Sex determination by measuring the maximum width of maxillary incisors, canines and mandibular canines in a sample of young South African adults

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ABSTRACT

Sex determination of human remains is often a dilemma for forensic experts due to the decomposing factor, or, if only part of a body is found. The analysis of DNA is thought to be the most accurate method for sex determination, but the cost and time involvement usually causes a delay in the identification process and in some cases, DNA is not obtainable due to the state of decomposition or contamination.

Sexual dimorphism refers to the difference in shape, form or appearance between male and females in the same species. It can also be described as the systematic difference between individuals of different sex in the same species. Dimorphism in the human skeletal system and dentition is well establish. It is generally assumed that the male dentition is larger than the female dentition.

In this study, the mesio-distal width of the maxillary incisors and canines, as well as the mandibular canines were measured. Orthodontic study models were used in this study, 50 males and 50 females, in which the sizes of the maxillary central incisors, maxillary lateral incisors, and maxillary and mandibular canines were measured.

The results showed that the sizes of the maxillary and the mandibular canines were significantly more accurate in determining sexual dimorphism than the incisors. The logistic regression model, using tooth 13 and 33, provides prediction accuracy of 52% for males and 74% for females.

Keywords: Sexual dimorphism, sex determination, maxillary and mandibular canines.

DECLARATION

I declare that *Sex determination by measuring the maximum width of maxillary incisors and canines and mandibular canines in a sample of young South African adults* is my own work, that it has not been submitted for any degree of examination to any other university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Liezl Claassens October 2016

Signed: ………………….

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Chapter 1

Introduction

In forensic dentistry, teeth play a vital part in the identification process of bodies or skeletal remains which are unrecognisable or unidentifiable due to various factors e.g. fire or decomposition.

Teeth are the most reliable tissue in the body for contributing to the physical and chemical evidence for evolutionary change (Vishwakarma and Guha 2011). They show resistance to damage when subjected to decomposition, fire or humidity that makes them a valuable tool in forensic dentistry (Rao *et al.* 1989). In cases where only tooth-remains are available for identification, it should be possible to determine if the teeth are of male or female origin without using DNA analysis.

Sexual dimorphism refers to the morphological difference in size or shape (appearance) between males and females in the same species. In the modern-day human population, the male dentition is thought to be larger than females (Khangura *et al.* 2011). Several studies have shown that male teeth are usually bigger than the female, and canines show a significantly greater difference in size. In studies on maxillary canines and incisors including mandibular canines, the canines were found to be more accurate determining the sex of the individual (Khangura *et al.* 2011; Hemanth *et al.* 2008). In comparison to DNA analysis, the advantage of determining sex from the teeth is less complicated and not subject to contamination as is found in DNA analysis (Vishwakarma and Guha 2011).

In a recent study on Chilean teeth of young adults, sexual dimorphism of the maxillary central incisors and canines were found to be significant in determining the gender of the individual. (Peckmann *et al.* 2016).

Chapter 2

Literature Review

Sex determination using dental traits is generally based upon the measuring and comparison of the tooth dimensions in males and females, or comparing non-metric dental traits like the Carabelli's cusp of maxillary molars, the deflecting wrinkle of mandibular first molars, the distal accessory ridge of maxillary and mandibular canines or shovelling of maxillary central incisors. Although tooth morphology is the same or similar in males and females, the size of the teeth are not necessarily always the same (Sonika *et al.* 2011).

The suggestion that variation of sexual dimorphism in teeth could possibly be due to environmental influences, e.g. the variation in food resources for different populations or even the interference of cultural factors with biological forces and even genetic factors, was proposed by Acharya and Mainali (2007).

Various odontometric studies have been used for sex determination, for example the bucco-lingual dimensions of teeth, heights of teeth and the mandibular inter-canine index (Khangura *et al*. 2011). Doris *et al. (1981)* determined that the ideal teeth to use for tooth size measurements is the early permanent dentition, because the elderly dentition shows more signs of attrition or mutilation (restorations, caries, etc.) in many individuals. The widths of teeth change very little with aging, although there is a small amount of interdental attrition in the elderly dentition, but not significant enough to have an influence on the sexual dimorphism of teeth.

Teeth of males tend to be bigger in each arch than those of females (Richardson and Malhotra 1975). In a study by Howe *et al.* (1983), they found that the combined mesio-distal width of the incisors and canines was more accurate for determining the difference between males and females. However, in a study by Anderson and Thompson (1973) on a Canadian population, the mandibular canines showed greater dimensional differences between male and female teeth with male teeth being larger. A similar study by Rao *et al.* (1989), done on a South Indian population, stated that the width of mandibular canines were significantly greater in males, however, other investigators (Kuwano, 1983; Minzuno, 1990) who conducted a study on a sample of the Japanese population, showed that the maxillary canines show a higher degree of sexual dimorphism. There is therefore controversy as to which canines (maxillary or mandibular) are appropriate for determining the sex of an individual. Different ethnic groups may show different results.

Mandibular canines have a late eruption age and are usually also the last teeth to be removed with respect to age. They are least affected than any other teeth by periodontal diseases, and therefore considered to have high degree of sexual dimorphism (Agrawal *et al.* 2015).

Dahlberg considered mandibular canines as the ‘key-tooth’ for sex estimation (Yuwanati *et al.* 2012). Garn *et al.* (1967), as well as Nair *et al.* (1999), found that the mandibular canines presented the greatest sexual dimorphism of all teeth (Sai kiran *et al.* 2014).

Nair *et al.* (1999), who conducted his study on a South Indian Population, found that greater sexual dimorphism was found in the left mandibular canine, than the right mandibular canine. When the width of a mandibular canine was more than 7mm, the probability was 90% that it was male.

The overall tooth-width ratios between male and females are not significantly different within four ethnic groups namely Black (African), White, Afro-Mediterranean (Black and European parents) and Japanese (Fernandes *et al.* 2010). Schield *et al.* (1990) reported sexual dimorphism among European, Monogoloid and Black American populations, by making use of dental (periapical) radiographs, on all teeth. Sexual dimorphism was distinct in all groups. The degree of sexual dimorphism of the width of the mandibular canine was more significant in African Americans and indigenous Australians than in North American Indians and the Tristanite population, who are from Tristan de Cuna Island (Yuwanati *et al.* 2012). In a study by Bailit (1975) it was stated that body size did not seem to have an effect on tooth size.

The Hashim and Marshid study done in 1993 on Saudi males and females showed that the only teeth that display sexual dimorphism were the canines. They also found that there are no statistical differences between the left and right sides. An implication of this statement, could be that the measurements of teeth on one side of the dentition, could be positively representative, if matching/correspondent teeth on the opposing side were unobtainable. Pratibha *et al*. (2009), showed the same sexual dimorphism in canines in a study on the native residents of Mysore district, Karnataka in India. However, in a study done by Sai kiran *et al.* (2014), on Indian teeth, the right mandibular canine showed a greater sexual dimorphism than the left mandibular canine. Left mandibular canines showed a greater sexual dimorphism compared to the right mandibular canines in a South Indian population (Kapila *et al.* 2011).

Kaushal *et al.* (2003) who did a study on Indian population, found a statistical greater sexual dimorphism in mandibular canines. This study concluded that the left mandibular canine is larger than the right mandibular canine. They also came to an interesting conclusion that if a mandibular canine width is greater than 7mm, the likelihood the sex of that person being a male was 100%.

In a study by Khangura *et al.* (2011) they proposed that according to Moss's theory canine dimorphism is due to a greater thickness of enamel in males compared to females, due to the longer period of amelogenesis, as well as the effect of the Y-chromosome which produces slower early male maturation.

Barret *et al*. (1963) stated that intra-oral measurements are less reliable than measuring the teeth using impression casts. Studies by Kaushal *et al.* (2003), Sai kiran *et al.* (2014), indicated that there is no significant difference between clinical measurement and measuring on dental casts. (Yuwanati *et al.* 2012).

Chapter 3

Aim, objectives and hypothesis

3.1 Aim

The aim of this study was to evaluate the estimated level of accuracy in sex determination, using permanent maxillary incisors, laterals and canines as well as mandibular canines on a sample of young South African adults.

3.2 Objectives

The objectives of this study were:

1. To establish whether there is sexual dimorphism between the mesio-distal dimensions of maxillary central incisors.
2. To establish whether there is sexual dimorphism in the mesio-distal dimensions of maxillary lateral incisors.
3. To establish whether there is sexual dimorphism measuring the mesio-distal dimensions of maxillary canines.
4. To establish whether there is sexual dimorphism measuring the mesio-distal dimensions of mandibular canines.
5. To establish if the left and right maxillary canines show a significant difference in size by measuring the mesio-distal dimensions.
6. To establish if the left and right mandibular canines show a significantly difference in size by measuring the mesio-distal dimensions.
7. To compare the results of this study with a similar study done by Dr Peckmann *et al.* (2016) on the teeth of young Chilean adults.
8. To statistically analyse the results of this study.

3.3 Hypothesis

Male teeth are perceived to be larger than those of female. Therefore the sex of an individual can be determined by measuring the mesio-distal dimensions of the maxillary incisors or the maxillary and mandibular canines.

Chapter 4

Methodology

This study consisted of examining orthodontic plaster of Paris study models to measure the mesio-distal width of incisors and canines to determine the difference between the widths in males and females.

The study models were obtained from a private orthodontic practice. The models were of patients who were undergoing or had undergone orthodontic treatment. The sample consisted of 100 study models (50 male and 50 females). A digital Vernier calliper (Fig. 1) was used to measure the maximum labial dimension of the crown of each of the (eight) teeth investigated, namely the left and right maxillary central and lateral incisors, the left and right maxillary canines as well as the left and right mandibular canines (Fig. 2). This technique is the optimal choice for speed, repeatability and accuracy of measurement of the mesio-distal tooth widths as described by Horton *et al.* (2010).

Fig. 1 Digital Vernier Calliper (millimetres).

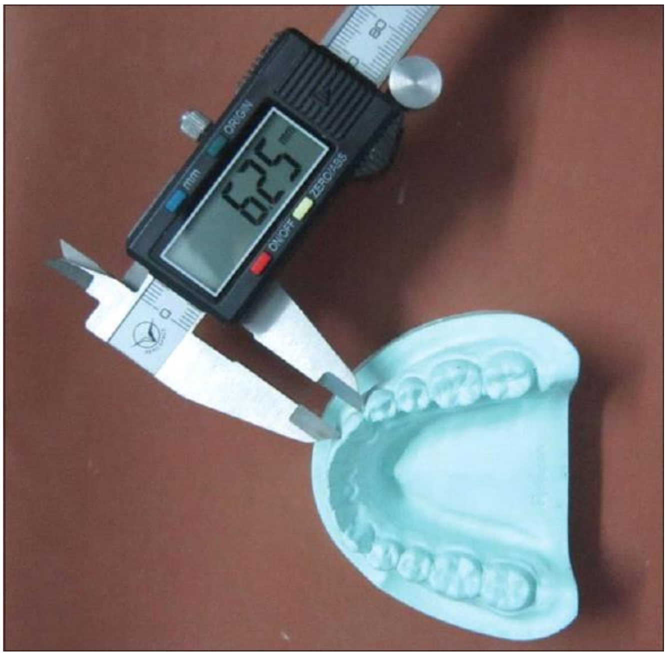


Figure 2 Mesio-distal width of a mandibular canine measured on the plaster model with the digital Verniercalliper indicating 6.25 mm.

The study models were selected to meet the following criteria:

- Age: 13 – 21 years
- 50 Female orthodontic models and 50 male orthodontic models of patients who were undergoing or had completed their orthodontic treatment.
- Fully erupted maxillary and mandibular anterior teeth.
- No caries.
- No history or evidence of crowns, restorations or trauma to the anterior teeth.

Descriptives of the data

The width of 50 samples of each type of tooth per gender were measured (n=50 per gender per tooth). In each case, the teeth 11, 12, 13, 21, 22, 23, 33 and 43 were measured (FDI tooth notation).

Dental notation (FDI)

11 = Right maxillary central incisor
12 = Right maxillary lateral incisor
13 = Right maxillary canine
21 = Left maxillary central incisor
22 = Left maxillary lateral incisor
23 = Left maxillary canine
33 = Left mandibular canine
43 = Right mandibular canine

Figure 3: Plaster of Paris study models of the upper and lower teeth showing the teeth measured.

Two examiners undertook the measurements of the teeth of each of the cases and recorded their results. The results were statistically analysed. These results were compared to a similar study on a sample of Chilean teeth undertaken by Peckmann *et al.* (2016).

The sexual dimorphism was calculated using the formula given by Garn *et al.* (1967) as follows:

<u>Sexual dimorphism</u> = [Xm/Xf - 1] x 100

Where Xm = mean value for males and Xf = mean value for females (Khangura *et al.* 2011).

The percentage of dimorphism is defined as the percentage by which the tooth size of males exceeds that of females. The formula simply states that male tooth sizes dominate female tooth sizes for the dominator and is always smaller than the numerator in all cases where the size of females and males are equal. Thus the probability that male teeth sizes are bigger than females is biased. Although this formula from Garn *et al.* (1967) was recommended, it was found not to have a very accurate predictability, and thus not suitable for this study.

A logistic regression model was therefore used in this study to predict group differences on the basis of the type of tooth and the tooth-width.

The logistic regression model is simply a non-linear transformation of the linear regression. Logistic regression measures the relationship between the categorical dependent variable and one or more independent variables by estimating probabilities using a logistic function, which is the cumulative logistic distribution.

The "logistic" distribution is an S-shaped distribution function which is similar to the standard-normal distribution but easier to work with in most applications (the probabilities are easier to calculate). The logistic distribution constrains the estimated probabilities to lie between 0 and 1.

Predicting group gender differences based on the width of 8 different teeth

Although the Peckmann *et al.* (2016) results were based on Discriminate Analysis, a Logistic Regression was considered more appropriate to analyse the data in the present study.

In Discriminant Analysis, prediction of group membership is based on (discriminant Z) scores calculated from a linear combination of the independent variables (discriminant function) such that it optimally discriminates between pre-defined groups. This requires Discriminant Analysis to strictly rely on meeting assumptions such as normality and linearity.

Logistic regression analysis is more robust and does not face such strict assumptions. It is a non-linear transformation (S- shaped curve) of a linear combination and predicts values that are bounded to a range between zero and one. These probabilities are used to determine group membership by applying a cut-off criterion (e.g. 50% chance) for classification. The S-shaped curve is a model that represents the relationship between the dependent and independent variables.

Chapter 5

Results

5.1 The inter-examiner results.

The tooth measurements were tested by two examiners who independently measured the mesio-distal width of the eight teeth with a Vernier (digital) calliper. Repeated measurements were undertaken on 10 randomly selected models (5 male and 5 female), with appropriate resting time in between to minimize any mistakes. The data is presented in Figure 4 The inter-examiner reliability (N=80) was determined using Pearson correlation rx,y = 0.983; p<0.01. This confirms consistency in the accuracy of the measurements of the teeth by the examiners.

Inter-examiner reliability

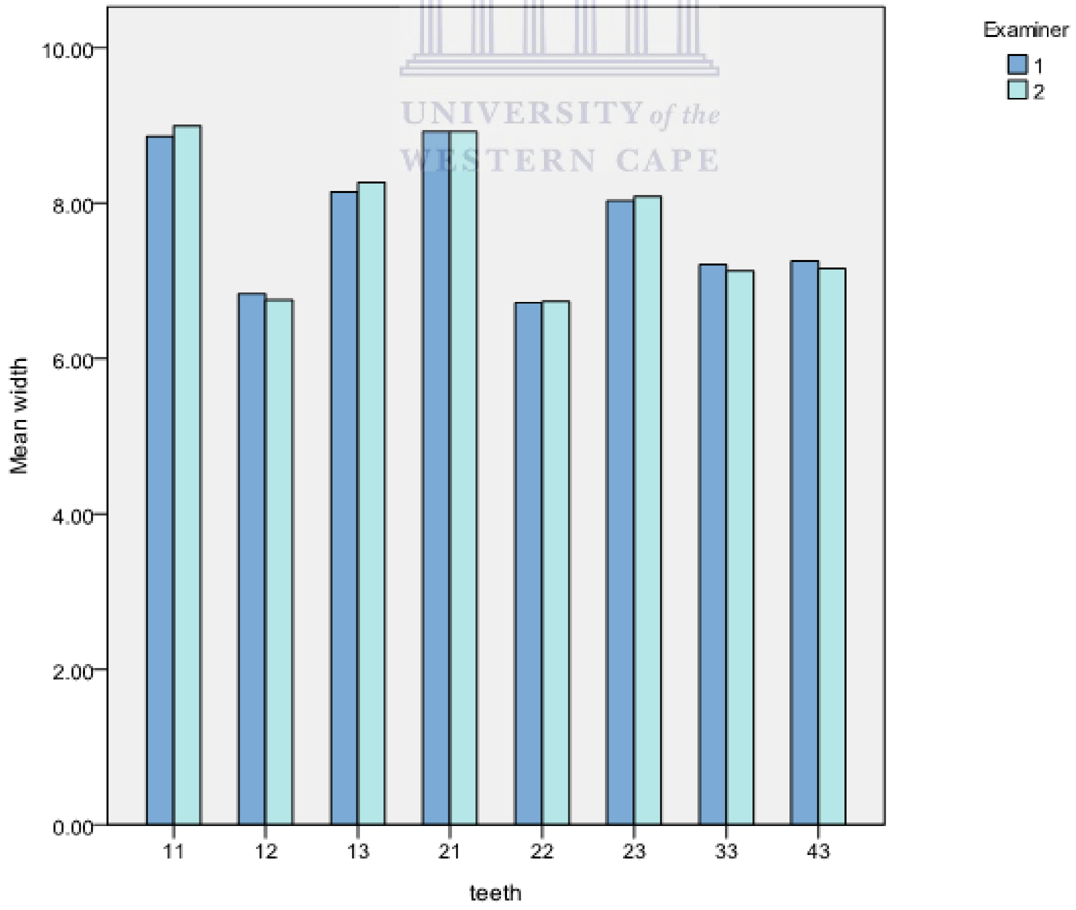


Figure 4: Mean width per tooth measured by examiner 1 and examiner 2.

Figure 4 showed that there were no significant differences between the measurements of the teeth by the examiners.

5.2 The measurements of the various teeth and the results of the measurements.

Upper and lower sets of 50 male and 50 female study models were examined and eight teeth per individual were measured and recorded.

Descriptive statistics of the data are presented in Table 1. F-test was applied to evaluate the differences between genders per tooth. The F-test was done to identify a model which best fits the population and data samples. Then a logistic regression analysis was used to predict group differences on the basis of the type of tooth and the tooth-width.

The results of the logistics regression were validated by supportive results of a CATPCA, sn optimal scaling technique.

Table 1: The mean widths (standard deviation) of the teeth in millimetres for males and females of each tooth measured (t = tooth = 50 males and 50 females).

Gender		Mean (mm)	Std. Deviation (mm)
Male N=50	t13	8.2760	.46448
	t12	6.9580	.53303
	t11	8.8960	.60944
	t21	8.8980	.60693
	t22	7.0040	.54171
	t23	8.2640	.47067
	t33	7.4140	.47122
	t43	7.3860	.45356
Female N=50	t13	8.0660	.52357
	t12	6.8100	.67499
	t11	8.7220	.60214
	t21	8.7340	.60021
	t22	6.8040	.65620
	t23	8.1080	.51144
	t33	7.1200	.45535
	t43	7.1060	.43397

The mean width of the male teeth was found to be greater than that of the females.

Table 1 shows the results of the mean widths of the teeth and the standard deviation. These results are presented in a graphical form in Figure 5.

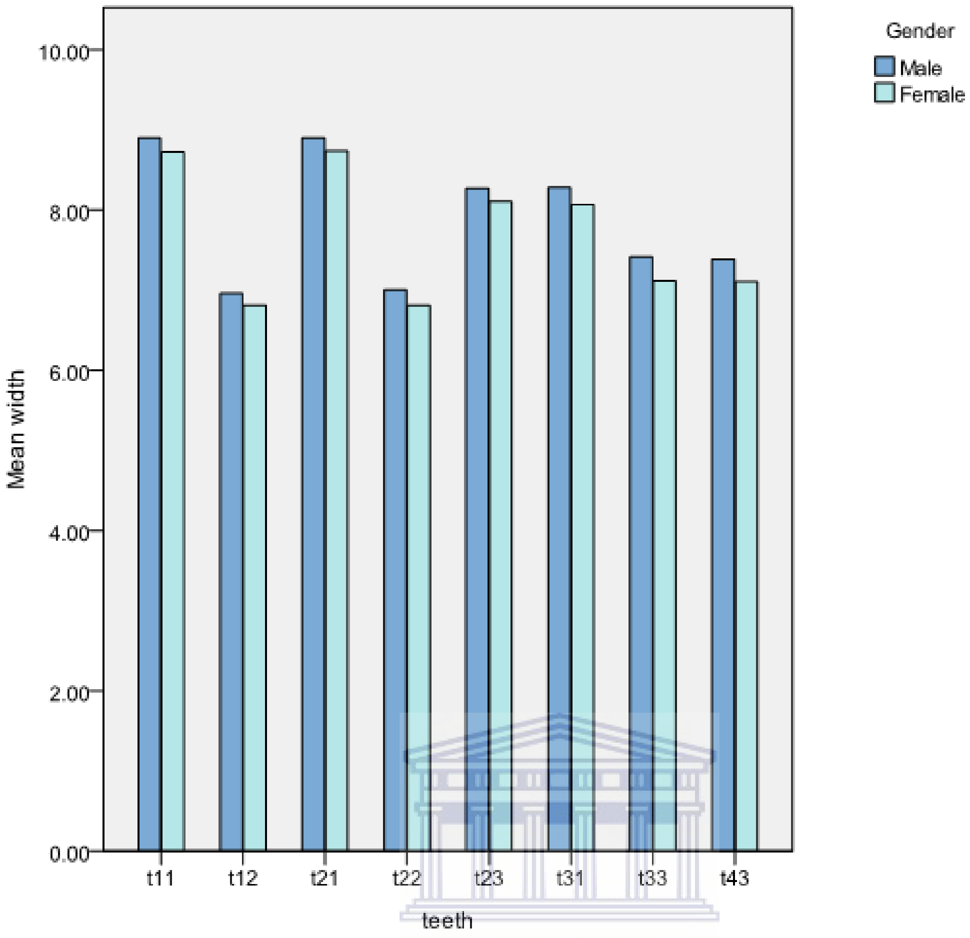


Figure 5: The mean width per type of tooth per gender.

The mean width of the female teeth (in millimetres) was found to be consistently less than the mean of the width of male teeth.

5.3 The statistical analysis of the tooth measurements showing the male / female differences.

Table 2 shows that the differences in the width of male and female teeth was great enough to reject the null hypothesis. The null hypothesis implies that the difference in width between male and female teeth are too small to indicate a significant difference between them. These results showed that the null hypothesis can be rejected for only right maxillary canine (t13), the left mandibular canine (t33) and the right mandibular canine (t43). The incisors are not significantly different in males and females.

Table 2: Differences in width between male and female teeth.

Tests of Equality of Group Means					
	Wilks' Lambda	F	df1	df2	P value
t13	**.956**	**4.501**	**1**	**98**	**.036**
t12	.985	1.481	1	98	.227
t11	.979	2.062	1	98	.154
t21	.982	1.846	1	98	.177
t22	.973	2.762	1	98	.100
t23	.975	2.519	1	98	.116
t33	**.907**	**10.065**	**1**	**98**	**.002**
t43	**.908**	**9.948**	**1**	**98**	**.002**

Meaning of symbols

F = In this case it is the equivalent to the square of a *t*-statistic

df = Degrees of Freedom

P-value = Shows the probability of these results given the data and size when based on coincidence. A P-value of 0.05 or lower indicates statistically significant differences.

These results indicate that teeth 13 (right maxillary canine), 33 (left mandibular canine) and 43 (right mandibular canine), each show statistically significant difference in size ($p<0.05$), compared to the other teeth, in this study.

The P-value is the probability that the data would be at least this inconsistent with the hypothesis, assuming the hypothesis is true. A high P-value means that the data is highly consistent with the hypothesis, nothing more. A low P-value encourages us to reject the hypothesis.

A logistic regression was performed with initially t_{11} to t_{43} entered as a single block. The coefficients are presented in Table 3.

Table 3: The coefficients of each tooth.

	B	S.E.	Wald	df	Sig.	Exp(B)
t13	-5.839	4.287	1.855	1	.173	.003
t12	1.027	1.248	.677	1	.411	2.792
t11	-3.851	3.207	1.442	1	.230	.021
t21	3.748	3.226	1.350	1	.245	42.444
t22	-1.152	1.302	.783	1	.376	.316
t23	5.752	4.343	1.754	1	.185	314.837
t33	-2.372	2.110	1.263	1	.261	.093
t43	.921	2.133	.186	1	.666	2.511
Constant	12.961	4.881	7.051	1	.008	425694.751

Notes:

t = tooth

B = the estimated logit coefficient.

S.E. = the standard error of the coefficient.

Wald = $[B/S.E.]^2$

df = degrees of freedom which is the number of values in the final calculation of a statistic that are free to vary.

Exp(B) is the “odds ratio” of the individual coefficient.

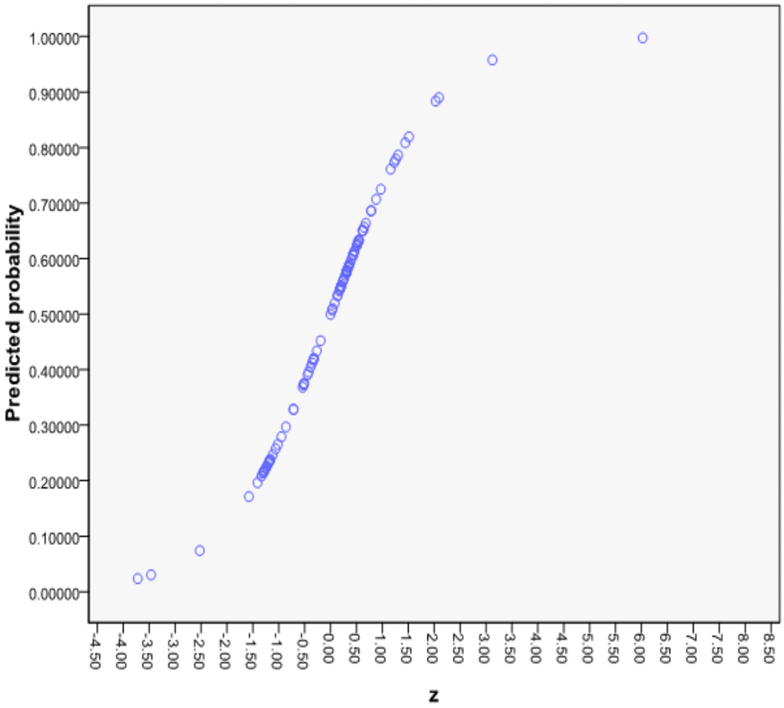


Figure 6: Logistic regression curve of predicted probability.

Figure 6 shows the logistic regression curve where the predicted probability is plotted against z.

$[Z = B_0 + B_1 X_1 + B_2 X_2 + \ldots.\ B_p X_p$ and $Est\ Prob = \frac{1}{1+ e^{-Z}}]$

This is the non-linear transformation of the logistic regression model, which shows that models (teeth) can be predicted, even if they are bounded to a range between one and zero. The S-shaped curve is a model that represents the relationship between the dependant (tooth) and independent variables (the predictors).

Table 4: Classification Table of male and female teeth.

Classification Table[a]

	Observed		Predicted		
			Gender		Percentage Correct
			Male	Female	
Step 1	Gender	Male	28	22	56.0
		Female	11	39	78.0
	Overall Percentage				67.0

a. The cut-off value is .500

Although the model was able to classify 56 % of the male and 78% of the female teeth correctly, Table 4 indicates poor contribution to the model due to small Wald statistics (the squared ratio of the coefficient to the standard error).

Whenever a relationship within or between data items can be expressed as a statistical model with parameters to be predicted from a sample, the Wald test can be used to test the true value of the parameter based on the sample estimate.

Therefore a forward logistic analysis was conducted with the variables divided as pairs in four blocks: block 1 t_{11}-t_{21}; block 2 t_{12}-t_{22}; block 3 t_{13}-t_{23}; block 4 t_{33}-t_{43}. Table 5 presents how the model improved when a block of variables was added.

Table 5: Adding Blocks of variables to the logistic regression model.

	-2 LL	Contribution	Classification Accuracy	
		Block	Male	Female
Constant	136.223		50%	50%
Block 1	138.629	p=0.30	66%	50%
Block 2	133.385	p=0.24	58%	54%
Block 3	128.287	p=0.08	64%	62%
Block 4	120.285	p=0.02	56%	78%

The results indicate that t_{13} and t_{33} were the best predictors for the model to discriminate between genders.

Table 6: Classification accuracy between the male and female teeth 13 and 33.

Classification Table[a]

Observed		Predicted		
		Gender		Percentage Correct
		Male	Female	
Gender	Male	26	24	52.0
	Female	13	37	74.0
Overall Percentage				63.0

a. The cut value is .500

Z = 12.522 +- 0.467 t13 +- 1.199 t33

Classification accuracy: Male 52% & Female 74%

The ability of the proposed model to discriminate between male and female teeth is also confirmed by the concordance statistics which deviated significantly from 0.50: *c* = 0.69 p=0.01.

Although the model appears to fairly fit the data, the prediction to determine males is close to chance (50%) suggesting that the model assigns higher probabilities to t_{13} and t_{33} belonging to females.

A “casewise” analyses was conducted to firstly identify which cases may have dominated the model and secondly to identify the 37 misclassified cases of the sample of 100 individuals.

Figure 7 presents the leverage of each case: the orange coloured are cases with high leverages. This means teeth that had a higher influence on the measurements or are ‘out of the norm’, could give a ‘wrong’ prediction. The measurements, that predicted probability and gender of these cases, are presented in Table 7.

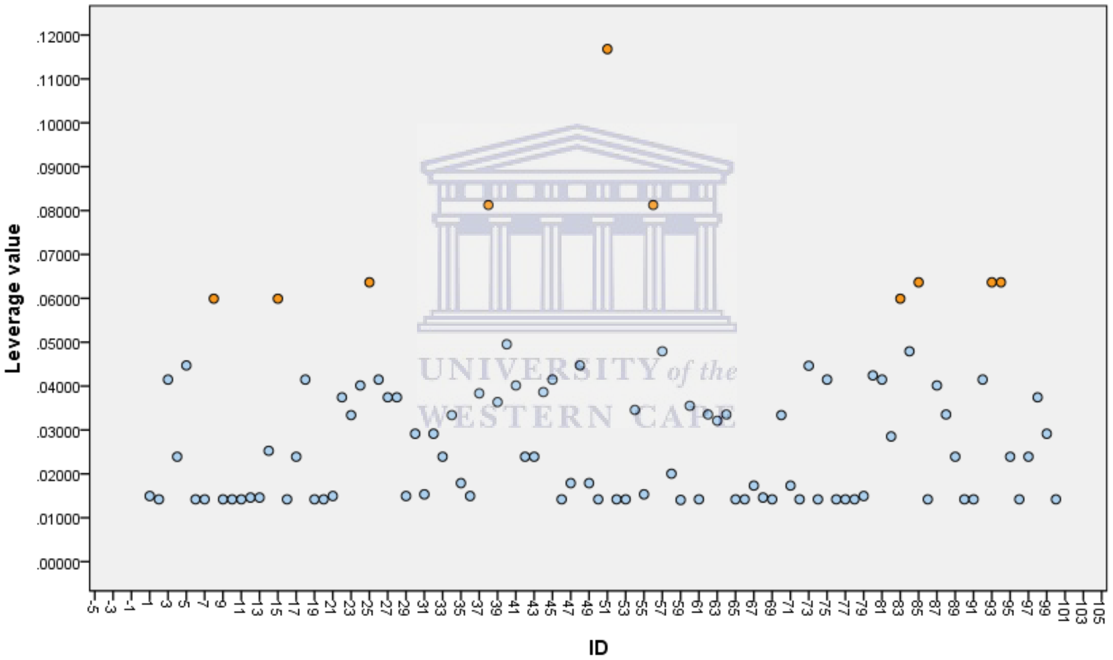


Figure 7: Tooth leverage or influences of each model measured.

This figure shows the particular teeth that do not fit the model, due to the extreme or outlying values that were measured and are thus ‘misclassified’. This can be due to either a mistake in measurement of that particular tooth, or due to an abnormally large female tooth, or abnormally small male tooth.

Table 7: The measurements, predicted probability and gender of these cases.

ID	Observed Gender	t13	t33	Predicted Gender	Estimated Probability
8	1	9.00	7.00	1	.48035
15	1	9.00	7.00	1	.48035
25	1	7.00	7.00	2	.70172
38	1	7.50	8.00	1	.35950
51	2	7.20	8.00	1	.39236
56	2	7.50	8.00	1	.35950
83	2	9.00	7.00	1	.48035
85	2	7.00	7.00	2	.70172
93	2	7.00	7.00	2	.70172
94	2	7.00	7.00	2	.70172

Table 7 shows that the maxillary canine and the mandibular canine (t13 and t33) do not bias the model. Gender was correctly predicted and balanced in most of these cases (3 correctly predicted teeth belonging to males and 3 correctly predicted teeth belonging to females).

In three cases female teeth were predicted as belonging to males. One of these (ID= 56) had identical measurements to (ID 38) and was therefore misclassified.

The measurements, gender and predicted probabilities of the 37 misclassified cases, are presented in Table 8.

Table 8: The misclassified gender cases

ID	Observed Gender	t13	t33	Predicted Gender	Estimated Probability
1	1	8.20	7.00	2	.57323
2	1	8.00	7.00	2	.59591
4	1	8.50	7.00	2	.53865
6	1	8.00	7.00	2	.59591
7	1	8.00	7.00	2	.59591
9	1	8.00	7.00	2	.59591
10	1	8.00	7.00	2	.59591
11	1	8.00	7.00	2	.59591
16	1	8.00	7.00	2	.59591
17	1	8.50	7.00	2	.53865
19	1	8.00	7.00	2	.59591
20	1	8.00	7.00	2	.59591
21	1	8.20	7.00	2	.57323
25	1	7.00	7.00	2	.70172
29	1	8.20	7.00	2	.57323
30	1	7.50	7.00	2	.65067
31	1	7.90	7.00	2	.60710
32	1	7.50	7.00	2	.65067
33	1	8.50	7.00	2	.53865
36	1	8.20	7.00	2	.57323
42	1	8.50	7.00	2	.53865
43	1	8.50	7.00	2	.53865
46	1	8.00	7.00	2	.59591
50	1	8.00	7.00	2	.59591
51	2	7.20	8.00	1	.39236
56	2	7.50	8.00	1	.35950
67	2	8.50	7.50	1	.39059
68	2	8.20	7.50	1	.42440
70	2	8.50	8.00	1	.26027
71	2	8.50	7.50	1	.39059
75	2	9.00	8.00	1	.21787
81	2	9.00	8.00	1	.21787
82	2	8.80	7.50	1	.35779
83	2	9.00	7.00	1	.48035
87	2	9.00	7.50	1	.33662
92	2	9.00	8.00	1	.21787
98	2	8.20	8.00	1	.28813

Gender 1 = males, Gender 2 = females

These mis-classified cases do not necessarily mean that they were incorrectly measured. It could mean the following: The individual could be a very large female, with significantly bigger teeth, which could influence the measurements. Alternatively it could mean a noticeably small male, with significantly smaller teeth.

The Table also appears to have a pattern: all t_{13} belonging to males were larger than the t_{33} that were predicted as females. There were female teeth that were larger that the male predicted size.

Further support for the selection of t_{13} and t_{33} in the proposed model is provided by a non-linear optimal scaling analysis (Categorical Principal Component Analysis, CATPCA) on the measurements of all teeth and their gender.

With the variables of the teeth t_{11} to t_{43} in analysis respectively showed the gender as nominal and the teeth types as numerical, a two dimensional CATPCA explained 65% of the total variance. Figure 8 shows that the variables t_{13}, t_{23}, t_{33}, $t_{43,}$ are highly related to gender, whereas the remaining variables, which are perpendicular projected to gender, are not.

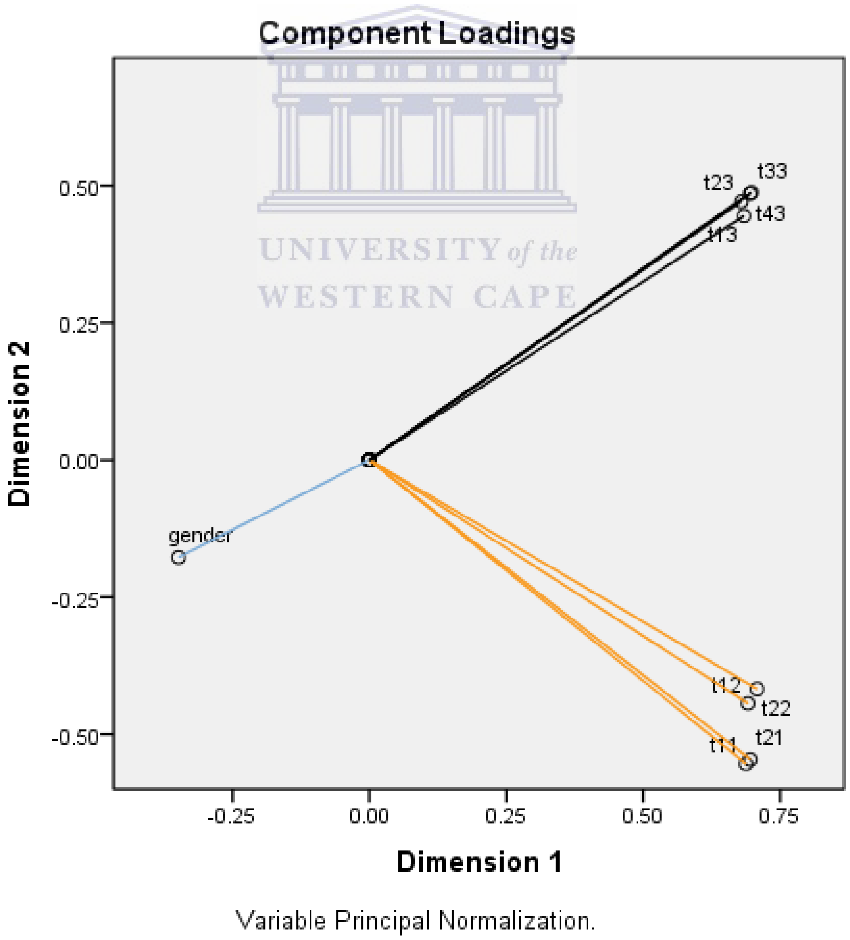
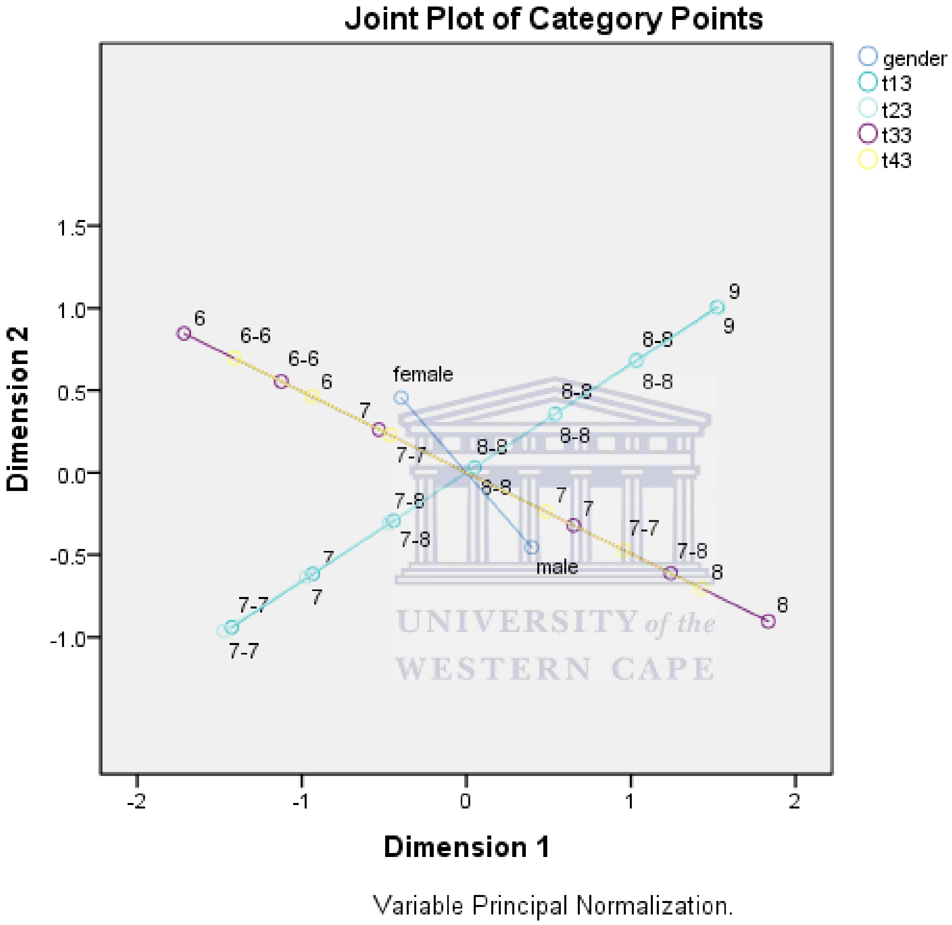


Figure 8: Mandibular and maxillary canines highly related to gender differences.

A CATPCA with the variables gender t_{13}, t_{23}, t_{33}, t_{43} supports the proposed logistic model strongly. A two dimensional analyses explained almost 82% of the total variance. Figure 8 shows the most important variables related to gender are t_{33} and t_{43}. It further shows that females tend to have smaller t_{33} and t_{43} compared to males (the lowest t_{33} and t_{43} in the left top quadrant start with 6.0 and increase with steps of 0.20 to 8.30).



Note: The values of the teeth in the plot are classes e.g. 7-7 represents 7.00 to 7.20 (the decimals are not provided for reasons of readability).

Figure 9: Mandibular canines showing the greatest variable importance to gender.

A one-dimensional solution with t_{13} and t_{33} in the analysis would indicate whether it would be able to discriminate gender between these types of teeth. The solution of scaling these variables in a one-dimensional space explained 56% of the total variance.

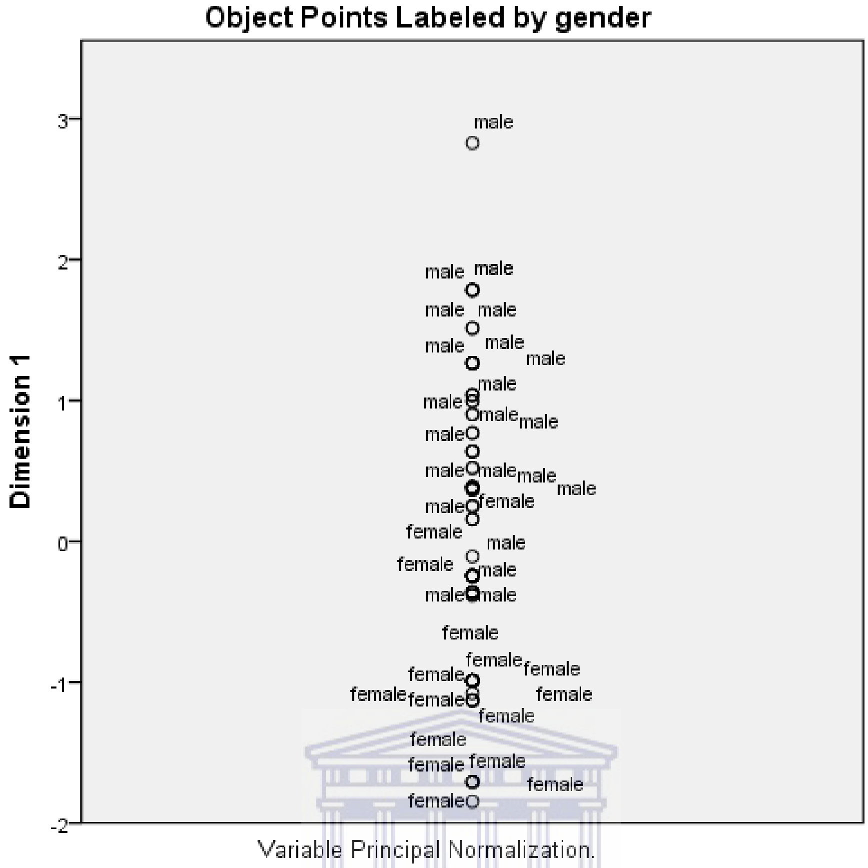


Figure 10: Clusters of male and female teeth corresponding with mixed (bigger and smaller) teeth measurements.

Figure 10 shows some clustering of males and females at the extremes which corresponds with respectively larger and smaller teeth measurements and an expected mixture of gender in the middle range.

Chapter 6

Discussion

Mandibular and maxillary canines display the greatest portion/percentage of sexual dimorphism in their mesiodistal width amongst all the teeth.

Although male central and lateral incisors appear to be larger than females, there is no significant difference between the male and female central and lateral incisor teeth as shown in this study.

The reason for the high level of sexual dimorphism in specifically the canine teeth is unclear, but could suggest that in the evolutionary process, the canine tooth has a more functional purpose than mastication, and primates depended on their canines for survival, especially in males.

This study has shown that maxillary and mandibular canines have the most significant difference between males and females. The study also showed no significant sexual dimorphism in the mesio-distal dimensions of either the maxillary central incisors or lateral incisors in the sample examined.

Kaushal *et al.* (2003) observed statistically significant dimorphism in the mandibular canines in a North Indian population, where the left mandibular canine was seen to display greater sexual dimorphism. They also found that if the lower canine width is more than 7mm, the likelihood of the sex of the individual under consideration being male was 100%.

In this study it was found that there is significant dimorphism in mandibular canine teeth and that there was only one male mandibular canine smaller than 7mm that agrees with the Kaushal *et al.* (2003) study.

The probability being male existed when the lower canine width was greater than 7.3mm; if the size was 7.0mm to 7.2mm this was a female (Sreedhar *et al.* 2015).

Vishwakarma and Guha (2011), who did a study on a Gwalior population, found that the right mandibular canine shows a higher degree of sexual dimorphism than the left mandibular canine. However, Sharma and Gorea (2010) reported that maxillary canines showed statistically significant sexual dimorphism.

This study on South African teeth showed a similar result measuring maxillary canines, but the mandibular canines showed a greater predictable difference between males and females.

In comparison to the study of Peckmann *et al.* (2016) their statistical analyses showed that only the central incisors and canines were sexually dimorphic. Their study also showed an accuracy of sex classification range from 61.1% to 65.9% for males and 59.3% to 67.2% for females, using direct discriminant function equations.

The study of a South African sample the level of accuracy was 52% for males and 74% for females if teeth 13 and 33 are measured, using the logistic regression model.

There is some consistency with the present study and the Peckmann *et al.* (2016) study:
(i) Teeth originating from females are better predicted by using both upper and lower models;
(ii) the models evidently fit the data fairly well;
(iii) both models misclassify in a number of cases. The present study was only able to find a representative level of discrimination with t13 and t33 and does not support the finding in the Peckmann (2016) study.

This study has shown that the maxillary and mandibular canines can be used for estimating gender but is not sufficient to make an absolute distinction between males and females. Other gender features need to supplement the estimation of sexual dimorphism.

Chapter 7

Conclusion

This study showed that there is significant sexual dimorphism when mandibular and maxillary canines are measured. Therefore it can be stated that the width of canines can be used as an additional help for gender identification purposes. If only mandibular canines are used, the prediction accuracy is 52% male and 74% female.

There is a greater level of accuracy if the right maxillary canine (13) and the left mandibular canine (33) is used for sex determination. By using a logistic regression model, it is able to classify 56% Male and 78% Female teeth correctly.

There is no significant sexual dimorphism between the mesio-distal width of maxillary central incisors. There is no significant sexual dimorphism between the mesio-distal width of maxillary lateral incisors.

There is sexual dimorphism between the maxillary canine teeth.

There is sexual dimorphism between the mandibular canine teeth.

The left and right maxillary canines show a significant sexual dimorphism.

The right maxillary canine has a greater sexual dimorphism than the left maxillary canine.

The left and right mandibular canines show a significant sexual dimorphism; with the right mandibular canine being greater than the left mandibular canine.

In the Peckmann *et al.* (2016) study, a much bigger sample size (126 males and 177 females) was used, compared to this study (50 males and 50 females), but the prediction accuracy was not very high (54,4% to 63,3%); with a more accurate prediction for males, whereas this study on South Africans showed that females were mostly predicted correctly.

To have a more accurate prediction, a much larger sample size should be used, as well as keeping ethnic/ancestor populations in consideration.

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APPENDICES

Male (measurements in mm):

13	12	11	21	22	23		33	43
8.2	7	8.2	8.2	7	8.2		7	7.1
8	8	10	10	8	8		7	7
9	7	9	9	7	9		8	8
8.5	6.5	9.1	9	6.5	8.5		7	6.5
8	7.5	9	9	7.2	8		8	8
8	8	9	9	8	8		7	7
8	7	9	8.8	7	8		7	7
9	6.8	8.8	9	7	9		7	7
8	7	8	8.2	7	8		7	7
8	7	9	9	7	8		7	7
8	7	9	9	7	8		7	7
8.2	7	10	10	7	8.2		7.5	7.5
8.2	7	8	8	7	8.2		7.5	7.5
8.5	7	9.5	9.5	7	8.5		7.8	7.8
9	7	9.5	9.5	7	9		7	7
8	7	10	10	7	8		7	7
8.5	7.5	9	9	7.5	8.5		7	7
9	7	8.5	8.5	7	9		8	8
8	7	9	9	7	8		7	7
8	7	9	9	8	7.5		7	7
8.2	6.5	9	9	6.5	8.2		7	7
8.2	7	9	9	7	8.2		8	8
8.5	7.8	9	8.8	7	8.5		8	8
9	7	8.2	8.2	7	9		7.5	7.5
7	6	8	8	6	7		7	7
9	8	9.5	9.5	8	9		8	8
8.2	7	8.5	8.5	7	8.2		8	7.9
8.2	7	9	9	8	8		8	8
8.2	7.8	9.5	9.5	7.8	8.2		7	7
7.5	7	8.5	8.5	7	7.5		7	7
7.9	7	8.8	8.8	7	7.9		7	7
7.5	6	7	7	6	7.5		7	7
8.5	7	8.2	8.2	7	8.5		7	7
8.5	6	9	9	6.2	8.5		8	8
8	7	9.2	9	7	8		7.5	7.5

8.2	6.2	8	8.1	6.4	8		7	7
8	7	9	9	7.5	8		7.9	7.9
7.5	7.5	10	10	7.5	7.8		8	7.5
8.8	8	9.5	9.8	8	8.8		8	8
8.9	7	9	9	7.1	8.9		8.5	8
9	7.1	8.9	8.9	7.1	9		7.5	7.5
8.5	6	8.5	8.5	6	8.5		7	7.1
8.5	6.5	8.5	8.5	6.5	8.5		7	7
8.9	7	9.5	9.5	7	8.9		8	8
9	7	9.2	9.2	7	9		8	8
8	6.5	9.5	9.5	6.5	8		7	7
8	6.5	9	9	6.5	8		7.5	7.5
8	7.2	9	9	7.2	8		8	8
8	6	8	8	6	8		7.5	7.5
8	6	8.2	8.2	6.2	8		7	7

Female (measurements in mm):

13	**12**	**11**	**21**	**22**	**23**		**33**	**43**
7.2	7	8.2	8.2	7	8.5		8	7.5
8	7	8.9	8.9	7	8		7	6.8
8	7	8.5	8.5	7	8		7	7
8.4	6	9	9	6	8.4		6.7	6.5
7.9	7.5	8.5	8.5	7	7.9		7	7
7.5	6.5	8.2	8.6	6.5	7.5		8	8
7.2	7	8.2	8.2	7	7.2		7	7
8	7	9	9	7	8		6.8	7
8.1	7.5	9	9	7.5	8.1		7	7
7.5	6	8	8	6	7.5		6.5	6.5
8	7	10	10	7	8		7	7
8	6	8	8	6	8		6.5	6.5
7.8	7.5	9.5	9.5	7	7.8		6.5	6.5
8	7	9.5	9.5	7	8		6.5	7
8	7	9	9	6.2	8		7	7
8	7	9	9	7	8		7	7
8.5	8.5	8.1	8.1	8.5	8.5		7.5	7
8.2	7	8.5	8.5	7	8.2		7.5	7.5
8	6	9	9	6	8		7	7
8.5	7.5	9.5	9.5	7.5	8.5		8	8
8.5	6.7	8	8	6.7	8.5		7.5	7.5
8	6	9	9.2	7	8		7	7

7.5	7	8.5	8.5	7	7.5		7.5	7.5
8	7	9	9	7	8		7	7
9	7	10	10	7	9		8	8
8	6	9	9	6	8		7	7
8	5.5	8.5	8.5	5.5	8		7	7
8	7.5	9	9	7.5	8		7	7
8.2	6	8	8	6	8.2		7	7
8.8	7	8.8	8.8	7	8.8		7	7
9	7	9	9	7	9		8	8
8.8	8	10	10	8	8.8		7.5	7.5
9	6.5	8	8	6.8	9		7	7
7.5	6	8	8	6	7.5		6	6
7	6	8	8	6	7		7	7
8	7	9	9	7	8		7	7
9	8	9.8	9.8	8	9		7.5	7.5
8	7.5	9	9	7.5	8		6.5	6.5
8.5	7	8	8	7	8.8		7	7
8	7	9	9	7	8		7	7
8	8	9	9	8	8		7	7
9	7	9.5	9.5	7	9		8	8
7	6	8	8	6	7		7	7
7	6.5	8.5	8.5	6.5	7		7	7
8.5	6	7.9	7.9	6	8.5		7	7
8	5.5	8.5	8.5	5.5	8		7	7
8.5	7	8.5	8.5	7	8.5		7	7
8.2	7	8	8	7	8.2		8	8
7.5	6.8	8	8	7	8		7	7
8	6	9	9	6	8		7	7