TOOTH SIZE PREDICTION FORMULAE:

A PRELIMINARY STUDY ON DATA DERIVED FROM A SAMPLE OF SOUTH AFRICAN WHITE AND BLACK PATIENTS

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A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree

of

Master of Science in Dentistry.

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DECLARATION

I, Taryn di Pasquale, declare that this research report is my own work. It is being submitted for the degree of Master of Science in Dentistry in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other University.

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Taryn di Pasquale

_____ day of _____________, 2013

This work is dedicated to my loving husband,

Mark di Pasquale,

for his patience and understanding during this challenging situation

ABSTRACT

The aim of this study was to derive the best combination of teeth with which new prediction equations could be formulated, resulting in more accurate prediction of the combined sizes of the permanent canine and premolar teeth for the white and black South African populations. The mesio-distal tooth sizes of each tooth from first molar to first molar were measured for both arches on a sample of dental casts. The data were subjected to a series of statistical correlation and regression. The sum of the permanent upper first molar, upper central incisor and lower lateral incisor were found to produce the most accurate predictions for both the white and black samples. The newly formulated equations were more applicable to and accurate in the South African white population, and for South African black female population; however, there was no improvement in the accuracy of forecasting tooth size for the South African black male population.

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1.0 INTRODUCTION

Mixed dentition space analysis is an integral aspect of orthodontics in that it measures the amount of space available in the arch to accommodate the permanent teeth, predicts the mesio-distal sizes of the unerupted permanent canine and premolar teeth and determines the relationship between the measurements. The analysis enables assessment of whether the treatment of the patient should involve space maintenance, space regaining, extraction or other options. Dental casts and prediction equations and tables have been used for these forecasts. Examples of the more popular methods are provided in Appendix A.

The Moyer's prediction tables are commonly used; [1] however, these tables were created from data gathered from a North American white sample and have been shown to be not applicable to black patients of African descent[2] nor to the Western Cape white population. [3] The Tanaka-Johnston prediction equations are also based on a North American white sample[4] and have been popular worldwide due to their simplicity. These equations are not applicable to South African black males and new equations are required for this population. [5]

The Moyer's prediction tables, Tanaka-Johnston prediction equations and the studies done on the South African population have used the lower permanent incisors as the independent variable in their equations or tables. More recent studies have shown that combinations of the sizes of teeth other than the lower incisors (i.e. different combinations of first molars and incisors) are better predictors for the sums of the mesio-distal dimensions of the unerupted canines and premolars. [1, 6]

The aim of this study, therefore, was to derive the best combination of permanent teeth present in the mixed dentition (i.e. from amongst the first molars and incisors) which would lead to the formulation of reliable new equations, resulting, it is hoped, in more accurate prediction equations of the combined sizes of unerupted permanent canines and premolars for the South African white and black populations. The equations should be simple, and should provide more accurate predictions, which will positively contribute to the diagnosis of and treatment planning for malocclusions in South African white and black patients in the mixed dentition phase. The similarities or differences between the tooth sizes according to race and gender were also examined during the analysis.

1.1 Review of the literature

It can be said that dental crowding and spacing is determined by the relationship between the size of the teeth and the size of the dental arch. [7] If the factor of the arch size is taken into consideration, it can be argued that an evolutionary reduction in the size of the jaws could lead to an increased incidence of dental malocclusion. [8] Tooth size, which has a large impact on dental malocclusion, is determined by both genetics, which includes gender and race, and by environmental factors. [9, 10] Variation in tooth size is not determined by a single gene but is a result of the influence of multiple genes. [9] Body size, however, does not influence tooth size. [9]

The most influential environmental factor is diet. Our diets are more refined and soft compared with what our ancestors ate, which results in less attrition or wear of the teeth, thereby invoking a greater challenge for accommodation in contemporary jaws.[8, 11] The effect has been identified as contributing to the occurrence of crowding. The absence of this environmentally determined and post eruption reduction of tooth size emphasizes the need for accurate prediction. There can be little confidence that natural inter-dental attrition will be of any value in resolving crowding problems.

Mixed dentition space analysis is therefore an important aspect in the prevention of dental malocclusion and in determining the most appropriate stage for treatment intervention, taking advantage of growth and development factors. [12]

One of the first attempts at predicting tooth sizes was by Black, who calculated average tooth sizes. [13] The results were found to be inaccurate due to the considerable variability in tooth sizes between individuals. [4] Subsequently the use of full-mouth radiographs became the recommended method. [14] In an attempt to improve on this approach, it was suggested that the measurements of a lower permanent central and lateral incisor and the size of the x-ray images of the two unerupted premolars on the same side be used for prediction of the dimensions of the lower permanent canines and premolars. [12] The composite sum could be entered into a table and the estimated measurement of the lower permanent canine and premolars obtained. [12] A further improvement to this method made use of the average tooth measurements (averaged left and right) instead of the measurements of a specific side. This value was used in a revised regression equation for the prediction that gave more accurate predictions. [15]

The accuracy of these methods depended upon whether there had been distortion and magnification on the radiographs[14] and could not be used if there was rotation of the teeth in the crypts. [14] Another, simpler method would therefore be desirable. Statistical methods appeared to offer a more practical method of prediction. These included prediction equations and prediction tables based on statistical data to achieve the predicted value. Moyer's tables were the first of the statistical methods to be accepted and used clinically. [4] He used regression analysis and presented the different percentiles of this analysis in a table which was published in his textbook. [4] Tanaka and Johnston found that their statistical results were very similar to Moyer's and used the 75 percentile level of their probability tables to create simple prediction equations[4] that have been well accepted and utilised clinically. Both of these methods used the sum of the dimensions of the lower incisors for their prediction calculations.

Moorrees published two articles which looked deeply into the relationship between tooth sizes and groups of teeth. [7, 16] He showed that the permanent incisors and canines are larger, but the premolars smaller than their primary tooth predecessors. [7] Patients with small primary teeth tended to have permanent teeth that were also small and conversely larger primary teeth were followed by permanent teeth that were also large. [7] However, it was also noted that the permanent teeth can be proportionally larger or smaller than the deciduous predecessors and that this discrepancy can cause complications for the prognosis of dental development. [16] When looking at the correlation in tooth size between individual teeth in either the primary dentition or permanent dentition, low to moderate correlations were found. When assessing the correlation between the sizes of corresponding primary and permanent teeth, low to moderate associations were found, [7, 16] with the exception of a relatively high correlation between the upper central incisor and both central and lateral lower incisors of the primary teeth to the permanent teeth. [16]

Moorrees then tested the relationships between groups of primary and permanent teeth. [16] Moderate to high correlations were found between the upper and the lower teeth. [16] Low association was found between the upper and lower canines and premolars with the incisors and therefore Moorrees concluded that this association (as used by Moyers) is not suitable for predictions that seek to provide sufficient precision to be used clinically. [16] Multiple correlation between the primary canines and molars as well as between the permanent two lower central and lateral incisors and permanent lower first molar and the permanent canines and premolars was found to give a much higher association. [16]

As stated earlier, tooth size is determined by genetics. This is evidenced by the numerous reports stating that male samples had larger teeth than female samples. These reports come from research done on a Brazilian white population, [13] a Peruvian population, [1] a Turkish population, [17] a North-eastern Thai population, [18] an American white and an American black population, [19] Indian populations, [10, 20] a Hong Kong Chinese population, [21] a Croatian population, [22] a South African white population, [3] a South African black population, [5] and a Japanese population (with the exception of the upper central incisors and the lower central and lateral incisors which were not statistically different between males and females). [23]

There are also differences in tooth sizes between different racial groups. A study of British white patients and Nigerian black patients found that all the teeth, from the incisors to the first molars in the upper and lower jaws, were statistically larger in the black sample. The Nigerian sample had an overall larger mesio-distal tooth size of approximately 5.5 mm in the upper arch and 6.0 mm in the lower arch. [24] When comparing Brazilian black with Brazilian whites, it was found that there were no statistical differences between the sum of the sizes of the lower incisors and the corresponding sum of the canines and premolars. [25]

Most reports have shown that the American black population has larger teeth than those of the white population. [19, 26, 27] A comparative examination of the extracted posterior teeth of American white and black patients showed that there was no difference in the size of the lower first molar and there were significant differences in the tooth sizes only for the lower second and third molars, and the upper second premolar. [28] A further study comparing the tooth sizes and arch perimeters between American white and black patients in the lower left quadrant of the mouth, found that the lower incisors (which are traditionally used for tooth size prediction) were similar in size; however, the lower canines, premolars and molars were significantly larger in the black sample. [27] It was shown that the mean mesio-distal tooth size measurement of the lower left quadrant was approximately 2 mm larger in black than the white sample. [27]

It may, therefore, have been expected that the black sample would display more crowding; however, that sample showed a smaller mean amount of crowding (though not significantly different from the white sample). [27] This was explained by the fact that the black population has larger mean arch widths and depths than whites. [26, 27] The arch width was approximately 9% larger in black males than white males, and approximately 11% larger in black females than in white females. The black sample also tended to have arch forms that were less tapered than the white sample (i.e. more squared). [26]

Recognising these proven differences in tooth sizes between population groups, further studies have looked into the applicability of the prediction tables/equations derived from a specific population group to another population group. The Moyer's prediction table and the Tanaka-Johnston equations were formulated on a North American white population and the application to other populations and races has been questioned and tested. The Tanaka-Johnston equations have been shown to over-predict the actual widths in a Turkish population, [17] a Syrian population, [6] an American white female population, [19] and an Indian population. [20] Moyer's prediction tables at the 75th percentile confidence level tended to over-predict the tooth size in an Indian sample. [10] Both the Tanaka-Johnston equations and the Moyer's Tables have been shown to over-predict the actual sizes in a Croatian population[22] and a Saudi Arabian population. [29] The Tanaka-Johnston equations under-predicted the actual size in the lower jaw of an American black male population. [19]

A difference of approximately 2 mm in each arch between the predicted and actual values of the canines and premolars has been reported as being of clinical significance as it affects the treatment decision. A decision on whether to extract or not in cases where there is already crowding in the mixed dentition can be mistakenly made. [10] In general, over-prediction of the tooth size has been preferred to under-prediction in order to protect against crowding of teeth. [21] As shown above, the 75th percentile of Moyer's probability tables, which is most often used for the prediction, tends to over-predict the actual tooth sizes. [21] Tanaka-Johnston equations also relate to this percentile and, therefore, similar results are seen. [21] There are a few clinicians who tend to use the 50th percentile level. It has been suggested that utilisation of this percentile will give a more precise estimate due to the fact that error would distribute equally on both sides. [21] There are, however, some clinicians who would prefer to under-predict in order to be more conservative and to avoid unnecessary extractions.[21] There is a current societal preference towards fuller lips and facial profile. [19] If tooth size is over-predicted, the estimate could result in unnecessary extraction, which may result in a negative effect on the lip and the facial profile. [19] This decision on whether to over- or under-predict the actual size seems to be a challenge. An argument can be put that every attempt should be made to achieve the most accurate predictions possible in order to reduce errors in treatment decisions.

The use of the sum of the four lower incisors for prediction calculations has been challenged in more recent studies, which have suggested that these teeth are not the best predictors of the sums of the permanent canines and premolar. [1, 6, 13, 20, 23, 30]
In a Brazilian white population, the lower first permanent molars and the four lower permanent incisors were found to have the strongest correlation with the sum of the lower permanent canines and premolars. [13] These teeth also gave the best predictions for the upper and lower canines and premolars in an Indian population. [20]
In a Peruvian population, it was found that the sum of the permanent upper first molar, upper and lower central incisors gave the most accurate predictions. [1] The sum of the lower central incisors and the upper first molars was found to be the best predictor in a Syrian population. [6] In a Japanese male population, the best predictor teeth were a combination of the upper central and lateral incisors and upper first molars in the upper jaw and the lower central and lateral incisors and the lower first molar in the lower jaw. [23] In a Japanese female population, the best predictor teeth were the combination of the upper central incisor, the upper first molar and the upper intermolar distance for the upper jaw, and the combination of the lower central and

lateral incisors, the lower first molar and the lower molar basal arch length in the lower jaw.[23] The best correlation with the sizes of the canines and premolars for both males and females was given in an Indonesian Javanese population by a combination of the widths of the upper first molars and the lower lateral incisors.[30]

As seems to be with all populations, South Africans are unique with regards to tooth size. Research done on a South African white population described their tooth sizes to be slightly larger than the American whites but slightly smaller than the American blacks.[3] The correlation of the first molars as well as of different combinations of upper and lower incisors to the sums of the widths of the upper and lower canines and premolars were assessed. It was found that the sum of the lower four incisors provided the best predictor and a new prediction table was constructed for this population.[3] The correlations of different combinations of first molars and incisors to the sums of the canines and premolar were not, however, assessed in that research.

Two research reports were published on the black population, one specifically on South African black population and one on a black population of African descent. New prediction tables were created for the latter, utilising the sum of the lower incisors.[2] The predicted values for the unerupted canines and premolar determined by the new prediction tables were approximately 1 mm larger per quadrant than those determined by the Moyer's tables.[2] New prediction equations were also created for the South African black population by Khan, Seedat and Hlongwa,[5] which also utilised the sum of the lower four incisors for the prediction. The Tanaka-Johnston equations were shown to be not applicable in the black male sample as they tended to under-predict the size of the canines and premolars; however, the Tanaka-Johnston equations were applicable to the black females. Khan *et al*, therefore, recommended that the equations they had formulated should be utilised for black South African males.[5]

No literature is available on the use of different combinations of first molars and incisors to predict the sum of the canines and premolars in a South African population. It has been noted previously that in other population groups, a combination of teeth alternative to the lower incisors can provide more accurate predictions.[1, 6, 13, 20, 23, 30] There is, therefore, a need to investigate whether other combinations would offer more accurate predictions in South African groups.

2.0 MATERIALS AND METHODS

2.1 Study population

The sample consisted of dental casts that were selected from the records held by the Schools of Oral Health Sciences of the University of Witwatersrand, Johannesburg, and of the University of Limpopo, Pretoria; as well as from a private orthodontic practice in Johannesburg. These records represented South African white and black patients who had presented for orthodontic treatment in the last decade (January 2000 – September 2009).

The selection criteria for the inclusion in the sample are listed below:

- All permanent teeth in the arch, up to the first molars, were present and had erupted to a degree sufficient to allow for the measurements at the inter-proximal contact areas.
- Any malocclusion was minor, such as mild crowding, rotations, or diastemata.
- At the time of the impression, the patient was between the ages of 12 and 21 years.

The criteria for exclusion from the sample are listed below:

- Visible loss of tooth material mesio-distally as a result of caries, fractures or inter-proximal wear.
- Congenital defects of the teeth.

- Flawed impressions resulting in loss of, or increase in, tooth material mesio-distally.

Figure 2.1.1 Example of dental study casts that fulfil the selection criteria

2.2 Sample size

The sample comprised dental casts of 102 white patients (47 male and 55 female) and 89 black patients (41 male and 48 female). A total of forty dental casts, 10 from each group (i.e. white male, white female, black male and black female), was randomly selected and set aside for validation testing.

2.3 Sampling Procedure

The mesio-distal sizes of each of the teeth around the arch from and including the first molar to the first molar for both the maxilla and mandible were obtained by using a fine-tipped digital calliper*, measuring to an accuracy of 0.01 mm. The calliper had an electronic input tool with foot pedal**. Once the calliper was correctly positioned to measure the mesio-distal tooth size, the foot pedal was pressed, and the measurement was automatically entered into a Microsoft Excel worksheet. This allowed for more accurate recordings as the eyes of the observer could remain focussed on the calliper and the teeth on the model. The FDI dental notation system was used in this study.

*** Mitutoyo Calliper (Digital Pointed Jaw) Model No: NTD12-6”PMX**

****Mitutoyo Input Tool Model No: IT-012U**

Figure 2.3.1 Fine-tipped digital calliper

Figure 2.3.2 Input tool and foot pedal

At the start of every session, the digital calliper was calibrated using metal objects of known size. At no stage were correction factors required.

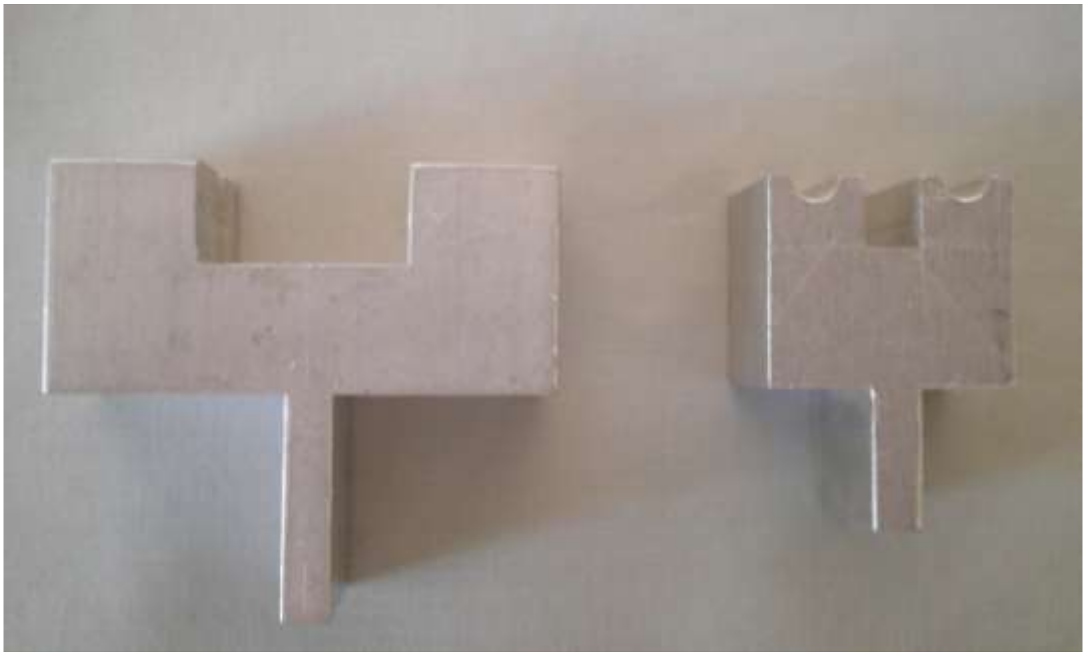

Figure 2.3.3 Metal objects used for calibration

All the measurements were performed by a single observer, and adhered to the guidelines advocated by Hunter and Priest. [31] A quiet room with minimal disturbances was used. The observer was seated below a ceiling light and in addition there was a fluorescent desk lamp on the table. The eye, instrument and light sources lay in approximately the same plane in order to reduce errors of parallax.

The tips of the calliper were placed in a position allowing for the greatest confidence that the normal contact areas were being measured. This was usually performed by inserting the callipers from the buccal or labial aspect.

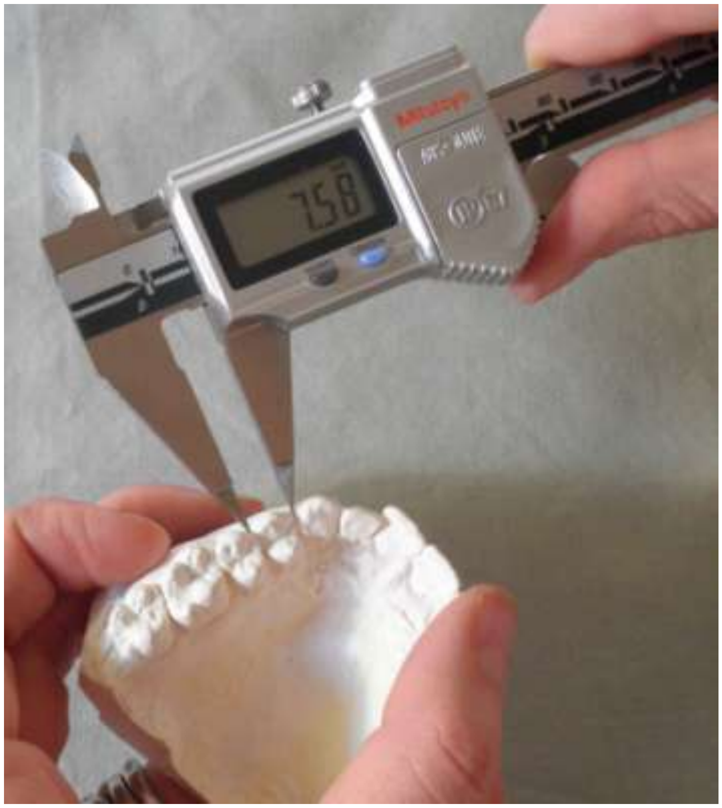

Figure 2.3.4 Measuring technique

In order to avoid eye fatigue, only five casts were examined at a time with a minimum of thirty minutes of rest before proceeding to the next five casts. No more than thirty casts were measured in one day. Each tooth of every cast was measured twice with a minimum of twenty four hours between measurements. If the difference between the two measurements was less than 0.2 mm then the first measurement was registered. If the second measurement differed by 0.2 mm or more from the first measurement then the tooth was re-measured three times and the average of these three measurements used. The results were entered into a Microsoft Excel worksheet.

2.4 Ethical clearance

Application to perform this research was made to and accepted by the Human Research Ethics Committee (Medical). The ethical clearance certificate number is M91138.

2.5 Reliability

The intra-observer reliability was monitored in the manner described in the above paragraph. The value of 0.2 mm was used for the evaluation, as suggested by Schirmer and Wiltshire,[2] and Bernabé and Flores-Mir.[1]

Inter-observer calibration was determined by having an experienced orthodontist measure five randomly selected casts twice in the manner described in the sampling procedure. The reliability was examined by using the Pearson Correlation Coefficient to measure the extent of agreement between the data recorded by the two observers.

2.6 Data analysis

The statistical analysis was performed with Statistical Package for Social Sciences 20 (IBM SPSS Statistics, Version 20). A flowchart demonstrating the statistical process is displayed in Appendix B.

Descriptive statistics were used to describe the tooth sizes of the individual teeth (mean, standard deviation, minimum and maximum values). Independent sample t-tests were performed to compare the differences between the means for race and gender. The combined data were statistically analysed using the Kolmogorov-Smirnov test of normality to determine whether parametric (normal distribution) or non-parametric assessments were appropriate. The groups were analysed with a two-way ANOVA test (comparison of all four groups) to analyse similarities and to assess whether they could be combined into one sample. Paired sample t-tests and Pearson correlation was performed to determine whether it is possible to use the mean value of the left and right quadrants for the maxilla and mandible.

The sums of the measurements of the canine and premolars in the maxilla and in the mandible were considered to be the dependant variables. The remaining teeth in both upper and lower arches were grouped into different combinations of the first molars and incisors (excluding the upper lateral incisor due to the variability in size that it demonstrates[1, 6]) and their mesio-distal dimensions recorded. These were designated as the independent variables. Correlation and regression analysis was performed between these groups (the independent and dependant variables). The independent variables that provided the largest correlation coefficients (r) and coefficients of determination (R^2) for both the white and black samples were used to construct the prediction equations.

Normality was tested on the validation sample, a smaller group, by using the Shapiro-Wilk Test for Normality to ensure that parametric statistical methods may be used.

The paired sample t-test was used to evaluate the difference between the means of the predicted values and the actual values. The predicted values from the new equations, the Tanaka-Johnston equations[4] and the equations constructed by Khan *et al*[5] (only for the black sample) were evaluated against the actual values of the canines and premolars in the upper and lower jaw. The difference and absolute difference between the actual values and the predicted values were calculated for each tooth on each individual dental cast in the validation sample.

3.0 RESULTS

3.1 Repeatability of measurements

Only one observer performed the measurements on the sample and, therefore, a test was undertaken to ensure that the measurements could be accurately repeated by another observer. An experienced orthodontist measured five randomly chosen dental casts following the guidelines defined for the measurement of the main sample. The resulting data were compared with the measurements recorded by the observer on the same five casts. This resulted in a total of 120 teeth whose dimensions were compared. As the measurements constituted continuous data, the Pearson Correlation test was chosen to evaluate the agreements between these measurements. The Pearson correlation coefficient of this comparison was 0.986 and was significant (p=0.00). High agreement, with no outliers, was therefore found, indicating that these measurements can to be accurately repeated (Figure 3.1.1).

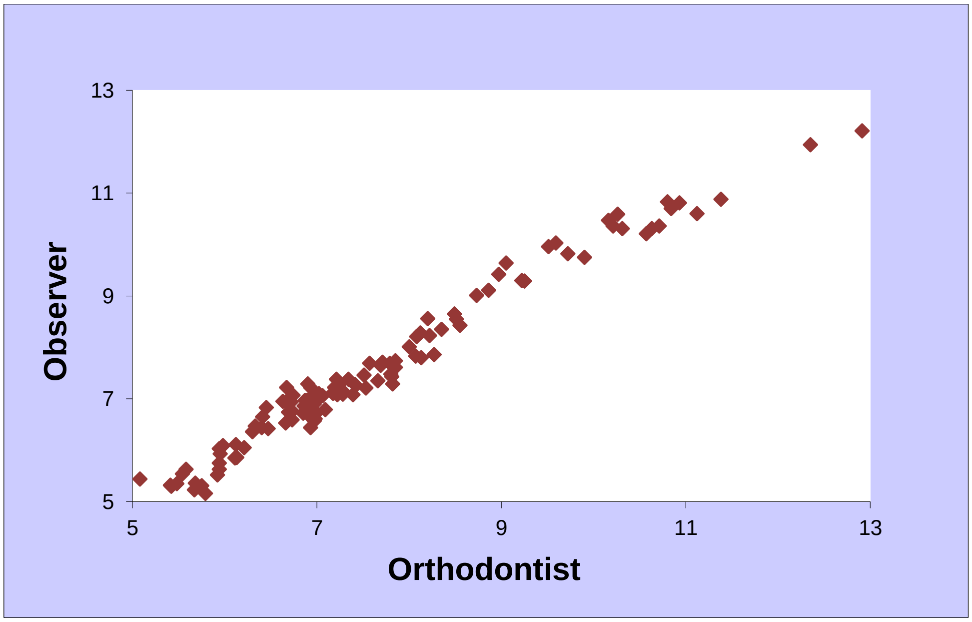

Figure 3.1.1 Scatter plot of the measurements recorded by the observer versus those by the orthodontist

3.2 Description of sample

The descriptive statistics for the sample are shown in Tables 3.2.1 and 3.2.2. There was a large variability between the tooth sizes for the lower 1st molar in white samples (standard deviation= 0.60), and in the black female sample (standard deviation= 0.56). The black male sample displayed large variability between all teeth (standard deviation ranging from 0.46 to 0.58), with the exception of the lower central and lateral incisors (standard deviations= 0.31 and 0.40 respectively). The tooth showing the greatest variability in the black male sample was the upper central incisor with a standard deviation of 0.58.

Table 3.2.1 Descriptive statistics for white sample in millimetres

		Mean	Std. Deviation	Minimum	Maximum
White Male	Upper 6	10.35	0.46	9.30	11.52
	Upper 5	6.81	0.39	5.83	7.61
	Upper 4	7.20	0.38	6.54	7.96
	Upper 3	8.22	0.30	7.71	8.91
	Upper 2	7.07	0.41	6.35	7.89
	Upper 1	8.86	0.50	7.64	9.83
	Lower 6	11.20	0.60	10.31	12.86
	Lower 5	7.33	0.38	6.60	8.09
	Lower 4	7.34	0.38	6.60	8.17
	Lower 3	7.18	0.32	6.43	7.91
	Lower 2	6.10	0.32	5.52	6.82
	Lower 1	5.52	0.33	5.01	6.20
White Female	Upper 6	9.98	0.43	9.00	11.00
	Upper 5	6.54	0.39	5.82	7.68
	Upper 4	6.93	0.44	5.83	7.81
	Upper 3	7.75	0.35	6.85	8.57
	Upper 2	6.65	0.57	5.25	7.73
	Upper 1	8.62	0.53	7.58	9.83
	Lower 6	10.83	0.60	9.46	11.83
	Lower 5	7.02	0.37	6.27	8.17
	Lower 4	7.01	0.47	5.93	8.01
	Lower 3	6.71	0.33	5.83	7.31
	Lower 2	5.89	0.37	5.04	6.60
	Lower 1	5.35	0.35	4.34	6.10

Table 3.2.2 Descriptive statistics for black sample in millimetres

		Mean	Std. Deviation	Minimum	Maximum
Black Male	Upper 6	10.90	0.52	10.06	12.24
	Upper 5	7.16	0.55	6.05	8.70
	Upper 4	7.84	0.48	6.96	8.96
	Upper 3	8.44	0.46	7.44	9.40
	Upper 2	7.62	0.55	6.84	9.20
	Upper 1	9.50	0.58	8.44	10.80
	Lower 6	11.92	0.55	11.29	13.27
	Lower 5	7.86	0.46	6.68	8.91
	Lower 4	8.02	0.47	7.21	9.24
	Lower 3	7.70	0.48	7.09	8.85
	Lower 2	6.37	0.40	5.59	7.28
	Lower 1	5.67	0.31	5.05	6.31
Black Female	Upper 6	10.50	0.41	9.65	11.15
	Upper 5	6.97	0.38	6.21	7.67
	Upper 4	7.55	0.43	6.70	8.54
	Upper 3	7.88	0.41	6.83	8.74
	Upper 2	7.28	0.53	5.85	8.01
	Upper 1	9.04	0.49	7.80	10.20
	Lower 6	11.47	0.56	10.36	12.77
	Lower 5	7.59	0.44	6.71	8.52
	Lower 4	7.64	0.43	6.85	8.59
	Lower 3	7.10	0.31	6.54	7.86
	Lower 2	6.13	0.33	5.57	6.86
	Lower 1	5.47	0.31	4.72	6.35

Independent sample t-tests were performed to compare the differences between the means for race and gender (Tables 3.2.3 and 3.2.4). Regarding the differences between the means, it was found that the black sample has generally larger teeth than the white sample, and that the male sample has generally larger teeth than the female sample.

The upper quadrant is 2.94 mm and the lower quadrant is 2.88 mm larger in the means in black males than white males, whilst black females recorded mean measurements 2.75 mm larger in the upper quadrant and 2.59 mm in the lower quadrant than the white female data.

When comparing the means of the male sample to that of the female sample, the upper quadrant was shown to be 2.04 mm larger and the lower quadrant 1.85 mm larger in white males than white females. Similarly, the upper quadrant was in the mean 2.23 mm larger and the lower quadrant 2.13 mm larger in black males than black females.

When statistically assessing the differences between the means for the white and black samples (Table 3.2.3), as well as those for male and female samples (Table 3.2.4), it was found that there were significant differences ($p<0.05$) between these four groups for most of the teeth. The only exceptions which did not show significant differences were the lower central incisor (between white and black males and females), the upper canine between white and black females, and the upper second premolar between black males and females.

Table 3.2.3 Independent sample t-test examining the differences between the means among the white and black samples for gender in millimetres

		Mean Difference (White vs Black)	Sig.
Male	Upper 6	-0.55	0.00
	Upper 5	-0.34	0.00
	Upper 4	-0.64	0.00
	Upper 3	-0.22	0.02
	Upper 2	-0.55	0.00
	Upper 1	-0.64	0.00
	Lower 6	-0.73	0.00
	Lower 5	-0.53	0.00
	Lower 4	-0.68	0.00
	Lower 3	-0.52	0.00
	Lower 2	-0.27	0.00
	Lower 1	-0.15	0.06
Female	Upper 6	-0.51	0.00
	Upper 5	-0.43	0.00
	Upper 4	-0.62	0.00
	Upper 3	-0.13	0.11
	Upper 2	-0.63	0.00
	Upper 1	-0.42	0.00
	Lower 6	-0.64	0.00
	Lower 5	-0.57	0.00
	Lower 4	-0.63	0.00
	Lower 3	-0.39	0.00
	Lower 2	-0.24	0.00
	Lower 1	-0.12	0.11

Table 3.2.4 Independent sample t-test examining the differences between the means among the male and female samples for race in millimetres

		Mean Difference (Male vs Female)	Sig.
White	Upper 6	0.36	0.00
	Upper 5	0.28	0.00
	Upper 4	0.28	0.00
	Upper 3	0.47	0.00
	Upper 2	0.42	0.00
	Upper 1	0.24	0.04
	Lower 6	0.36	0.01
	Lower 5	0.31	0.00
	Lower 4	0.33	0.00
	Lower 3	0.47	0.00
	Lower 2	0.21	0.01
	Lower 1	0.17	0.03
Black	Upper 6	0.40	0.00
	Upper 5	0.18	0.10
	Upper 4	0.29	0.01
	Upper 3	0.56	0.00
	Upper 2	0.34	0.01
	Upper 1	0.46	0.00
	Lower 6	0.46	0.00
	Lower 5	0.27	0.02
	Lower 4	0.38	0.00
	Lower 3	0.60	0.00
	Lower 2	0.23	0.01
	Lower 1	0.20	0.01

3.3 Normality testing

Normality of the distribution of the variables for the two races was assessed by using the Kolmogorov-Smirnov test. There were no statistically significant results (none of the p-values < 0.05); indicating that the data is normally distributed and that parametric statistical methods may be used in the remaining analyses.

Table 3.3.1 Test for normality of the distribution

		Kolmogorov-Smirnov	Sig.
White	Upper sum 3,4,5	0.05	0.20
	Upper 6	0.07	0.20
	Upper 2	0.05	0.20
	Upper 1	0.05	0.20
	Lower sum 3,4,5	0.09	0.20
	Lower 6	0.05	0.20
	Lower 2	0.05	0.20
	Lower 1	0.05	0.20
Black	Upper sum 3,4,5	0.08	0.20
	Upper 6	0.09	0.20
	Upper 2	0.08	0.20
	Upper 1	0.09	0.20
	Lower sum 3,4,5	0.07	0.20
	Lower 6	0.08	0.20
	Lower 2	0.07	0.20
	Lower 1	0.08	0.20

3.4 Comparison of groups

A two-way between-groups analysis of variance (ANOVA) was conducted to explore the impact of race and gender on the sum of the canines and premolars in each quadrant. The ANOVA showed that there was a gender effect ($p<0.00$) and a race effect ($p<0.00$) for each quadrant. The interaction effect of race and gender was not statistically significant for each quadrant (Quadrant 1: $F = 0.002$, $p= 0.962$; Quadrant 2: $F= 0.000$, $p= 0.989$; Quadrant 3: $F= 0.213$, $p= 0.645$; Quadrant 4: $F= 0.089$, $p= 0.766$).

This indicates that there is no interaction effect between race and gender, and that regardless of the race, male teeth will be consistently larger than those of females. It is, therefore, important that the four groups (namely white male, white female, black male and black female) be kept separate. For the sake of simplicity, instead of constructing models for upper and lower for each of the four subgroups, it was decided to create models (see section 3.7) for whites and blacks separately with gender being used as a dummy variable.

3.5 Comparison of left and right sides of arch

The tooth sizes of the right and left sides of each arch were compared using Pearson correlation analysis and paired sample t-tests, as shown in Table 3.5.1. There were high correlations demonstrated by the Pearson analysis between the sides of each arch ($r = 0.83$ and above) which were all significant ($p= 0.00$).

However, on analysis of the paired sample t-test, the differences between the means for the upper second premolars, upper canines, upper lateral incisors, lower first molar, lower first premolar and lower canines showed statistical significance ($p < 0.05$). This apparent discrepancy with the high correlation coefficients could be resolved by a consideration of the clinical relevance of the mean differences, which were all below 0.07 mm, a value well below any clinical impact. Hence, it was deemed not necessary to keep the right and left quadrants separate. It can also be argued that the significance of the mean difference could have been due to the large sample size (n=151) which introduced wider variability. It was decided on these grounds, with the agreement of the statistician, to use the mean of values for the left and right sides of each arch.

Table 3.5.1 Pearson correlation and paired sample t-test for comparison of left and right sides of the arch

	Correlation		**Paired Sample t-test**		
	r	**Sig.**	**Mean diff.**	**Std. Deviation**	**Sig.**
16 vs 26	0.90	0.00	-0.02	0.26	0.33
15 vs 25	0.87	0.00	0.05	0.25	0.03
14 vs 24	0.93	0.00	-0.02	0.21	0.17
13 vs 23	0.89	0.00	0.06	0.22	0.00
12 vs 22	0.90	0.00	0.06	0.28	0.01
11 vs 21	0.92	0.00	0.00	0.25	0.84
36 vs 46	0.93	0.00	0.07	0.27	0.00
35 vs 45	0.83	0.00	0.05	0.31	0.05
34 vs 44	0.91	0.00	0.07	0.25	0.00
33 vs 43	0.89	0.00	0.07	0.24	0.00
32 vs 42	0.88	0.00	0.03	0.20	0.10
31 vs 41	0.87	0.00	0.02	0.18	0.26

3.6 Correlation and regression analysis

A multivariate outlier, identified by a large Mahalanobis distance, [32] was removed from the white female sample prior to the regression analysis in the interest of securing a well fitting model for the sample.

The independent variables for the regression analysis consisted of 30 groups of sums of teeth. The groups consisted of all the possible combinations that could be constructed with the upper first molar and upper central incisor, and the lower first molar, and lower lateral and central incisors (the upper lateral incisor was excluded from this selection due to the variability in size of this tooth e.g. as in the case of “peg-laterals”). The dependant variables for the regression analysis consisted of four groups, namely the means of the sums of the widths of the permanent canines and premolar, for upper and lower arches, in the white and the black samples.

Correlation and regression analyses were performed between these groups (the independent and dependant variables). The independent variables with the largest correlation coefficients (r) and coefficients of determination (R^2) are displayed in Table 3.6.1. It was decided to use the sum of the means of left and right upper first molar, upper central incisor and lower lateral incisor for the prediction equations due to the fact that this combination gave good correlation coefficients and coefficients of determination in both the white and black sample (as highlighted in Table 3.6.1)

Table 3.6.1 Independent variables with the highest correlation coefficients and coefficients of determination

		Maxilla		Mandible	
Race	**Independent variable**	**r**	**R 2**	**r**	**R 2**
White	Lower 2	0.73	0.60	0.71	0.61
	Sum Upper 1, Lower 2	0.74	0.62	0.71	0.60
	Sum Lower 1, Lower 2	0.74	0.62	0.71	0.60
	Sum Upper 6, Upper 1, Lower 2	0.78	0.64	0.72	0.59
	Sum Upper 1, Lower 6, Lower 2	0.75	0.62	0.70	0.57
	Sum Upper 1, Lower 2, Lower 1	0.75	0.63	0.71	0.60
	Sum Upper 1, Lower 6, Lower 2, Lower 1	0.76	0.63	0.70	0.58
	Sum Upper 6, Upper 1, Lower 2, Lower 1, Lower 6	0.77	0.63	0.70	0.56
Black	Sum Upper 6, Upper 1	0.73	0.54	0.75	0.59
	Sum Upper 6, Lower 2	0.73	0.54	0.75	0.59
	Sum Upper 6, Upper 1, Lower 6	0.69	0.49	0.77	0.61
	Sum Upper 6, Upper 1, Lower 2	0.74	0.55	0.74	0.58
	Sum Upper 6, Upper 1, Lower 6, Lower 2	0.72	0.52	0.77	0.62
	Sum Upper 6, Upper 1, Lower 6, Lower 1	0.71	0.51	0.76	0.59
	Sum Upper 6, Upper 1, Lower 2, Lower 1, Lower 6	0.72	0.52	0.76	0.59

3.7 Determination of new equations

The results of the regression analysis are displayed in Table 3.7.1. The regression equation was determined to be:

$$\mathbf{Y = a + b\,(X_1) + c\,(X_2)}$$

Where **Y** = the predicted size of the canine and premolars in any one quadrant in millimetres

$\mathbf{X_1}$ = the sum of the mean measurement of left and right upper 1st molar, the upper central incisor and the lower lateral incisor in millimetres

$\mathbf{X_2}$ = a dummy variable that takes the value of 1 for males and 0 for females

a, b & c = constants that needed to be derived

There were two equations constructed for each race (upper and lower), with the dummy variable included into these equations for gender. In the black sample, it was found that the dummy variable was not significant (upper p= 0.39, lower p= 0.05), therefore it was not making a significant unique contribution to the prediction of the permanent canines and premolars, [33] and that it could be excluded from the equations. The dummy variable, applicable only in the case of the white sample, takes the value of 1 for males and 0 for females. The regression constant **a** has been kept in the equation, due to reference to statistical text, even though it is not significant in the case of the black sample. [34]

The prediction equations derived from the regression analysis are as follows:

White Upper: $Y = 4.94 + 0.67 X_1 + 0.44 X_2$

White Lower: $Y = 6.42 + 0.59 X_1 + 0.59 X_2$

Black Upper: $Y = 3.08 + 0.75 X_1$

Black Lower: $Y = 4.03 + 0.71 X_1$

Table 3.7.1 Results of regression analysis

		r	R 2	Constants					
				a	sig.	b	sig.	c	sig.
White	Upper	0.78	0.64	4.94	0.00	0.67	0.00	0.44	0.01
	Lower	0.72	0.59	6.42	0.00	0.59	0.00	0.59	0.00
Black	Upper	0.74	0.55	3.08	0.24	0.75	0.00	0.21	0.39
	Lower	0.74	0.58	4.03	0.11	0.71	0.00	0.46	0.05

3.8 Validation testing of equations

Normality was tested using the Shapiro-Wilk Test. The data of all groups were not significant, indicating that there is a normal distribution and that parametric methods may be used.

The paired sample t-test was used to evaluate the difference between the means among the predicted values and the actual values. The predicted values from the new equations, from the Tanaka-Johnston equations and from the Khan *et al* equations (only for the black sample) were evaluated against the actual values of the canines and premolars in the upper and lower jaw. The results from these tests are displayed in Table 3.8.1.

For the white sample, the new equations gave lower mean difference values than the Tanaka-Johnston equations and can be said to better suit the sample. It is, however, important to note that the predictions determined by the new equations and by the Tanaka-Johnston equations were very similar for the white males. Indeed, the Tanaka-Johnston equations fit this sample well and can be used to provide relatively good predictions. However, the Tanaka-Johnston equations were not appropriate for the white female sample, with significant differences (upper and lower p= 0.00) between the predicted and actual values.

The upper canines and premolars for the black male sample were predicted well by all the three models (new equations, Tanaka-Johnston and Khan *et al*), with Tanaka-

Johnston displaying the best results. However, the differences between the results were minimal. All these equations can therefore be claimed to be applicable for the prediction of the upper canines and premolars for black males.

Both the new equations and Khan *et al* equations provided good predictions for the lower canine and premolars in black males, with the latter producing the better forecasts. The Tanaka-Johnston equations were shown not to be applicable ($p = 0.01$).

The upper canine and premolars for the black female sample was well predicted by the Tanaka-Johnston equations, with the new equations and Khan *et al* not providing as good predictions.

The lower canine and premolars for the black females sample was best predicted by the new equations with poor predictions from the Tanaka-Johnston and Khan *et al* equations.

Table 3.8.1 Paired sample t-test between the predicted values and actual values

				Paired Sample t-test				Sig.
				Mean Diff.	Std. Deviation	95% Confidence Interval of the		
						Lower	Upper	
White	Male	Upper	New equation	0.05	0.88	-0.57	0.68	0.85
			Tanaka-Johnston	-0.08	0.90	-0.73	0.56	0.77
		Lower	New equation	-0.03	0.73	-0.55	0.49	0.91
			Tanaka-Johnston	-0.10	0.81	-0.67	0.48	0.71
	Female	Upper	New equation	-0.06	0.60	-0.49	0.37	0.75
			Tanaka-Johnston	-0.81	0.62	-1.25	-0.37	0.00
		Lower	New equation	-0.19	0.67	-0.67	0.28	0.38
			Tanaka-Johnston	-0.94	0.74	-1.47	-0.41	0.00
Black	Male	Upper	New equation	-0.19	1.06	-0.95	0.56	0.58
			Tanaka-Johnston	0.14	0.94	-0.53	0.81	0.65
			Khan *et al*	-0.15	1.00	-0.86	0.57	0.66
		Lower	New equation	0.25	0.80	-0.32	0.83	0.35
			Tanaka-Johnston	0.93	0.90	0.29	1.58	0.01
			Khan *et al*	0.07	1.00	-0.65	0.78	0.84
	Female	Upper	New equation	0.38	1.11	-0.42	1.17	0.31
			Tanaka-Johnston	0.15	1.18	-0.70	0.99	0.70
			Khan *et al*	0.59	1.17	-0.25	1.42	0.15
		Lower	New equation	0.56	1.22	-0.32	1.43	0.18
			Tanaka-Johnston	0.74	1.41	-0.27	1.74	0.13
			Khan *et al*	0.73	1.41	-0.27	1.74	0.13

The absolute difference of between the actual values and the predicted values were calculated for each individual dental cast in the validation sample. This provides the clinical applicability of the equations. This difference was placed into groups using the criteria below:

Good = 0.5 mm or less

Acceptable = greater than 0.5 mm but less than or equal to 1 mm

Poor = greater than 1 mm but less than or equal to 1.5 mm

Unacceptable = greater than 1.5 mm

The percentage that fell into each group is represented in Tables 3.8.2 and 3.8.3. These display the differences between the actual values and the predicted values using the new equations, the Tanaka-Johnston equations and the Khan *et al* equations (for the black sample only). In addition to these, the predicted values of the new equations utilising either only the teeth in the right quadrants ("Right inputs") or only the teeth in the left quadrants ("Left inputs") instead of the average values of the right and left quadrants were tested against the actual values.

The new equations and the Tanaka-Johnston equations had similar clinical accuracy for the white male sample with both displaying 80% of predictions for the upper permanent canines and premolars, and 90% of predictions for the lower permanent canines and premolars, in the good and acceptable groups.

The new predictions provided better predictions for the white females. The new equations displayed 90% of predictions for the upper and lower permanent canines and premolars in the good and acceptable groups, whereas the Tanaka-Johnston equations only displayed 60% of predictions for the upper and lower permanent canines and premolars in the good and acceptable groups.

The use of the right or left inputs for the white sample had very little effect on the accuracy of the predictions, with a maximum of 10% of prediction falling into the poor or unacceptable groups.

The Tanaka-Johnston equations provided better predictions for the upper permanent canine and premolars for the black male sample with 80% of the prediction falling in the good and acceptable group. Khan *et al* provided the next best predictions, with 70% of the predictions falling in the good and acceptable group. The new equations only had 50% of the predictions falling in the good and acceptable groups.

The Tanaka-Johnston equations failed to follow this accuracy into the prediction of the lower permanent canine and premolars in the black male sample, with only 50% of predictions falling into the good and acceptable groups, whereas the new equations and Khan *et al* provided 80% of the predictions in the good and acceptable groups.

The new equations and the Tanaka-Johnston equations provided the most accurate predictions for the sizes of the upper canine and premolars in the black female sample, with 60% of the predictions falling into the good and acceptable groups. The Khan *et al* equations had 50% of the predictions falling into these groups.

All equations provided poor results for the prediction of the lower canine and premolar in the black female sample, with only 40% of prediction falling into the good and acceptable groups.

The use of the right or left inputs for the black sample had very little effect on the accuracy of the predictions, with a maximum of 10% of prediction falling into the poor or unacceptable groups. There was, however, in most cases an improvement in predictions by using these inputs.

Table 3.8.2 The absolute differences between the actual values and the predicted values for the white sample

			Model	Good	Acceptable	Poor	Unacceptable
White	Male	Upper	New equations	60	20	10	10
			New equations (Right inputs)	50	20	20	10
			New equations (Left inputs)	50	20	30	0
			Tanaka-Johnston	50	30	10	10
		Lower	New equations	70	20	0	10
			New equations (Right inputs)	70	20	0	10
			New equations (Left inputs)	60	20	10	10
			Tanaka-Johnston	60	30	0	10
	Female	Upper	New equations	60	30	10	0
			New equations (Right inputs)	70	20	10	0
			New equations (Left inputs)	60	30	10	0
			Tanaka-Johnston	30	30	30	10
		Lower	New equations	60	30	0	10
			New equations (Right inputs)	60	20	10	10
			New equations (Left inputs)	70	20	0	10
			Tanaka-Johnston	40	20	10	30

Table 3.8.3 The absolute differences between the actual values and the predicted values for the black sample

			Model	Good	Acceptable	Poor	Unacceptable
Black	Male	Upper	New equations	40	10	30	20
			New equations (Right inputs)	40	10	40	10
			New equations (Left inputs)	40	30	10	20
			Tanaka-Johnston	50	30	10	10
			Khan *et al*	40	30	10	20
		Lower	New equations	40	40	20	0
			New equations (Right inputs)	30	50	10	10
			New equations (Left inputs)	50	20	30	0
			Tanaka-Johnston	50	0	20	30
			Khan *et al*	10	70	10	10
	Female	Upper	New equations	10	50	20	20
			New equations (Right inputs)	20	60	10	10
			New equations (Left inputs)	0	50	30	20
			Tanaka-Johnston	30	30	30	10
			Khan *et al*	30	20	10	40
		Lower	New equations	20	20	30	30
			New equations (Right inputs)	20	30	20	30
			New equations (Left inputs)	40	0	30	30
			Tanaka-Johnston	20	20	20	40
			Khan *et al*	20	20	20	40

Altherr *et al*[19] advised that a difference of approximately 2 mm per arch (i.e. 1 mm per quadrant) between the predicted sizes and the actual sizes should be considered clinically significant because discrepancies of this size might significantly affect extraction decisions in patients with moderate crowding (4-7 mm) in the mixed dentition.

This criterion was used to group the type of predictions produced with the new equations, the Tanaka-Johnston equations and the Khan *et al* equations (only the black sample). The groups were constructed using the criteria below:

Underestimation = predicted values per quadrant were more than 1 mm smaller than the actual values

Overestimation = predicted values per quadrant were more than 1 mm larger than the actual values

The percentage that fell into each group is represented in Tables 3.8.4.

The Tanaka-Johnston equations overestimated the actual sizes in 40% of the cases for the white females. For the black males, the new equations showed poor predictions with 30% overestimation and 20% underestimation for the upper quadrant. The Tanaka-Johnston equations underestimated the actual sizes in 50% of the cases in the black male lower quadrant.

The prediction values determined by all of the equations were particularly poor for the black female sample. For the upper quadrant, the Tanaka-Johnston equations and the Khan *et al* equations tended more towards underestimation, whereas the new equations distributed evenly between under- and overestimation. For the lower quadrant, all the equations tended to underestimate the actual sizes by 50%.

Table 3.8.4 Percentage over-estimation or under-estimation of the prediction equations

			Model	**% Over estimation**	**% Under estimation**
White	Male	Upper	New equations	10	10
			Tanaka-Johnston	20	0
		Lower	New equations	10	0
			Tanaka-Johnston	10	0
	Female	Upper	New equations	10	0
			Tanaka-Johnston	40	0
		Lower	New equations	10	0
			Tanaka-Johnston	40	0
Black	Male	Upper	New equations	30	20
			Tanaka-Johnston	10	10
			Khan *et al*	20	10
		Lower	New equations	0	20
			Tanaka-Johnston	0	50
			Khan *et al*	10	10
	Female	Upper	New equations	20	20
			Tanaka-Johnston	10	30
			Khan *et al*	10	40
		Lower	New equations	10	50
			Tanaka-Johnston	10	50
			Khan *et al*	10	50

4.0 DISCUSSION

Tooth size has been shown to be subject to a genetic influence, [9, 10] which include gender and race. This study has taken those factors into account as well as the additional possible influences of left to right size discrepancies. In depth analysis of the data, adjusted to compensate for these effects, has enabled the determination of prediction equations designed specifically for various South African groups. The analyses certainly confirm the complexity of achieving accurate predictions and it is evident that there are sound statistical reasons for the application of selected equations for specific groups.

The sum of the upper first molar, upper central incisor and lower lateral incisor were used for the construction of the prediction equations due to the fact that this sum gave good correlation coefficients and coefficients of determination in both the white and black sample. These teeth erupt early in the mixed dentition stage and are ideal teeth to be used in these prediction equations. Space analysis during this period is relevant to decisions for treatment that takes advantage of the peak growth phase, [12] a time when maxillary expansion, distalisation of first molars and other options are feasible and which are more difficult to achieve at a later stage of development. This may result in reduction in the need for extraction of permanent premolars to allow for alignment of teeth, and would avoid any undesired influence on the soft-tissue profile,[19] an effect which has in fact been challenged by some authors. [35]

Accuracy in data gathering is of obvious importance in a study which depends upon direct measurements and this investigation may have benefitted from the use of an input tool and foot pedal to capture the measurements from a digital calliper directly into an Excel spreadsheet, thereby avoiding the need to divert the focus of the eyes away from the measurement model. The accuracy of equations determined from these data may therefore have been enhanced.

In this study, a validation sample was utilised to test the applicability of these equations. This has been rarely used in similar studies; however, it is certainly appropriate that newly formulated equations be tested on a sample different to that on which the calculations were originally formulated. This process highlighted the statistical applicability of the new equations. However, the clinical relevance of size prediction may come into effect at levels of accuracy of two millimetres per arch, [19] reducing to some extent the value of predictions carrying higher degrees of statistical accuracy.

Some clinicians prefer to overestimate the actual tooth sizes, whereas others prefer an underestimate. [21] In this study the endeavour was to create equations that would provide prediction values that were as close to the actual values as possible in order to allow the clinician to make accurate treatment decisions. Despite this intention, assessment following the work of Altherr *et al*[19] showed relatively consistent forecasting only for white males and females, and rather wide variations for the black male sample. Indeed, prediction was always somewhat better for the white sample. Perhaps this may be associated with the relatively larger and more varied tooth sizes amongst the black sample, especially in the black male sample where the upper central incisor (which is an independent variable in the prediction equation) is the tooth that displays the greatest variability. It is, therefore, recommend making use of the new equations for the South African white population, as well as the South African black female population and that the Khan *et al* equations[5] rather be used for the South African black male population.

A useful contribution may be associated with the evidence that the use of the right or left inputs for the white and black samples had very little effect on the accuracy of the predictions, with a maximum of 10% of prediction falling into the poor or unacceptable groups. This helps in the clinical environment as there is then a need to measure only one side of the mouth, and if there is a missing tooth due to extraction or congenitally, then the tooth on the other side of the arch can be used. This may have particular application in the clinical environment as it is often necessary to utilise mixed dentition space analyses in children having carious or missing teeth.

As stated previously, tooth size differs between populations and the Tanaka-Johnston equations have been found not to suit many population groups, with the majority of studies displaying overestimation after application of the equations. [6, 17, 19, 20] Similar results were seen in this study, with the Tanaka-Johnston predictions showing significant differences for the white female sample, the lower arch for the black male sample and the upper arch for the black female sample. Tanaka and Johnston formulated equations which ignore genders. As shown in this study, there are significant differences between genders and therefore it may be prudent to apply these equations with caution, including at Dental Schools where the method is used. Rather it would be preferable that equations formulated on South African samples be applied. An argument can be made that the Tanaka-Johnston equations are simpler and therefore easier for students and clinicians to memorise; however, with the development of computer software, it is relatively simple to include these specific equations into a computer program that can calculate the predicted values instantaneously for the specific group.

The sample was selected from Gauteng, South Africa, and limited to only South African white and black patients but should ideally be repeated on a larger sample size in order to obtain even more accurate predictive equations. Further research is recommended to include other race groups of South Africa (e.g. Indian and Coloured), and possibly to look at the differences within a race group (e.g. tribal differences). A further investigation into differences between race and gender groups depending on geographic location in South Africa may have merit.

The use of laser or scanning techniques could provide further accuracy in the measurements and should be considered in any additional research on this topic. Previous studies have evaluated the correlations between body size, facial pattern and tooth size. [9, 36] This was not a feature of the present study but may advantageously be further investigated.

5.0 CONCLUSIONS

In this sample, the South African black patients have larger teeth than the white patients, and the South African male patients have larger teeth than their female counterparts.

The sum of the upper first molar, upper central incisor and lower lateral incisor was shown to be most applicable for the formulation of new prediction equations.

The teeth from either the left or right quadrant can be used instead of using the mean of both quadrants for the equations, with minimal loss of accuracy of predictions.

The prediction equations derived from the regression analysis are as follows:

White Upper: $Y = 4.94 + 0.67 X_1 + 0.44 X_2$

White Lower: $Y = 6.42 + 0.59 X_1 + 0.59 X_2$

Black Upper: $Y = 3.08 + 0.75 X_1$

Black Lower: $Y = 4.03 + 0.71 X_1$

Y is the predicted size of the canine and premolars in one quadrant

$\mathbf{X_1}$ is the sum of the upper first molar, the upper central incisor and the lower lateral

$\mathbf{X_2}$ is a dummy variable that takes the value of 1 for males and 0 for females

The new equations are more appropriate for the South African white population; however, the Tanaka-Johnston prediction equations may also be used for the white male population. The new equations are also more appropriate for the South African black female population; however, there is no shown improvement in prediction accuracy for the South African black male population and hence the Khan *et al* equations are recommended for this population. These equations are as follows:

Black Male Upper: Y = 8.31 + 0.62 X

Black Male Lower: Y = 7.15 + 0.67 X

Y is the predicted size of the canine and premolars in one quadrant

X is the sum of the lower four incisors

Further studies on larger sample sizes are required to confirm these findings.

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APPENDIX A

Example of Prediction Equations and Tables

Tanaka and Johnston Prediction Equations [4]

Sum of unerupted maxillary canines and premolars = 0.5(width of mandibular incisors) + 11mm

Sum of unerupted mandibular canines and premolars = 0.5(width of mandibular incisors) + 10.5mm

Moyers Prediction Tables [37]

Probability Tables for Predicting the Sizes of Unerupted Cuspids and Bicuspids*

A, Mandibular Bicuspids and Cuspids

21/12 = (%)	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0	25.5
MALES													
95	21.6	21.8	22.0	22.2	22.4	22.6	22.8	23.0	23.2	23.5	23.7	23.9	24.2
85	20.8	21.0	21.2	21.4	21.6	21.9	22.1	22.3	22.5	22.7	23.0	23.2	23.4
75	20.4	20.6	20.8	21.0	21.2	21.4	21.6	21.9	22.1	22.3	22.5	22.8	23.0
65	20.0	20.2	20.4	20.6	20.9	21.1	21.3	21.5	21.8	22.0	22.2	22.4	22.7
50	19.5	19.7	20.0	20.2	20.4	20.6	20.9	21.1	21.3	21.5	21.7	22.0	22.2
35	19.0	19.3	19.5	19.7	20.0	20.2	20.4	20.67	20.9	21.1	21.3	21.5	21.7
25	18.7	18.9	19.1	19.4	19.6	19.8	20.1	20.3	20.5	20.7	21.0	21.2	21.4
15	18.2	18.5	18.7	18.9	19.2	19.4	19.6	19.9	20.1	20.3	20.5	20.7	20.9
5	17.5	17.7	18.0	18.2	18.5	18.7	18.9	19.2	19.4	19.6	19.8	20.0	20.2
FEMALES													
95	20.8	21.0	21.2	21.5	21.7	22.0	22.2	22.5	22.7	23.0	23.3	23.6	23.9
85	20.0	20.3	20.5	20.7	21.0	21.2	21.5	21.8	22.0	22.3	22.6	22.8	23.1
75	19.6	19.8	20.1	20.3	20.6	20.8	21.1	21.3	21.6	2.9	22.1	22.4	22.7
65	19.2	19.5	19.7	20.0	20.2	20.5	20.7	21.0	21.3	21.5	21.8	22.1	22.3
50	18.7	19.0	19.2	19.5	19.8	20.0	20.3	20.5	20.8	21.1	21.3	21.6	21.8
35	18.2	18.5	18.8	19.0	19.3	19.6	19.8	20.1	20.3	20.6	20.9	21.1	21.4
25	17.9	18.1	18.4	18.7	19.0	19.2	19.5	19.7	20.0	20.3	20.5	20.8	21.0
15	17.4	17.7	18.0	18.3	18.5	18.8	19.1	19.3	19.6	19.8	20.1	20.3	20.6
5	16.7	17.0	17.2	17.5	17.8	18.1	18.3	18.6	128.9	19.1	19.3	19.6	19.8

B, Maxillary Bicuspids and Cuspids

21/12 = (%)	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0	25.5
MALES													
95	21.2	21.4	21.6	21.9	22.1	22.3	22.6	22.8	23.1	23.4	23.6	23.9	24.1
85	20.6	20.9	21.1	21.3	21.6	21.8	22.1	22.3	22.6	22.8	23.1	23.3	23.6
75	20.3	20.5	20.8	21.0	21.3	21.5	21.8	22.0	22.3	22.5	22.8	23.0	23.3
65	20.0	20.3	20.5	20.8	21.0	21.3	21.5	21.8	22.0	22.3	22.5	22.8	23.0
50	19.7	19.9	20.2	20.4	20.7	20.9	21.2	21.5	21.7	22.0	22.2	22.5	22.7
35	19.3	19.6	19.9	20.1	20.4	20.6	20.9	21.1	21.4	21.6	21.9	22.1	22.4
25	19.1	19.3	19.6	19.9	20.1	20.4	20.6	20.9	21.1	21.4	21.6	21.9	22.1
15	18.8	19.0	19.3	19.6	19.8	20.1	20.3	20.6	20.8	21.1	21.3	21.6	21.8
5	18.2	18.5	18.8	19.0	19.3	19.6	19.8	20.1	20.3	20.6	20.8	21.0	21.3
FEMALES													
95	21.4	21.6	21.7	21.8	21.9	22.0	22.2	22.3	22.5	22.6	22.8	22.9	23.1
85	20.8	20.9	21.0	21.1	21.3	21.4	21.5	21.7	21.8	22.0	22.1	22.3	22.4
75	20.4	20.5	20.6	20.8	20.9	21.0	21.2	21.3	21.5	21.6	21.8	21.9	22.1
65	20.1	20.2	20.3	20.5	20.6	20.7	20.9	21.0	21.2	21.3	21.4	21.6	21.7
50	19.6	19.8	19.9	230.1	20.2	20.3	20.5	20.6	20.8	20.9	21.0	21.2	21.3
35	19.2	19.4	19.5	19.7	19.8	19.9	20.1	20.2	20.4	20.5	20.6	20.8	20.9
25	18.9	19.1	19.2	19.4	19.5	19.6	19.8	19.9	20.1	20.2	20.3	20.5	20.6
15	18.5	18.7	18.8	19.0	19.1	19.3	19.4	19.6	19.7	19.8	20.0	20.1	20.2
5	17.8	18.0	18.2	18.3	18.5	18.6	18.8	18.9	19.1	19.2	19.3	19.4	19.5

* Measure and obtain the mesial distal widths of the four permanent mandibular incisors and find that value in the horizontal row of the appropriate male or female table. Reading downward in the appropriate vertical column obtain the values for expected width of the cuspids and premolars corresponding to the level of probability you wish to choose. Ordinarily I use the 75% of probability rather than the mean of 50% since although the values distribute normally toward crowding and spacing, crowding is a much more serious clinical problem and the 75% predictive values thus protects the clinician on the safe side. Note that the mandibular incisors are used for the prediction of both the mandibular and maxillary cuspid and bicuspid widths.

APPENDIX B

Flowchart of Statistical Analyses