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Case Report

Contribution of teeth in human forensic identification – Discriminant function sexing odontometrical techniques in Portuguese population

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ABSTRACT

We investigate the accuracy of odontometric methods in sex determination, using a sample from the Portuguese population. Measurements were made on dental casts using a digital caliper, and various odontometric indexes have been defined using upper incisor and canine teeth.

Comparison of the means in both sexes was performed using Student's *t*-test. Significant differences ($p < 0.05$) were found in all variables except for the "Incisor Index". The canine showed the greatest sexual discriminant characteristics. In the presence of one or both canines the distobuccal-mesiolingual crown diameter and the "Robustness Value" allowed discrimination between sexes in the studied population. We also provide further arguments on the debate on whether sex determination is population specific.

1. Introduction

Forensic dentistry is an applied branch of dental anthropology and forensic medicine.[1] The first includes population and demographic characteristics such as determination of sex and race, and estimation of age. The second deals mainly with personal identification to assign an unknown body to a specific person.[2]

During the last few years DNA techniques have been developed providing accurate sex determination, but usually some skeleton measurements are enough for sex identification. Determination of sex is not a problem when a complete skeleton is available, primarily with measurements from the pelvis and the skull.[3] An alternative option is to use teeth size. This method is important in cases where only teeth or jaws are preserved, namely in mass disasters, when bodies have been subjected to severe damage, when decomposition or mutilations of the corpse prevent sex identification from, e.g. the pelvis, and in cases of non-adult skulls where sex characteristics have not developed.[4]

Dental sexual dimorphism has been extensive studied by means of odontometric analysis, and most studies have shown statistically significant differences in the permanent dentition.[5–7]

So far, discriminant function solutions have been used sparingly for dental data, in classifying individuals to the correct sex group.[8] This research addresses two main problems in this area: characterization of teeth size differences between sexes and populations, and assessing the probability of male/female individual from an index using odontometrics.

Namely, the objective of this work is to contribute to filling up of these gaps with new data for the Portuguese population, investigating the accuracy of odontometric methods in sex determination of the permanent dentition, verifying existing measurements, and computing new parameters to differentiate male from female teeth using statistical discriminant analysis.

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2. Materials and methods

The sample used in this investigation consisted of 80 dental casts obtained from students of the School of Dentistry, University of Lisbon. All participants were of Portuguese ancestry (Portuguese parents by generations), 55 females and 25 males. The mean age was 23 and 24 years, respectively. Teeth were selected for measurement only if morphologically normal and fully erupted without attrition, caries, restorations or a history of orthodontic treatment.[9]

Alginate impressions (Vival®, Ivoclar Vivadent) were taken in perforated trays of the upper dental arch, and cast immediately in dental stone type IV (Fujirock® EP). Procedures were preformed in accordance with the manufacturer's instructions. Measurements were taken directly on the dental casts after at least 24 h. A digital vernier caliper (Absolute Digimatic Caliper®, Mitutoyo), giving two decimal points was used for the measurements.

Twelve different tooth measurements were recorded, and from those six indexes have been computed (Table 1).

The incisors were measured in one dimension and the canines in four different dimensions.

Mesio-distal diameter (m-d) of each tooth was obtained by measuring the greatest distance between the proximal surfaces of the crown with the caliper held parallel to the occlusal and buccal surfaces, as described by Hunter and Priest.[10] If a tooth was rotated or malposed the measurement was taken between the points on the proximal surfaces of the crown where it was considered that contact with the adjacent teeth would normally occur.[11] Bucco-lingual (b-l) diameter was recorded according to the technique described by Seipel,[12] that is, the greatest distance between the buccal and lingual surfaces of the crown measured at right angle to the mesio-distal plane of the tooth. The other two linear diameters were performed according to the technique described by Lund in a Swedish population[13]: the mesiobuccal-distolingual diameter (mb–dl), the greatest distance between the mesiobuccal and distolingual surfaces of the crown, and the distobuccal-mesiolingual diameter (db–ml), the greatest distance between the distobuccal and mesiolingual surfaces of the crown, in both cases with the caliper held parallel to the occlusal plane.

The Incisor Index (I_i) was computed by Aitchison's formula: $I_i = \frac{MDI^2}{MDI^1} \times 100$, where MDI^2 is the maximum mesio-distal diameter of the upper lateral incisor and MDI^1 is the maximum mesio-distal diameter of the upper central incisor.[14] The Canine Crown Module ($|c|$) is the average of the mesio-distal and bucco-lingual diameters: $|c| = \frac{MD+BL}{2}$, where MD is the maximum mesio-distal diameter and BL is the maximum bucco-lingual diameter, giving an overall picture of tooth size. The Canine Robustness Value is (I_r) the product of the mesio-distal and bucco-lingual diameters: $I_r = MD \times BL$, also giving an indication of the overall tooth size.[15]

To estimate intra-observer error, a second determination was made after 3 months by the same investigator. If the discrepancy between the two measurements was greater than ±1.96 standard deviation, a new set of measurements was taken, and the nearest two measurements were averaged.

Table 1
Independent variables: measurements and indexes in the experimental study.

Mesio-distal crown diameter (m-d) upper central incisor
Mesio-distal crown diameter (m-d) upper lateral incisor
Mesio-distal crown diameter (m-d) upper canine
Bucco-lingual crown diameter (b-l) upper canine
Mesiobuccal-distolingual crown diameter (mb–dl) upper canine
Distobuccal–mesiolingual crown diameter (db–ml) upper canine
"Incisor Index" (I_i)
"Canine Crown Module" ($\|c\|$)
"Canine Robustness Value" (I_r)

Statistical analysis was performed using the SPSS® (SPSS INC., Chicago, USA). Descriptive statistics (mean, standard deviation, and minimum and maximum values) was computed for each variable and Student's t-test was used for statistical evaluation of the data. Statistical significance was established at the 5% level. Sex differences were also compared by the percentage of sexual dimorphism according to Garn et al.[16] An average measure of mesio-distal diameters and dimorphism percentage has been computing using the ratio expression: $100[(M - F)/F]$. Dimorphic ranking was then attributed, allotting the first rank to the tooth presenting the highest dimorphism and the last rank to the one presenting the lowest ratio.

Data analysis used stepwise discriminant functions in order to develop functions which optimally separate sexes with a variable measurement composition. Our option has been to use the stepwise discriminant analysis available in SPSS to select the variables best suited to differentiate between the sexes. At each step, the variable which provided the greatest univariate discrimination (i.e. the largest value of the acceptance criterion) was selected and the criterion was re-evaluated for all the remaining variables. The algorithm terminates when the benefit from adding new terms to the discriminant function is statistically irrelevant.

3. Results

3.1. Descriptive statistics and Student's t-test: male–female comparisons

Male values exceeded female ones in all observed dimensions. All variables, with the exception of the "Incisor Index", showed statistically significant differences between males and females, at the $p < 0.05$ level. The canine showed the highest mean difference ($p < 0.001$) (Tables 2 and 3).

Table 2
Student's t-test for the mean (m-d) of incisors teeth (mm) between males and females. Student's t-test of the different variables of canines showed that the comparison of means between males and females were very significant: m-d, b-l, mb–dl, db–ml (mm); I_r (%) and $|c|$. Teeth named according to the FDI system.

Tooth	Independent variable	Male	Female	Difference	t value	p value
11	m-d	8.990	8.707	0.283	−2.367	0.020
21	m-d	9.025	8.719	0.306	−2.510	0.014
12	m-d	6.940	6.552	0.388	−2.457	0.016
22	m-d	6.969	6.608	0.361	−2.635	0.010
13	m-d	8.171	7.770	0.401	−4.132	0.000
	b-l	8.759	8.206	0.553	−4.387	0.000
	mb–dl	7.882	7.500	0.382	−3.741	0.000
	db–ml	7.565	7.302	0.263	−2.486	0.015
	I_r	71.66	63.85	7.81	−5.089	0.000
	$\|c\|$	8.465	7.988	0.477	−5.038	0.000
23	m-d	8.029	7.696	0.333	−3.351	0.001
	b-l	8.744	8.209	0.535	−4.583	0.000
	mb–dl	7.817	7.540	0.277	−2.772	0.007
	db–ml	7.565	7.246	0.319	−3.732	0.000
	I_r	70.30	63.27	7.03	−4.658	0.000
	$\|c\|$	8.387	7.952	0.435	−4.650	0.000

Table 3
The incisor index for the two sides of the jaws. The t-test was not significant to differentiate the two sexes on basis of Incisor Index (%).

Dental arch	Male	Female	Difference	t value	p value
Right side	77.17	75.24	1.93	−1.451	0.152
Left side	77.28	75.85	1.43	−1.094	0.279
Mean	77.21	75.74	1.47	−1.261	0.213

Table 4
Dimorphic ranks.

Tooth	Male	Female	Difference	Percentage	Rank
11	8.99	8.71	0.28	3.25	6
21	9.03	8.72	0.31	3.51	5
12	6.94	6.55	0.39	5.95	1
22	6.97	6.61	0.36	5.45	2
13	8.17	7.77	0.40	5.15	3
23	8.03	7.70	0.33	4.29	4

3.2. Percentage of sexual dimorphism

Percentage of dimorphism estimated from Garn's et al. formula[16] showed that the upper lateral incisor of the right side was the most dimorphic tooth and that the upper central incisor of the right side was the least dimorphic of the six teeth (Table 4).

3.3. Right–left comparisons

Paired *t*-tests were used to compare the corresponding teeth on each side of the arch. Overall, only the mesio-distal diameters of the canines were significantly different at the 5% level. When discriminated by sex only the female group showed a significantly different bilateral asymmetry ($p < 0.05$) (Table 5).

3.4. Discriminant analysis

The best discriminant function was:

$$F = -1.697 * (13_{\text{db-ml}}) + 1.307 * (C_{I_r}) + 1.130 * (C_{\text{db-ml}}),$$

where C is the mean of 13 and 23 for each independent variable of the function.

The cut point between the sexes was 0.289. The male group centroid was 1.054 and the female group centroid was −0.477. A group centroid is the mean discriminant score for each sex. A cut point, which separates one sex from the other, is the average of the two centroids and a smaller value than this one, we consider an individual female (between 0.289 and −0.477). Raw coefficients, the discriminant function coefficients, were used to calculate the discriminant score.

4. Discussion

It is commonly accepted that standards for skeletal identification varies among different populations, and that standards for one population may not be used for another population. Another factor that may call for revision of standards is the possible occurrence of change in the population over time.[18]

Table 5
Bilateral asymmetry of the Portuguese population (Population), by sex.

Pair	Group	N	Difference	*t* value	*p* value
11–21 m-d	Population	78	0.018	−0.683	0.496
	Male	24	0.035	−0.754	0.458
	Female	53	0.011	−0.322	0.749
12–22 m-d	Population	78	0.071	−1.729	0.088
	Male	24	0.029	−0.420	0.679
	Female	53	0.09	−1.770	0.082
13–23 m-d	Population	77	0.088	2.953	0.004
	Male	23	0.135	2.032	0.054
	Female	53	0.066	2.138	0.037
13–23 b-l	Population	77	0.011	−0.323	0.747
	Male	23	0.008	−0.124	0.903
	Female	53	0.012	−0.315	0.754

5. Sexual dimorphism and human evolution

Human dental sexual dimorphism was greater during the upper Paleolithic than at any subsequent time, and it has almost vanished in some modern human populations, a phenomenon that seems to be related to gracilization of the male.[19] Our findings are consistent with those results (Table 6). However, the degree of reduction of teeth size of our population when compared with others from modern era was smaller, and consequently, the sexual dimorphism in the Portuguese population is greater than in any of the other modern populations so far studied.[19]

Actually, only Australian aborigines and Negroid individuals could present ethnic characteristics such as being megadontoid.[19] Portuguese population because of the migration history have more similarity with this population.

Variability of tooth size (standard deviation) differed between the sexes, with males showing greater variability than females for each group (Table 7).

6. Mesio-distal and bucco-lingual diameters

The mesio-distal and bucco-lingual crown diameters showed statistically significant sex differences in all teeth, a finding that agrees with the results found for others populations.[6,7,13–15,20–26] However, the diameters of the Portuguese population (male and female) were found to be larger when comparing with other modern caucasian populations[7,14,21] – Table 8 (mean right–left side) and VIII (separated by sides).

Differences in teeth dimensions among the various populations could be related, in part, to the degree of ethnic mixing. O'Rourke and Crawford[27] concluded that the extent and direction of the micro-differentiation are reflections of differential amounts of mixing. There is actually a decrease in "racial" differences inherent to the increase of "racial" mixture. However, for the Portuguese population, tooth sizes were, in general, larger than those of the modern caucasians and comparable with Bantu (African blacks) from an earlier study by Nelson from 1938.[28]

7. Mesiobuccal–distolingual and distobuccal–mesiolingual diameters

These two diameters had mean dimorphic differences that were statistically significant at the $p < 0.05$ level.

The canines showed the highest statistical difference, with $p < 0.001$. When comparing our findings with those of a study on a Swedish population,[13] our results support their conclusion: the statistically significant high level of dimorphic differences of canines in the (db–ml) crown diameter ($p < 0.001$) suggest a high level of reliability in this dimorphic trait.

8. Canine crown module

A comparison with Icelandic[25] males revealed that the Portuguese males had a higher canine Crown Module. The females from both groups had about the same canine crown module. The sexual dimorphism was thus bigger in the Portuguese population (Table

Table 6
Mean cross-sectional area (I_r) for the canine (C-mean value of 13 and 23) of two groups: the European upper Palaeolithic and our Portuguese population, per sex. Reference values of the upper Palaeolithic era from [19].

	Upper Paleolithic (I_r C) (%)	Portuguese population (I_r C) (%)
Male	77.5 ± 13.5	71.1 ± 6.4
Female	64.5 ± 5.5	63.6 ± 5.9

Table 7
Present summary means of the teeth diameters (m-d and b-l) by sex between our population and others (mm). *IC* = mean 11 and 21; *IL* = mean 12 and 22; *C* = mean 13 and 23. (–): No data available.

Author	Population	Male			Female		
		Tooth	m-d diameter	b-l diameter	Tooth	m-d diameter	b-l diameter
Goose (1963)	Modern English	*IC*	–	–	*IC*	–	–
		IL	6.35	6.38	*IL*	6.12	5.97
		C	7.70	8.46	*C*	7.42	7.97
Garn (1964)	Ohio	*IC*	8.78	–	*IC*	8.50	–
		IL	6.70	–	*IL*	6.45	–
		C	7.93	–	*C*	7.47	–
Perzigian (1976)	Indian Knoll	*IC*	8.97	7.27	*IC*	8.61	7.18
		IL	7.55	6.55	*IL*	7.61	6.61
		C	8.27	8.73	*C*	7.95	8.29
Keith et al. (1997)	Southern Chinese	*IC*	8.73	–	*IC*	8.66	–
		IL	7.18	–	*IL*	7.12	–
		C	8.30	–	*C*	8.02	–
Pettenati-Soubayroux et al. (2002)	French	*IC*	8.36	–	*IC*	8.23	–
		IL	6.73	–	*IL*	6.28	–
		C	7.79	–	*C*	7.06	–
Axelsson et al. (1983)	Icelander	*IC*	8.99	7.35	*IC*	8.75	7.22
		IL	6.95	6.58	*IL*	6.83	6.51
		C	8.14	8.58	*C*	7.79	8.15
Iscan et al. (2003)	Turkish	*IC*	–	7.56	*IC*	–	7.11
		IL	–	6.84	*IL*	–	6.20
		C	–	8.61	*C*	–	7.78
Hattab et al. (1996)	Jordanian	*IC*	8.94	–	*IC*	8.63	–
		IL	6.93	–	*IL*	6.70	–
		C	8.01	–	*C*	7.62	–
	Iraqi	*IC*	8.99	–	*IC*	8.81	–
		IL	6.91	–	*IL*	6.87	–
		C	8.04	–	*C*	7.81	–
	Yemenite	*IC*	8.49	–	*IC*	8.44	–
		IL	6.44	–	*IL*	6.37	–
		C	7.43	–	*C*	7.43	–
	Caucasian	*IC*	8.78	–	*IC*	8.40	–
		IL	6.64	–	*IL*	6.47	–
		C	7.95	–	*C*	7.53	–
This study (2005)	Portuguese	*IC*	9.01	–	*IC*	8.71	–
		IL	6.96	–	*IL*	6.60	–
		C	8.10	8.76	*C*	7.74	8.21

9), which again gives empirical evidence that the teeth of males in the Portuguese population have not gone through the same reduction evolutionary process, as other populations.

9. Percentage of sexual dimorphism

Percentage sexual dimorphism ($100[(M-F)/F]$) ranged from 3.4% to 5.7%. When comparing our results with other populations, our ranking is similar to the Japanese population[29] – Table 10. The tooth with the highest percentage of sexual dimorphism is the lateral incisor. But in absolute terms is the canine the most dimorphic tooth like other population in general.

10. Asymmetry

Laterality is now recognized as an intrinsic characteristic of living organisms[17]. The slight perturbations it adds to the essential symmetry can have a hidden added value. It may even spoil the statistical analysis, since it can bring in a confounding factor that has to be taken into account.

Hence, we investigated possible differences between the two sides of the arches.

Dental asymmetry in the Neanderthals tends to be greater than in modern man.[30] Tooth size studies on modern populations generally have shown non significant or only small asymmetries, which have justified the use of an averaged size from the pair of antimeric teeth.[7,22] Differences between the means of any two antimeres have ranged between 0.1 mm and 0.4 mm. In our study the values ranged between 0.1 mm and 0.14 mm. These differences are smaller in magnitude. But one more time the results show that the Portuguese population are most compared with oldest human group.

11. Discriminant functions

Often there is no sufficient prior knowledge guiding the assignation of individuals IN to different groups. Under these circumstances, the appropriate tool is some form of classification, which clusters individuals on the basis of similarity of a set of multivariate measurements.

Discriminant functions have become a widely used method for sex determination of human skeletal remains.[31] Stepwise discriminant function analysis calculates the optimal combination of variables and weights them to reflect their contribution to sex diagnosis. Observe that several of the variables with significant values with Student's *t* were not included in the statistical model with the stepwise discriminant analysis.

The variables exhibiting best discrimination power were db–ml from 13, the average I_r of both canines, and the average db–ml of