0% (35/184)	1.611	22.8% (82/360)
Carabelli's Trait	UM1	Grades 5-7 (tubercle and cusp forms only)	1.9-36.0%	51.7% (64/184)	34.8% (91/176)	3.134a	43.1% (155/360)
Cusp 5	UM1	Grades 1-5 (total frequency)	10.4-62.5%	69.3% (122/176)	57.6% (106/184)	2.195a	63.3% (228/360)
4-Cusped	LM1	Grade 0 (4-cusped LM1)	0.0-10.0%	0.0% (0/176)	3.8% (7/184)	2.228a	1.9% (7/360)
4-Cusped	LM2	Grade 0 (4-cusped)	4.4-84.4%	73.3% (129/176)	81.0% (149/184)	1.611	77.2 (278/360)
Y Pattern	LM2	Y pattern	7.6-71.9%	21.0% (37/176)	19.0% (35/184)	0.342	20.0% (72/360)
Cusp 6	LM1	Grades 1-5 (total frequency)	4.7-61.7%	17.6% (31/176)	13.6% (25/184)	0.907	15.6% (56/360)
Cusp 7	LM1	Grades 1-4 (total frequency excluding grade 1A)	3.1-43.7%	21.0% (37/176)	15.2% (28/184)	1.293	18.1% (65/360)
Deflecting Wrinkle	LM1	Grade 3	4.9-39.5%	23.3% (41/176)	19.0% (35/184)	0.866	21.1% (76/360)
Distal Trigonid Crest	LM1	Grade 1 (presence)	0.0-18.7%	5.7% (10/176)	9.8% (18/184)	1.255	7.8% (28/360)

[a]the difference is statistically significant at the 0.05 probability level (2-tailed).
UI1: upper central incisor; UI2: upper lateral incisor; UC: upper canine; UPMs: upper first and second premolars; LPMs: lower first and second premolars; UM1: upper first molar; UM2: upper second molar; LM1: lower first molar; LM2: lower second molar

TABLE 2. Distance matrix among 22 regional groupings including the living Jordanian Arabs (C.A.B. Smith's Mean Measure of Divergence (MMD) values)

	JOR	WE	NE	NA	WA	SA	KH	CM	JOM	JR	NES	SS	AA	NWA	NSAI	SEE	SER	PO	MI	AUS	NG	ML
JOR	.000																					
WE	.621	.000																				
NE	.605	.035	.000																			
NA	.525	.020	.034	.000																		
WA	.723	.401	.388	.292	.000																	
SA	.722	.175	.183	.103	.102	.000																
KH	.840	.344	.428	.254	.116	.082	.000															
CM	.431	.385	.397	.312	.361	.326	.445	.000														
JOM	.694	.218	.243	.204	.291	.211	.317	.181	.000													
JR	.520	.366	.403	.313	.351	.303	.399	.061	.136	.000												
NES	.578	.484	.505	.419	.419	.368	.459	.064	.197	.040	.000											
SS	.359	.128	.150	.092	.294	.181	.293	.110	.100	.099	.170	.000										
AA	.610	.550	.574	.497	.521	.455	.559	.091	.207	.059	.016	.210	.000									
NWA	.540	.713	.720	.619	.606	.600	.695	.085	.333	.099	.042	.288	.043	.000								
NSAI	.547	.845	.836	.724	.692	.705	.812	.127	.461	.166	.090	.374	.116	.023	.000							
SEE	.440	.208	.203	.152	.173	.155	.265	.065	.089	.064	.109	.045	.173	.215	.285	.000						
SER	.462	.185	.194	.135	.175	.135	.237	.065	.096	.055	.124	.041	.183	.247	.321	.004	.000					
PO	.577	.199	.176	.157	.142	.145	.279	.136	.073	.120	.202	.093	.260	.338	.434	.020	.028	.000				
MI	.581	.253	.259	.205	.160	.161	.243	.091	.107	.077	.103	.102	.186	.243	.304	.012	.016	.033	.000			
AUS	.733	.378	.327	.305	.126	.199	.320	.201	.175	.179	.267	.238	.321	.391	.499	.095	.096	.047	.092	.000		
NG	.727	.092	.064	.051	.198	.085	.224	.421	.215	.417	.553	.206	.636	.778	.902	.193	.177	.134	.221	.215	.000	
ML	.603	.168	.113	.117	.111	.097	.257	.235	.140	.232	.309	.133	.390	.486	.573	.060	.068	.024	.072	.085	.065	.000

JOR: Jordan; WE: Western Europe; NE: Northern Europe; NA: North Africa; WA: West Africa; SA: South Africa; KH: Khoisan; CM: China-Mongolia; JO: Jomon; JR: Japan (Recent); NES: Northeast Siberia; SS: South Siberia; AA: American Arctic; NWA: Northwest North America; NSAI: North and South American Indian; SEE: Southeast Asia (Early); SER: Southeast Asia (Recent); PO: Polynesia; MI: Micronesia; AUS: Australia; NG: New Guinea; ML: Melanesia

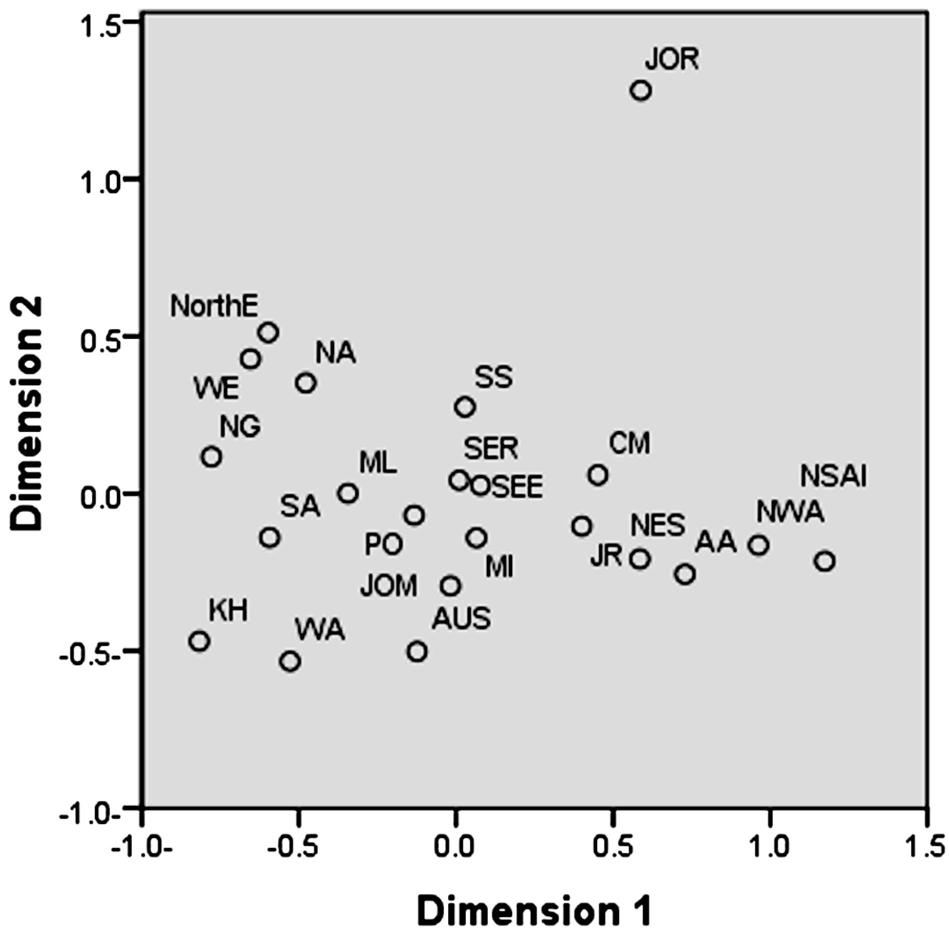

Fig. 1. Two-dimensional ordination based on multidimensional scaling of distance matrix for 16 non-metric crown traits in 22 regional groupings including the living Jordanian Arabs.

Abbreviations are: JOR: Jordan; WE: Western Europe; NorthE: Northern Europe; NA: North Africa; WA: West Africa; SA: South Africa; KH: Khoisan; CM: China-Mongolia; JO: Jomon; JR: Japan (Recent); NES: Northeast Siberia; SS: South Siberia; AA: American Arctic; NWA: Northwest North America; NSAI: North and South American Indian; SEE: Southeast Asia (Early); SER: Southeast Asia (Recent); PO: Polynesia; MI: Micronesia; AUS: Australia; NG: New Guinea; ML: Melanesia

None of the 21 regional groups is found apparently biologically close to the living Jordanians; however, the smaller distance values to the living Jordanians are those corresponding to South Siberia, China-Mongolia and Southeast Asia (Recent and Prehistoric) and, surprisingly, not to Western Eurasian groups (Western Europe, Northern Europe and North Africa).

Figure 1 provides a visual representation of the distance matrix shown in Table 2 by reducing these values to two dimensions through multidimensional scaling. It shows that the living Jordanian Arabs appear as an outlier and do not cluster with any of the 21 regional groups. However, relatively speaking, the Jordanian groups appear closer to South Siberia, China-Mongolia and Southeast Asia than to Western Eurasian groups.

DISCUSSION

Dental Morphological Pattern of Living Jordanians

The results of this study revealed that the living Jordanian Arabs have a unique dental morphological pattern exhibiting outstandingly high frequencies of UI1 double shoveling and UM1 Carabelli's tubercle/cusp forms that set this population apart from other world groups. Moreover, this population falls at the high end of the global scale for five crown traits (*i.e.*, UM1 cusp 5, UI2 interruption grooves, 3-cusped UM2, 4-cusped LM2, and UC Bushmen canine trait). In addition, UI1 shoveling assumes high intermediate position on the world range for this population group. Additionally, this group shows intermediate frequencies for deflecting wrinkle, cusp 6 and 7 on LM1. The remainder of crown traits described is at the low end of world variation (*i.e.*, UI1s bilateral winging, LM2 Y pattern, 4-cusped LM1, LM1 distal trigonid crest; and premolar odontomes). This pattern is apparently distinct from the Western Eurasian, or Caucasoid, dental pattern, which is characterized by (A) high frequencies of 4-cusped lower first and second molars, Carabelli's tubercle/cusp, and 3-cusped upper second molars, but the latter two traits are not distinctly high in this regional subdivision and are nearly equaled by groups in other regions, (B) intermediate frequencies of UI2 interruption grooves and LM2 Y pattern; and (C) low frequencies of the remainder of the crown traits described (*i.e.*, winging, shoveling, double shoveling, Bushmen canine, metaconule, cusp 6, cusp 7, deflecting wrinkle, distal trigonid crest, and premolar odontomes) (Scott and Turner, 1997). To summarize, the dental morphological pattern of living Jordanian Arabs is characterized by trait elaboration in contrast to that of Western Eurasians, which is felt by many researchers to be distinguished more by trait rarity or absence than trait elaboration (Mayhall *et al*., 1982; Scott and Turner, 1997).

Sexual Dimorphism

Sexual dimorphism among the living Jordanians was found statistically significant in only three out of the 16 crown traits described (*i.e.*, UM1 cusp 5, UM1 Carabelli's tubercle/cusp forms and 4-cusped LM1), where the first two variables are more frequent in males and the latter shows a higher occurrence in females, indicating a stronger trend toward crown morphological reduction or simplification in females among the living Jordanian Arabs, and this reduction trend involves not only accessory tubercles and cusps but also major cusps of molar teeth. As mentioned before, it seems that there are differences among populations regarding the sexual dimorphism in the expression of Carabelli's trait; many workers found statistically significant male-female differences in favor of males (Goose and Lee, 1971; Kaul and Prakash, 1981; Kieser and Preston, 1981; Townsend and Brown, 1981b, Scott *et al*., 1983; Mizoguchi, 1985), but others find no sex difference for this trait (Garn *et al*., 1966d; Turner, 1969; Scott, 1980; Townsend *et al*., 1992). Consistent with our results regarding the sexual dimorphism in UM1 Carabelli's tubercle/cusp and 4-cusped LM1 is the report that Carabelli's trait in upper molars and hypoconulid expression (5-cusped form) in lower molars are less frequent in individuals with Turner syndrome (XO or 45,X) than their relatives (Kirveskari and Alvesalo, 1982). These findings suggest a role for the X chromosome in favoring crown morphological simplification *versus* a balancing effect of the Y chromosome in retaining crown morphological complexity.

Biological Affinity of Living Jordanians

The biological distance values between the living Jordanians and 21 high-order groups from the five major subdivisions of humankind based on the 16 crown traits described, as well as the visual depiction of the distance matrix described based on multidimensional scaling, show that the living Jordanians are phenetically distant from the Western Eurasian groups and all other world groups. These suggest that the living Jordanian population has undergone a major genetic drift that set the dental phenotype of this population apart from that of the Western Eurasian groups included in the analysis (*i.e.*, Western Europeans, Northern Europeans and North Africans). Although less in magnitude, similar dental morphological differentiation among groups having recent common ancestral relationships has been well documented in the Middle Eastern Jews (Sofaer *et al*., 1986), the Southwest American Indians (Scott and Dahlberg, 1982; Scott *et al*., 1983), the Yanomama Indians of Venezuela (Brewer-Carias *et al*., 1976), and Melanesians (Harris, 1977). Such genetic drifts leading to local differentiation in dental morphology among biologically related groups over a relatively short period are generally viewed as a consequence of colonization events, population structure such as high rates of endogamy, and small population size (Scott and Turner, 1988).

CONCLUSIONS

This study revealed that the living Jordanian Arabs have a unique dental morphological pattern that sets this group apart from the Western Eurasian and other world groups. This pattern, in contrast to that of the Western Eurasian, is characterized by more trait elaboration than trait rarity or absence. Statistically significant sexual dimorphism has been found in the occurrence of three crown traits in the direction of stronger trend toward crown morphological simplification in females involving accessory tubercles as well as minor and major cusps in the molar region. The relatively large biological distance values of the living Jordanians from the Western Eurasian groups, with whom they share a recent common ancestor, suggest that this population has undergone a major genetic drift leading to a distinct dental morphological pattern for this population from the Caucasoid dental pattern over a relatively short time span.

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