CHAPTER ONE

INTRODUCTION

The mixed dentition stage of dental development is the transition period in the development of the dentition from primary to permanent. It is characterised by notable changes in the dental arches owing to the exfoliation of the twenty teeth that constitute the primary dentition and the subsequent eruption of thirty two permanent successors (Bishara, 2001). The transition from this stage to a well aligned arch form in the permanent dentition is dependent upon the space required, and that which is available.

The presence or predisposition of a malocclusion can be evaluated by conceptualizing the patient's dental arches at the mixed dentition phase to what is considered an 'ideal' dental arch pattern after the eruption of the permanent central and lateral incisor teeth. In this study, the feature of interest is ***leeway space***.

Nance (1947) defines leeway space as the difference between the larger primary molar teeth and smaller permanent premolar teeth in the buccal segments of the dental arches. In order to determine this leeway space, a comprehensive mixed dentition space analysis should be performed. This diagnostic exercise will enable the clinician to formulate treatment planning decisions that will guide the eruption of the dentition into a favourable arch form in the permanent dentition.

The space analysis involves the measurement of both the erupted and the unerupted teeth in the buccal segment of the arch. Previous methods to determine the value of the unerupted second premolar tooth to calculate the leeway space include the use of prediction tables (Moyers, 1973) or prediction equations (Huckaba, 1964; Tanaka and Johnston, 1974). Nationality, gender and the genetic inheritance specificity of tooth size are limiting factors in the application of the data in these previously derived tables.

Much work has been done to determine an accurate way to measure tooth size. Hunter and Priest (1960), Brook et al (1986) and Mok and Cook (1998) amongst others have sought to determine the most reliable technique to measure tooth size taken from study casts. These studies showed that measurements on study casts using calipers were most reliable. When teeth were measured from digitized study casts, Paredes et al (2006) found that the mesio-distal tooth size estimation was accurate, but the required adjunctive use of prediction tables as well as measurement of all teeth in the arch except the second and third molars, complicated further development of this method. Radiographically, little research has been done to prove a simple technique of measuring the size of the erupted and the unerupted teeth from images on the panoramic radiographs. The ideal method would yield data that would be individualized to each patient regardless of their demographic profile in order that the mixed dentition space analysis is as accurate as possible.

The purpose of this study was to provide and test an alternative method of:

1) Measuring the size of erupted and unerupted teeth from the images of the teeth on panoramic radiograph taken in the mixed dentition stage of dental development using the Leica QWin© System of Image Analysis
2) Measuring the anticipated leeway space

The University of the Witwatersrand Undergraduate Clinic sees mainly patients in the mixed dentition stage, where a mixed dentition space analysis is crucial for the timely treatment of the patients in order to predict and treat an impending malocclusion.

This study was guided by the following research questions:

1) What is the importance of space analysis in the mixed dentition phase?
2) What diagnostic records are required?
3) How measurements of tooth size may be carried out with a high level of confidence?
4) What are the limitations of applying the data of existing methods of tooth size measurement and prediction?
5) What does the new method entail?
6) Is the method reproducible and accurate?
7) Is this method easy for the clinician to use as a diagnostic tool?

CHAPTER TWO

LITERATURE REVIEW

2.1 Development of the human dentition

The human dentition undergoes significant changes as it develops from birth to adulthood. The four main stages of dental development are described as:

i. *The gum pads stage*. This period is characterised by elevations and grooves that can be seen in the mucosa of the neonate and infant. These ridges are the developing deciduous teeth lying within the alveolus. Occasionally, an incisor, also known as a ‘natal’ tooth may be present in the mouth at birth (Bishara, 2001).

ii. *The primary dentition stage.* This stage of dental development extends from the time of eruption of the first primary tooth until the eruption of the first permanent tooth. The first tooth to erupt is usually the mandibular central incisor at an average age of 6-7 months. The sequence ends with the eruption of the second deciduous molar at 2-3 years of age. An important characteristic of this stage is the molar relationship. This antero posterior positioning of the molar teeth is described in terms of the ‘terminal plane’. The terminal planes are the distal surfaces of the maxillary and mandibular second molar teeth. Determining the terminal plane relationship in the primary dentition is of great importance as the erupting first permanent molar teeth are guided into occlusion by the distal surfaces of the second deciduous molar teeth. At the late stage of this development of the primary dentition, there are some 20 erupted primary teeth, and 28 partially formed unerupted teeth in the alveolar processes of the maxilla and mandible (Moyers, 1973; Bishara, 2001).

iii. *Mixed dentition stage*. This stage begins with the eruption of the first permanent tooth. There are significant changes that occur during this stage. As in the primary dentition, the molar relationship is a feature to be noted (Bishara, 2001).

iv. *Permanent dentition stage.* After the last deciduous tooth has been shed and all the permanent teeth have erupted except the third molars, the dentition is in its permanent stage. The sequence of eruption in the mandible usually begins with the first permanent molar tooth. This is followed by the central incisor, lateral incisor, canine, first premolar, second premolar and then second and third molars. In the maxilla, the eruption of the first and second premolars precedes that of the canine. In comparison to the mixed dentition stage, this period is quite stable yet undergoes significant changes as well. These changes are related to growth of the dentofacial complex (Moyers, 1973; Bishara, 2001).

In the permanent dentition, Edward Angle (1899) stated that three types of 'normal' occlusion are found in the human dentition. He described a 'normal' occlusion as an evenly placed row of teeth arranged in a graceful curve with the upper and lower arches in harmony. Angle used the position of the canine and molar teeth. To describe the fundamental basis of orthodontic diagnosis, he stated that "In normal occlusion, the mesiobuccal cusp of the upper first molar is received in the sulcus between the mesial and distal cusps of the lower first molar…" This constitutes an Angle's Class I molar relationship 'neutrocclusion'. A Class II molar relationship is described as the mesiobuccal cusp of the maxillary first permanent molar occluding mesial to the buccal groove of the mandibular first molar tooth, i.e.'distocclusion'. An Angle's Class III molar relationship is characterised by the mesiobuccal cusp of the maxillary first permanent molar that occludes distal to the buccal groove of the mandibular first molar, or 'mesiocclusion'. These relationships are illustrated below in Figure 2.1.

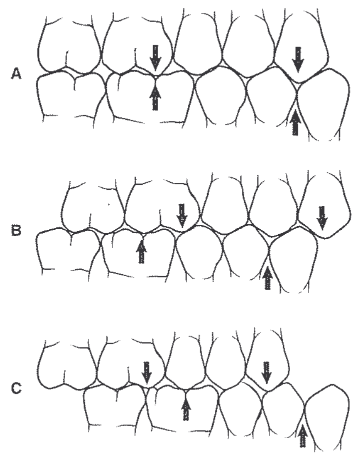


Figure 2.1 Angle's classification of occlusion according to molar position (A)Angle's Class I; (B)Angle's Class II and (C)Angle's Class III (Taken from: Bishara, 2001).

Tables displaying the information relevant to the maturation, the ultimate root length, the percentage of eruption, as well as the stages of calcification as represented by Nolla (1960) are detailed in Appendices1-4, and are taken from Moyers (1973).

2.2 The mixed dentition stage

During this period of the dental development, both deciduous and permanent teeth are present in the mouth. Permanent teeth that follow into the mouth in place of deciduous teeth are called 'successional' teeth, and those that erupt into the mouth but do not follow a precursor, erupting posterior to the primary teeth are called 'accessional teeth' (Baume, 1950). Clinically, the two most important aspects of the mixed dentition stage of dental development which is illustrated in Figure 2.2 below are:

- The arch perimeter. This must be utilised by aligning the permanent incisors, making space for the cuspids and the premolar teeth and adjusting the molar occlusion.
- The adaptive changes of the occlusion that occur during the transition of the dentition from the deciduous to the permanent (Moyers, 1973).

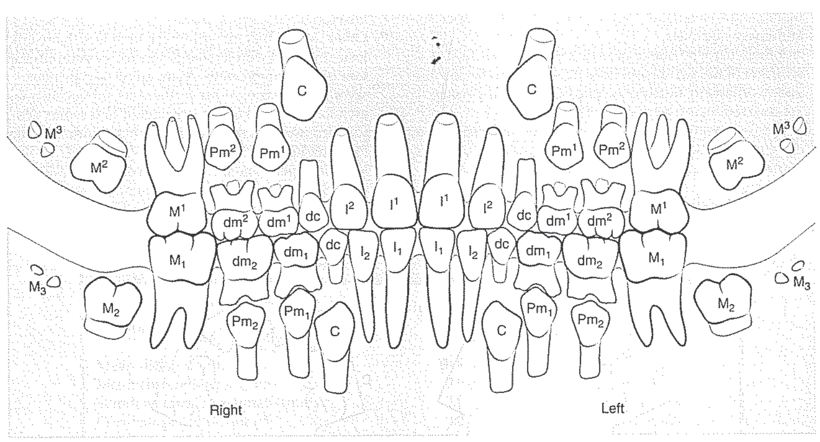


Figure 2.2- Schematic view of the mixed dentition (after eruption of the permanent incisors and first permanent molar teeth) (Taken from: Bishara, 2001).

2.2.1 Occlusal changes

The terminal plane mentioned in the primary dentition may be described in three ways: ‘flush’, ‘mesial step’ or ‘distal step’, as illustrated in Figure 2.3. The ‘flush’ terminal plane presents with the distal maxillary and mandibular planes at the same antero posterior level. In the ‘mesial step’ the maxillary terminal plane is relatively more posterior than the mandibular plane, and in the ‘distal step’ the maxillary terminal plane is relatively more anterior than the mandibular plane. These relationships are relative because the molar position does not indicate which jaw is ahead or behind the other (Bishara, 2001). Research by Bishara et al (1988) looked at 122 subjects that were studied over an eight year period. Of the subjects with a flush terminal plane, 56% developed a Class I occlusion. There are a number of factors involved in these changes of molar relationship from what is considered ‘normal’ in the mixed dentition stage, to a ‘normal’ occlusion in the permanent dentition stage. The factor of note is *leeway space*.

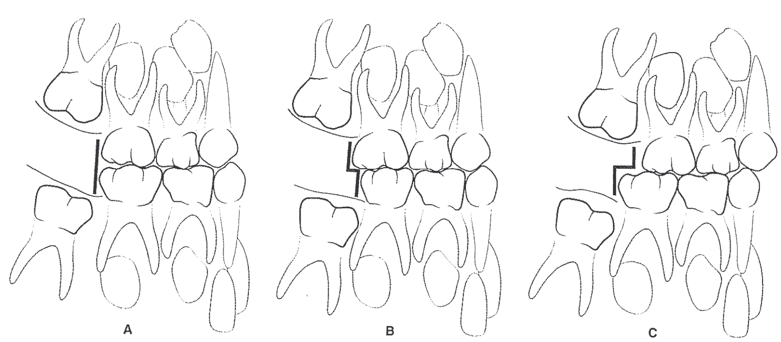


Figure 2.3: The terminal plane relationship of the deciduous molars (A) flush terminal plane; (B) mesial step terminal plane and (C) distal step terminal plane (Taken from: Bishara, 2001).

2.2.2 Leeway space

Nance (1947) observed that there was space gained due to the difference between the primary canine and molar teeth and permanent canine and premolar teeth. He termed this '*leeway space*'. Gianelly (1995) describes the leeway space in the dental arches as the actual 'e' space. This is the difference in mesio-distal width of the second deciduous molar and the second premolar of the permanent dentition, and is illustrated below in Figure 2.4. Moyers and van der Linden (1976) have stated that the combined widths of the primary canine and the first primary molar teeth (13.64mm) are approximately equal to the combined widths of the permanent canine and first premolar widths (13.84mm). The measurement of the difference between the second deciduous molar tooth and the second premolar tooth simplifies the calculation of leeway space.

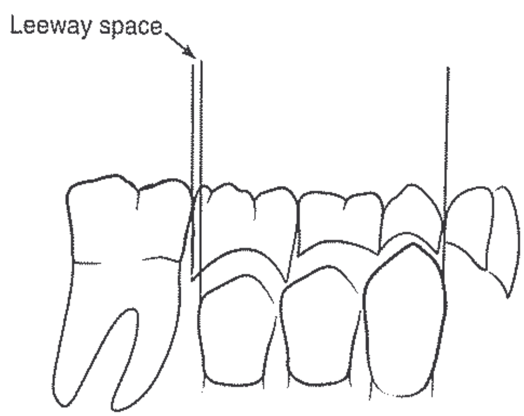


Figure 2.4: Diagram illustrating leeway space (or 'e' space) (Taken from: Bishara, 2001).

McDonald (1998) has tabulated the size differences of these teeth in Table 2.1 below.

Table 2.1: Combined mesiodistal widths of various deciduous teeth, and their permanent successors (Taken from: McDonald, 1998).

	Calcification commences (months)	Eruption (years) ± 6 months	Root complete (years)	Mesiodistal widths (mm)
Mandibular				
Central incisor	3–4	6.5		5.5
Lateral incisor	3–4	7.5		6.0
Canine	4–5	10.0		7.0
First premolar	21–24	10.5	2–3 post eruption	7.0
Second premolar	27–30	11.0		7.0
First molar	Birth	6.0		11.0
Second molar	28–36	12.0		10.5
Third molar	8–10 years	18.0		10.5
Maxillary				
Central incisor	3–4	7.5		8.5
Lateral incisor	12	8.5		6.5
Canine	4–5	11.5		8.0
First premolar	18–21	10.0	2–3 post eruption	7.0
Second premolar	24–30	11.0		6.5
First molar	Birth	6.0		10.0
Second molar	30–36	12.0		9.5
Third molar	7–9 years	18.0		8.5

	Combined mesiodistal widths (mm)	
	Deciduous – C, D, E	Permanent – 3, 4, 5
Mandibular	23	21
Maxillary	22	21.5

This leeway space in the mandibular arch is reserved to allow the mesial migration of the mandibular first permanent molars such that the molar relationship changes into an Angle's Class I occlusion. This generous space allows a certain degree of relief of crowding in the dental arch.

The values of leeway space in the mandible were found to be 1.7mm on each side, and 0.9mm on each side in the maxilla (Nance, 1947). Bishara et al (1988) found the average values of leeway space to be 1.8mm on each side of the mandible, and 0.9mm on each side of the maxilla. According to Moorrees and Chadha (1965), the available leeway space may be up to 4.5mm.

If the combined sizes of the unerupted permanent teeth are larger than that of the deciduous teeth there would be no leeway space gain. This is known as a 'leeway space deficiency' or 'negative leeway space'. In this instance, crowding of the teeth will often result (Bishara, 2001).

2.2.3 Dental arch crowding

Crowding in the dental arch is defined as the lack of space for the alignment of the teeth (McDonald, 1998). This is most often due to a tooth size arch length discrepancy (TSALD). Dental crowding is classified according to McDonald (1998) as:

- Mild- a space shortage in the arch of 1-2mm per quadrant,
- Moderate- a space shortage in the arch of 4mm per quadrant,
- Severe- space requirements greater than 4mm

Crowding can be further subdivided into two categories, i.e. *simple*, and *complex.* Simple crowding presents as a lack of space in the dental arch for the accommodation of the existing teeth, and there are no complicating factors such as skeletal, muscular or occlusal functional features. This type of crowding is often associated with a Class I Angle molar relationship, although it may also be found in a horizontal Class II type A case, i.e. maxillary dental protrusion with a 'normal facial skeleton' as classified by Moyers (1988).

Complex crowding presents as a discrepancy between the available space in the dental arches the teeth that need to be aligned together with a host of other complicating features such as

- skeletal imbalance,
- an oral habit such as abnormal lip and tongue function, and/or
- occlusal dysfunction (Moyers, 1988).

Gianelly (1969) states that the potential for crowding is often identified by three clinical signs during the development of the dentition:

- Lack of interdental spaces in the primary dentition,
- Crowded permanent incisors in the permanent dentition and
- The premature loss of a primary canine which presumably indicates that there will be inadequate space for the lateral incisor to erupt into.

Baume (1950) has disputed that the lack of interdental space is an indicator of crowding. The results of his study however, showed that nine out of the total sample of sixteen individuals with no deciduous interdental spacing did not exhibit a crowded permanent dentition. Moorrees and Chadha (1965) found crowding of 1-2mm in the incisal area in the mixed dentition as a characteristic feature of an individual that will demonstrate a normally aligned permanent dentition. In order to align a crowded dentition, space in the dental arch is required. Brennan and Gianelly (2000) found the leeway space adequate to resolve crowding in 73 out of 107 patients when arch length was preserved with a lingual arch. The correlation of leeway space and tooth size arch length discrepancy was found to be 0.44 in this particular study sample.

2.2.4 Space analysis in the mixed dentition

Early childhood evaluation is important when formulating an orthodontic treatment plan. The purpose of a comprehensive space analysis at this stage of the development of the dentition is to evaluate the amount of space in the arch for the eruption of the successive permanent teeth. This will aid in the decision making for any occlusal adjustments, such as possible extractions that may be required. The analysis is performed when the four mandibular incisors and the first permanent mandibular molar teeth have erupted (Ballard and Wylie, 1947, Bishara and Jakobsen 1998 and Flores- Mir et al, 2003). The analysis is intended to predict the size of the unerupted permanent canine and premolar teeth. For an analysis of mixed dentition, the three factors to note are the:

- Sizes of all permanent teeth from central incisor to the first permanent molar in all quadrants,
- Arch perimeter and
- Anticipated changes of arch length occurring with normal growth and development (Moyers, 1988).

2.2.4.1 Measurement of tooth size

The dimensions of tooth length and width are among the most widely documented anthropometric features. Significant information regarding biological events and problems, such as genetic and epigenetic differences, are displayed (Kieser, 1990). The mesiodistal widths of teeth are commonly measured from study casts and radiographs.

A) Study cast measurements

Traditionally, tooth size in its mesiodistal dimension was measured with a Vernier or Boley gauge. Describing the measurement of tooth size, Kieser (1990) stated that 'the mesiodistal diameter of the crowns of premolars and molars are measured parallel to the mesiodistal axis of the crown from contact point to contact point. Tobias (1967) cited in Kieser (1990), described the mesiodistal dimension as the distance between the two parallel lines perpendicular to the mesio-distal axis plane of the tooth. This measurement should be taken tangential to the most mesial and the most distal points of the crown along a parallel line to the occlusal plane. Bishara (2001) recommends measurement of mesiodistal tooth dimension from between the anatomically correct contact points of each tooth. Hunter and Priest (1960) found unavoidable systematic and experimental errors when measuring the mesiodistal tooth width. These errors occurred as a result of the taper of the points of the dividers that did not contact the greatest width of the tooth surfaces, but rather the sides of the divider points contacted the surfaces when this reading was taken. This was described as *systematic error*. The *experimental error* was described as the difference between the placement of the divider points on the study casts each time a reading was taken, as the points were not placed at exactly the same place each time.

Zilberman et al (2003) showed that digital calipers were more accurate when used to measure mesiodistal tooth width on study casts as compared to the measurements taken on virtual computerised models (OrthoCad). Thus digital calipers were shown to be more suitable for scientific use. Bell et al (2003) however, also compared the measurements taken from study casts and those from computer generated three dimensional images of the same models. They found that there was no statistical difference between the measurements. This was confirmed by the work of Quimby et al (2004). The technological development of 'e' models has peaked interest in accuracy of measuring teeth when performing space analyses. Measurement of these 'e' models was found to be just as accurate as and faster than using digital calipers on plaster study casts (Mullen et al, 2007).

Al Dashti et al (2005) assessed three different methods for measuring mesiodistal tooth diameters from study casts. Measurements of all erupted permanent teeth were taken with a digital caliper on the cast itself; a caliper measuring teeth on photocopies of the casts or teeth were measured with the 'Magiscan Image Analysis' system from photocopies of the study casts. The digital caliper method was the most accurate when compared to photocopies of casts measured with a caliper and the "Magiscan Image Analysis" and it was used directly on the casts. The error factors of the other two methods were found to be statistically higher.

Khalaf et al (2005) used an unspecified image analysis system on study casts to assess the asymmetry of crown form. The dimensions measured were mesiodistal, bucco-lingual and vertical height as measured by the occluso-gingival dimension. The mesio-distal dimension demonstrated the greatest symmetry.

There are various methods of space analysis utilizing study casts. These include the methods proposed by Black (1902), Howes (1947), Neff (1949), Bolton (1958) and Wheeler (1961). Yen (1991) introduced a method of measuring mesiodistal tooth size from photocopies of study casts and digitization of key landmarks. This method was meant to be designed as a two dimensional method of measurement that would be easier to perform, and have the same results as measurements taken from three dimensional models. It was however, shown to be unreliable for arch perimeter measurements and space analysis determination (Champagne, 1992).

Schirmer and Wiltshire (1997) compared manual and computer aided space analysis. Study casts were scanned onto computer and measured in two dimensions. They found that a computer aided method could be used with confidence. For manual measurements, a calibrated Vernier gauge produced the most reliable and reproducible results.

B) Panoramic radiographs

Panoramic imaging is a technique for producing a single tomographic image of the maxillary and mandibular dental arches and their supporting structures. It is based on the principle of the reciprocal movement of the x-ray source and the image receptor (x-ray film) around the central point or image layer where the patient is located. Objects that are in front of or behind this image layer are not clearly captured due to their movement relative to the centre of rotation of the receptor from the x-ray source.

Various shapes of the dental arches are projected onto a standard image layer as illustrated in Figure 2.5.Owing to these limitations, the problems of fit result in the inevitable blurring, dullness and variable enlargement and distortion of the image that must be acknowledged, and dealt with (Duterloo, 1991).

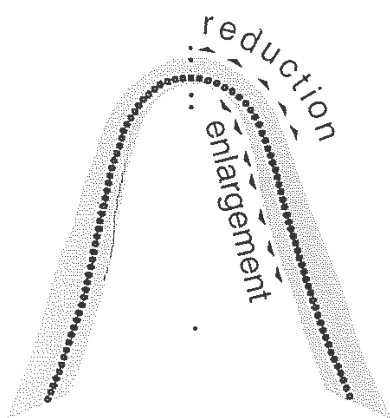


Figure 2.5–Representation of the image layer (shaded light grey area with dotted 'U' form), and consequential variations in position (Taken from: Duterloo, 1991).

Disadvantages of panoramic imaging include the lack of detail that enables one to distinguish certain areas with any confident degree of accuracy. The overlap of the proximal surfaces of premolars in the maxilla is an example of this. Other problems associated with this type of imaging, is the unequal magnification and the distortion across the image. Patient positioning is essential in order to obtain diagnostically useful radiographs. The anteroposterior position radiograph of the patient is achieved by placing the patient with the incisors of both upper and lower jaws into the trough of the bite block. This bite block is used to centre the patient and it is essential that the centre line of the patient's face corresponds with the vertical light line of the machine. Failure to do so places the patient out of the rotational midline of the machine and results in the unequal magnification of the right and left sides in the horizontal dimension. The asymmetrical positioning of the patient is a common error causing horizontal distortion in the posterior regions. A simple way to assess this is to distinguish between the apparent widths of the mandibular first molars bilaterally. The smaller side is too close to the receptor, and the larger side too close to the x-ray source (Duterloo, 1991).

Panoramic radiographs form an essential initial diagnostic record for an orthodontist. The quality of the radiograph, with regard to image clarity, is essential for the accuracy of assessment and calculation of tooth dimensions. On a clear panoramic radiograph, congenitally missing teeth, dental age, impacted and unerupted & resorbed teeth, root morphology, especially dilacerations, alveolar bone height, periodontal status and periapical pathology, are areas to be assessed before commencement of orthodontic treatment (Bishara, 2001). Despite the disadvantages of enlargement or distortion of images that may occur, these radiographs are an essential part of the diagnostic records taken.

On both intra oral peri apicals and extra oral panoramic radiographs, teeth are measured in the mesiodistal dimension, as the buccolingual dimension cannot be determined from the one dimensional radiographs. Teeth tend to be rotated, and even distorted on radiograph, and this is where an error could occur (Bishara, 2001). Volchansky et al (2006) have shown a reproducible method of linear measurement of teeth on panoramic radiographs using the Leica QWin© System of Image Analysis. 'Raw data' in the study was corrected for the specific magnification factor by calibrating the measuring tool with the dimensions of a marker known in size. The marker was placed at the same site at which the measurements were taken. The marker that was used was a 0.25 inch (6.35mm) steel ball-bearing and was placed on the buccal surface of the upper first permanent molar (in such a position that no landmarks were obscured). The dimensions of the ball-bearings were calculated in reality and on the radiograph once the area being x-rayed had been scanned onto a computer. The magnification was then calculated. Panoramic radiographs were used to take both vertical and horizontal measurements in the posterior areas of the mouth. The study proved that provided the patient was correctly positioned in the focal trough of the machine at the time of radiographic exposure and that measurements were corrected for by adjusting the raw data for magnification, the panoramic radiograph could be used for measurement studies in the posterior region (Volchansky et al, 2006).

2.2.4.2 Prediction of tooth size

The size of the unerupted teeth must be predicted so that any arch length discrepancy can be calculated. A meaningful space analysis relies on the accurate estimation of the mesiodistal widths of the unerupted permanent canine and premolar teeth. Commonly used methods of mixed dentition space analysis are grouped into two categories:

i. Radiographic method where the tooth size of the unerupted canine and first and second premolar teeth are estimated from radiographs
ii. Non radiographic method where the size of the unerupted permanent canine and both premolar teeth are derived by measuring the sizes of the permanent teeth already present in the mouth (mandibular incisors). These measurements are applied to the data of the prediction tables or equations in order to determine the size of the unerupted teeth.

A) Radiographic method

Researchers such as Nance (1947), Ballard and Wylie (1947), Carey (1949) and Griewe (1949) have developed methods of predicting tooth size of an unerupted permanent canine and first and second premolar teeth. Hixon and Oldfather (1958) were among the first to predict the mesio-distal width of unerupted permanent canines and premolar teeth. The children of the sample were taken from the Iowa Facial Growth Study. They recommended the measurement of the mandibular incisor teeth on one side of the dental arch measured on the study cast, plus the size of the unerupted premolar teeth on the same side measured from the intraoral periapical radiographs. For tooth size estimation, the sum of the permanent canine and premolar teeth are determined by entering the figure for the same teeth measured on study cast and radiograph into a table and then reading off the value for the size of the estimated teeth. The index of forecast of the size of the unerupted permanent canine, first and second premolar teeth was 25% more accurate than the previously suggested methods at the time, and in close agreement with the work of Ballard and Wylie (1947) and Griewe (1949). This method was technique sensitive and required the 16 inch skin target distance of the cone of the x-ray machine to be used when taking the intra oral peri apical radiographs.

In 1980, Staley and Kerber decreased the standard error of estimation of the original Hixon Oldfather (1958) equation from 0.57mm to 0.44mm in their Revised Equation. The co-efficient of correlation (r) in the Revised Equation (0.92) was higher than that of the original equation (0.87). The records used by Staley and Kerber (1980) included a study cast of the lower arch for measurement of the mandibular incisors, and peri apical radiographs taken with the long cone technique were used for measurement of the unerupted premolar teeth. Teeth were measured on both sides of the arch. By adding one standard error of estimation to the predicted sum, a predicted sum of widths of the permanent canine and premolar teeth at the 84th percentile was found as shown in Figure 2.3 and Table 2.2. This meant that the predicted sum of the canine and premolar teeth would be as large as or larger than the true sum in 84% of all possible patients (Moyers, 1973).

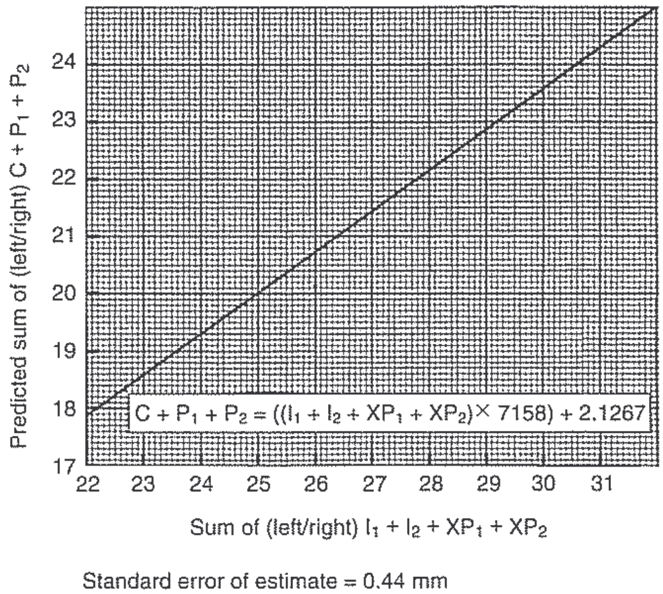


Figure 2.3- Standard error of estimation for predicted widths of teeth (Taken from: Bishara, 2001).

Table 2.2 - Prediction tables for predicted and actual means of the widths of the permanent canine and premolar teeth (Taken from: Bishara, 2001).

Variable	Original Equation N = 76	Revised Equation N = 57
Mean difference (mm)*	−0.4	−0.06
Mean absolute error (mm)	0.6	0.3
Standard error of estimate (mm)	0.57	0.44
Correlation coefficient (r)	0.87	0.92

Staley et al (1984) devised another method of predicting the size of the canine and premolar teeth in both arches. This was called the 'Iowa Prediction Method' and was based on data taken from the Iowa Facial Growth Study. Complete analysis required casts of upper and lower jaws, and peri apical radiographs of the maxillary and mandibular permanent canine to the second premolar taken with long cone paralleling or right angled techniques. Measurements of the unerupted canines and premolars taken on the radiographs were used as predictor variables. Standard errors of estimate were calculated at 0.48mm in the upper arch, and 0,47mm in the lower arch. Both the 'Revised Method of Prediction of Hixon and Oldfather' (Staley and Kerber, 1980), and the 'Iowa Prediction Method' (Staley et al, 1984) were found to have a cross validation of 53 orthodontic patients, a low standard error of estimation, and prediction tables that were easy to use.

The 'Proportional Equation Prediction Method', as developed by Bishara (2001) could be used if most of the permanent canines and premolars have erupted, and if one or two succedaneous teeth were still unerupted. The width of the unerupted tooth (second premolar) and the erupted tooth (second deciduous molar) were measured on the same peri-apical film. The width of the erupted 'e' was also measured on a plaster study cast. The size of the unerupted second premolar was solved by using the following equation recommended by Huckaba (1964) in order to reduce the factor of enlargement of teeth on radiographs:

$$\frac{\text{Unerupted tooth width}}{\text{Unerupted tooth width (x-ray)}} = \frac{\text{Erupted tooth width (cast)}}{\text{Erupted tooth width (x-ray)}}$$

$$x = \frac{(y)\,(x^1)}{y^1}$$

Where x is the estimated size of the permanent tooth

x^1 = radiographic size of the above tooth

y = size of the second deciduous mandibular molar on the study cast

y^1 = radiographic size of 'y'.

Moorees and Reed (1964) correlated the widths of permanent and deciduous teeth. The sum of the lower deciduous canine and molar teeth was correlated to the sum of lower permanent canine and premolar teeth. They concluded that prediction from radiographs was best for true mesio-distal widths.

More recently, De Paula et al (1995) introduced a technique using 45° cephalometric radiographs. This method had a high correlation of the predicted size of teeth with the actual size of teeth. This was provided the magnification of the teeth on radiograph was corrected for.

B) Non- radiographic method

The advantages of non- radiographic prediction methods were that measurements of erupted lower incisor teeth within the permanent or deciduous dentition were used. Tooth size from radiographs was not measured. With this method, Moyers (1973) however found a greater error of estimation when compared to the radiographic method.

Moyers (1973) suggested a method of tooth size prediction that involves the use of the erupted mandibular incisor teeth for the estimation of tooth size in both arches. These teeth erupt in the mouth at approximately six years of age, and are easily measurable. The maxillary incisor teeth were found to be too variable in size, and their correlation to other groups of teeth was too low to be of any value.

Moyers (1973) suggested this non-radiographic method for the following reasons:

a) There would be minimal systematic error, with a known range of such error.

b) There was no sophisticated clinical judgment necessary, and could be performed equally and reliably by an expert or beginner.

c) The method was not time consuming

d) There was no need for study casts and measurements could be taken directly in the mouth

e) It was suitable for use in both arches

The Moyers method was found superior to other similar methods as stated by Clauss (1955) and Barber (cited by Moyers, 1973). However, he (Moyers, 1973) stated that no prediction method was as accurate as one might like, and knowledge of growth and development as well as reasonable judgment should be employed.

For the Moyers (1973) method of space prediction, the mesiodistal widths of the four mandibular incisors were measured. The sum of these measurements was the amount of space needed for alignment of the incisors. This distance was marked on one side of the dental arch from a point at the midline of the alveolar crest between the central incisor teeth to the point along the line of the arch where the Boley gauge tip had touched. This mark indicated where the lateral incisor would be when it was aligned. The space available in the arch for the permanent canine and premolar teeth on one side was measured from the mark of the aligned incisors to the mesial surface of the first permanent molar tooth. Care should be taken to check the cephalogram, and perhaps account for cephalometric correction if the incisors need uprighting or retraction in the symphysis which would require more space in the dental arch.

The predicted size of the above teeth was then taken from probability charts as shown in Table 2.3. The value corresponding most closely to the sum of the widths of the four permanent incisor teeth is located on the chart. The figure of estimated tooth size is read from the same line in the adjacent column. Moyers (1973) explains that no single value obtained from the chart, which varies from a 95% down to a 5% confidence level, can represent the true sum of the three teeth estimated. There is a range of posterior tooth widths even when the incisors are identical. A value at 75% is chosen as the estimate after being found as the most predictable from a clinical standpoint.

Table 2.3- Moyers probability charts for calculation of size of the unerupted canine and premolars (Taken from: Moyers, 1973)

PROBABILITY CHART FOR PREDICTING THE SUM OF THE WIDTHS OF 345 FROM 21/12

Σ21/12 =	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
95%	21.6	21.8	22.1	22.4	22.7	22.9	23.2	23.5	23.8	24.0	24.3	24.6
85%	21.0	21.3	21.5	21.8	22.1	22.4	22.6	22.9	23.2	23.5	23.7	24.0
75%	20.6	20.9	21.2	21.5	21.8	22.0	22.3	22.6	22.9	23.1	23.4	23.7
65%	20.4	20.6	20.9	21.2	21.5	21.8	22.0	22.3	22.6	22.8	23.1	23.4
50%	20.0	20.3	20.6	20.8	21.1	21.4	21.7	21.9	22.2	22.5	22.8	23.0
35%	19.6	19.9	20.2	20.5	20.8	21.0	21.3	21.6	21.9	22.1	22.4	22.7
25%	19.4	19.7	19.9	20.2	20.5	20.8	21.0	21.3	21.6	21.9	22.1	22.4
15%	19.0	19.3	19.6	19.9	20.2	20.4	20.7	21.0	21.3	21.5	21.8	22.1
5%	18.5	18.8	19.0	19.3	19.6	19.9	20.1	20.4	20.7	21.0	21.2	21.5

PROBABILITY CHART FOR PREDICTING THE SUM OF THE WIDTHS OF 345 FROM 21/12

Σ21/12 =	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
95%	21.1	21.4	21.7	22.0	22.3	22.6	22.9	23.2	23.5	23.8	24.1	24.4
85%	20.5	20.8	21.1	21.4	21.7	22.0	22.3	22.6	22.9	23.2	23.5	23.8
75%	20.1	20.4	20.7	21.0	21.3	21.6	21.9	22.2	22.5	22.8	23.1	23.4
65%	19.8	20.1	20.4	20.7	21.0	21.3	21.6	21.9	22.2	22.5	22.8	23.1
50%	19.4	19.7	20.0	20.3	20.6	20.9	21.2	21.5	21.8	22.1	22.4	22.7
35%	19.0	19.3	19.6	19.9	20.2	20.5	20.8	21.1	21.4	21.7	22.0	22.3
25%	18.7	19.0	19.3	19.6	19.9	20.2	20.5	20.8	21.1	21.4	21.7	22.0
15%	18.4	18.7	19.0	19.3	19.6	19.8	20.1	20.4	20.7	21.0	21.3	21.6
5%	17.7	18.0	18.3	18.6	18.9	19.2	19.5	19.8	20.1	20.4	20.7	21.0

Well published probability tables have also been produced by Tanaka and Johnston (1974), Bishara and Staley (1984), and Staley et al (1979) amongst others. These methods, however popular, are limited to the population sample from which the data were derived. These tables are most applicable to the North European population group. Transference of values from one population group to another reduces accuracy. Tanaka and Johnston (1974) prediction tables have shown correlation co efficients of r=0.63 for maxillary teeth, and r=0.65 for mandibular teeth. The standard errors of estimate were 0.86mm for maxillary teeth, and 0.85mm for mandibular teeth. It is recommended that the values at the 75th percentile are used to guard against under predicting tooth size. The prediction table of Tanaka and Johnston (1974) is detailed below in Table 2.4

Table 2.4 Tanaka and Johnston Prediction Method (Taken from: Tanaka and Johnston, 1974).

One half of the mesiodistal width of the four lower incisors	+ 10.5 mm =	estimated width of mandibular canine and premolars in one quadrant
	+ 11.0 mm =	estimated width of maxillary canine and premolars in one quadrant

__2.2.5 Comparison of methods of space prediction__

Tootla and Fayle (2003) demonstrated that there was less variation and greater reproducibility when using the Moyers (1973) prediction method as opposed to estimation by a simple visual observation method (SVO) of twenty dental clinicians with varying levels of experience. It was noted that neither technique was more accurate, nor did the mean space prediction of either technique resemble the final space available in the permanent dentition more closely.

The method of Tanaka and Johnston (1974) was compared to that of the Boston University Prediction Method (BUPM). In general, there was a statistically significant correlation between the actual predicted tooth sizes. The Tanaka and Johnston method overestimated the tooth size of unerupted teeth (mean=1.1 +/- 0.9mm) and the Boston University method underestimated tooth size (mean 0.1 +/- 1.2mm). The standard error of estimation for the Boston University Prediction Method was between 0.92 and 1.02mm. The Tanaka and Johnston can be used when four mandibular incisors have erupted and the BUPM when the canines and deciduous molars are still present (Bishara and Jakobsen, 1998).

2.2.6 Factors affecting prediction tables

2.2.6.1 Genetic factors

Heredity plays a role in the different values in the prediction table. Arch size and shape linked to genetic influences shows a 50% correlation, although environmental influences may play a bigger role. These extrinsic factors need to be more thoroughly assessed (Cassidy et al, 1998), thus the following equation was proposed:

$$\mathbf{V_P = V_G + V_E}$$

- 'V' highlights the statistical variance.
- V_P is the phenotypic variation that is the result of the genetic variation, as well as the environmental influence.
- V_G can further be divided into $V_A + V_D + V_{EC}$, where
- D= dominance of alleles; A+ additive genetic effect; EC the common environment of siblings (Cassidy et al, 1998)

Kabban (2001) measured tooth size and morphology in twins, and found that the similarity of tooth size and morphology in monozygotic twins suggested a strong inheritance factor of tooth size and shape.

2.2.6.2 Gender

Moorrees and Reed (1964) found that females showed a greater degree of association of tooth size in deciduous and permanent dentitions, as well as for maxillary and mandibular teeth when compared to the males in the group. Gardner (1979) did not find gender as a factor that affected the prediction of tooth size in his comparative study of four methods of tooth size prediction, i.e. Nance (1947), Tanaka and Johnston (1974), Moyers (1973) and Hixon-Oldfather (1958). The prediction tables of Moyers (1973) separated the sexes, but Tanaka and Johnston (1974) combined boys and girls in the sample group. This could also explain the under prediction of tooth sizes in the male group and the over prediction of tooth sizes in the female group when applying the Tanaka and Johnston tables to a particular study sample (Khan, 2006). The sample of Khan (2006) consisted of Black patients in contrast to the sample of Tanaka and Johnston (1974) that consisted of a North European sample group. The differences were found to be more race related than gender related. Basaran et al (2006) et al conducted a study to measure intermaxillary Bolton tooth size discrepancy among malocclusive groups. They found no sexual dimorphism for tooth size ratios and the one way analysis of variance test showed no sexual dimorphism for the ratios tested in the five groups measured, hence the genders for each of the malocclusive groups studied were combined.

Sexual dimorphism was however shown by results from Adeyemi (2003) where values for males were greater than females.

There was no significant difference between the genders or of the upper and lower jaws in the odontometric studies of Khalaf et al (2005) to determine tooth asymmetry. In a sample of 65 Saudi subjects (male and female) there were no statistically significant differences between mean values of tooth size as determined by the Bolton (1958), or of gender as reported by Al-Tamimi and Hashim (2005). In a bigger sample group of 1124 African American male and females however, Anderson (2005), found an average of 3.5% in the maxilla and 3.2% in the mandible for values of sexual dimorphism when he measured the circumferential diameters of mesiodistal and posterior sagittal tooth size ratio. In this study, an interracial comparison between African Americans and European American samples showed larger mean circumferential diameters for the European American group of males, whereas the females in the samples were less statistically significant. Altherr et al (2007) found that the Tanaka and Johnston tables predicted tooth size reasonably well for both arches in White males and Black females, but over predicted in both arches in White females and under predicted in the mandibular arch for Black males in North Carolina, USA. Schwartz (2005) found that sexual dimorphism in males was shown to be due to an increased amount of dentine in the crowns of male teeth. Gender should be noted when comparing children of a particular racial (ethnic) group.

2.2.6.3 Race group

Most of the previous methods of tooth size prediction of the permanent canine and premolars in the mixed dentition stage were taken from population samples of North European ancestry. Evidence suggests that these values might be of use for patients of Egyptian and Northern Mexican origin, however Lee Chan et al (1998) found the values of Tanaka and Johnston (1974) did not satisfy the prediction values needed for American and Asian ancestry. Ferguson et al (1978) developed a non radiographic method of tooth size prediction in a sample of American Blacks which showed an increase of 0.2mm in the maxilla and 0.6mm in the mandible as compared to the values for the same method in White Americans. It has been recommended for these reasons that the prediction table specific to the patient's race group be used.

The Moyers (1973) tables underestimated the mesiodistal width of the canines and premolars for both males and females in the Black population group (Schirmer and Wiltshire, 1997). (These are detailed in Appendix Six)**.** Since the realization that the predicted tooth widths were not applicable to all nationalities, other simple linear regression equations have been proposed for populations of different ethnic origins. Equations for tooth size estimation are available for South African Black individuals (Schirmer and Wiltshire, 1997; Khan, 2006) Saudi individuals (Al Khadra, 1993), Hong Kong Chinese individuals (Yuen et al, 1998), Senegalese individuals (Diagne et al, 2003), Thai individuals (Jaroontham and Godfrey, 2000), and more recently Brazilian patients (Melgaço et al, 2007).

2.2.6.4 Cleft lip and patients

In a sample of children with cleft lip and palate, the total sample exhibited smaller lateral deciduous incisor teeth and second deciduous molars on the side of the cleft, while in the female sample, the central and lateral incisors were smaller on the affected side. The conclusion was drawn that the presence of a unilateral cleft lip and palate was associated with a decrease in tooth size on the affected side (Jaksic et al, 2002)

2.2.7 Pros and cons of existing prediction methods

Nance (1947) realised the importance of the technique that was used for taking the radiographs. The angle of the beam determined whether or not the images of the teeth were overlapped at the contact points. Overlapped teeth made the determination of the true mesiodistal dimension more difficult and not reproducible with a great level of confidence. Nance (1947) Staley et al (1979) and De Paula et al (1995) recommended the long cone technique for taking peri apical intra oral radiographs. It was also suggested that dial calipers versus a Boley gauge be used for measurements of tooth size on the study casts, as the former were readable to the nearest 0.05mm, and could be used with greater ease and accuracy for measurements

Staley and Kerber (1980) used a computer with sixteen significant digits which was not available to Hixon and Oldfather (1958) who used the x-ray films irrespective of quality, and measurements of the teeth on the study casts were taken on only one side of the arch. Staley and Hoag (1978) and Staley and Kerber (1980) measured both sides of the arch, did not use poor quality radiographs and did not measure teeth if they were rotated on radiograph. Both studies also made use of a dial caliper instead of a Boley gauge as used by Hixon and Oldfather (1958). Cohen (1959), like Huckaba (1964) incorporated a correction factor for enlargement of images on radiograph. The width of the first molar crown in reality was divided by its width on peri apical film. The sum of the width of the permanent canine and premolar teeth was then multiplied by the correction factor to obtain a predicted sum of the unerupted tooth width. The accuracy of this method was not available.

2.3 Technology: improved methods of measuring tooth dimensions

Measurements of teeth from dental casts were traditionally performed with the aid of Vernier calipers or Boley gauges (needle point dividers). Accuracy was essential, as errors greater than 1.5mm are seen as clinically significant (Proffit, 2000). Study casts have been photocopied (Al- Dashti et al, 2005), photographed, hologrammed (Bell et al, 2003) or digitized (Brook et al, 1996; Mok and Cook, 1998; Tomasetti et al, 2001; Paredes, 2003; Paredes et al, 2006) for measuring teeth. These calibrated methods have been suggested as improved alternate methods of tooth size measurement. Where evidence based orthodontics is becoming more popular, a proven method that exhibits reproducibility and accuracy amongst a range of different measurements is essential, and needs to be evaluated.

Technology is moving towards a ‘paperless’ office. Patient records including photographs and radiographs are preferably electronic; therefore a method of space analysis on computer is in keeping with these technological advances. Measuring teeth on a radiograph has obvious advantages. The distortion values are given for specific x-ray machines, but the calibration factor is essential when measuring on the computer the image of the radiograph. This will allow for absolution of the measurements regardless of the magnification of the image on computer (Volchansky et al, 2006).

CHAPTER THREE

MATERIALS AND METHOD

3.1 Sample group

The sample group consisted of 30 sets of records of patients attending the University of the Witwatersrand Dental Hospital, Department of Orthodontics. The chronological age of the patient was dependent on the stage of the dentition. Records of patients in the mixed dentition stage were chosen. Selection of the sample group did not discriminate as to gender, and a random numbers of boys and girls were chosen. Records consisted of complete sets (upper and lower arches) of study casts and panoramic radiographs corresponding to the same stage of the dentition. Patient records were selected according to the following inclusion criteria:

- Good quality study casts and radiographs
- Age- patients had to be of the dental stage of development where the second deciduous molar teeth were present, i.e. the mixed dentition phase. The approximate age was 9-11 years derived from the patients treated in the Undergraduate Orthodontic Clinic, University of the Witwatersrand.
- Teeth to be measured were the:
  a) Second deciduous molar teeth in all four quadrants
  b) First permanent molar teeth in all four quadrants
  c) Developing second premolar tooth follicle in all four quadrants on radiograph

- All teeth were sound and preferably unrestored. If restored, no teeth with interproximal restorations were accepted. Teeth with obvious coronal fractures or interproximal wear facets were not considered.
- No anomalous tooth shapes were included

3.2 Experimental design

3.2.1. Study models:

Thirty cast study models were chosen. These were poured with ‘Special Orthodontic Selenor’. This is hard gypsum, type III conforming to ISO standard 6873 for orthodontic study models. A water: powder ratio of 26-28 cc of water: 100g powder was recommended by the manufacturer (Nova dental©) for mixing. The powder had a working time of one minute, provisional setting time of 6-7 minutes, and final setting time of 16-17 minutes. The setting expansion was 0.11% (negligible to distort measurements); with a compression resistance of 720 kg/cm^2**.** Models, as illustrated in Figure 3.1, were poured by the auxiliary staff of the School of Oral Health Sciences, University of the Witwatersrand, Johannesburg.

Figure 3.1– Example of a set of study casts of a patient in the sample group- maxillary cast (above) and mandibular cast (below).

The accuracy of a model cast from an impression is related to the dimensional stability of the impression and the cast. These are operator sensitive procedures, hence adequate attention to syneresis (shrinkage due to loss of water), and imbibition (expansion due to water absorption) should be exercised to obtain an accurate study cast. These models were chosen retrospectively, hence a standardised technique has been assumed. Hollinger et al (1984) investigated laboratory procedures and found that the distortion of the material and shrinkage remained unpredictable and not readily controlled by the operator.

Teeth to be measured were: the deciduous second molar tooth (DM), and the first permanent molar tooth (M1) in both maxillary and mandibular arches.

3.2.1.1 Instrumentation used:

Measuring instruments used are seen in Figure 3.2. These were:

- Digital 'vernier' calipers
- A pair of manual dividers with a screw to fix the distance being measured, and to minimise slipping of the divider arms once the distance had been set

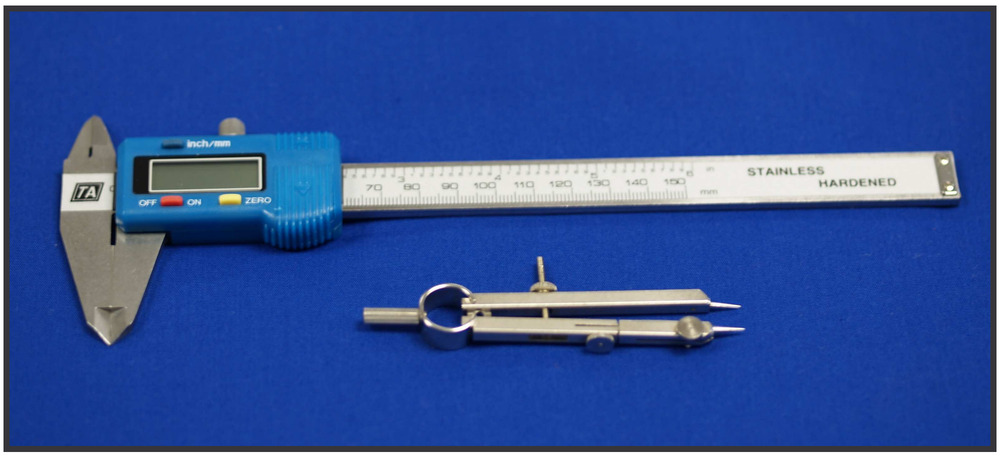


Figure 3.2– Digital vernier caliper (above), and a pair of manual dividers (below).

A) The vernier caliper

The digital vernier caliper is a variation to the traditional measuring caliper where a vernier scale has now been included. This allows for a more accurate measurement. This type of caliper is able to measure the internal and external dimensions of teeth on study casts. The scale included both metric and imperial measurements.

Measurement of teeth on study casts via the electric digital display vernier caliper simplifies reading of the value from the display. The display can be switched from ‘mm’ to ‘inches’ and has the function of zeroing the display at the beginning or anywhere along the slide. The slide of the digital caliper may also be locked using a lever or thumb screw (http://en.wikipedia.org/wiki/Caliper).

B) Pair of Dividers

The dividers were also used to measure teeth on the study casts. Measurements were difficult to perform and were not reproducible, thus the results were not included in this study.

3.2.1.2 Measurement parameters:

Measurements were taken on study casts from the occlusal aspect of the tooth from the mesial marginal ridge to the distal marginal ridge. This was in keeping with the mesio-distal dimension of the tooth as described by Kieser (1990). The sites measured on the study casts were:

- Mesio-distal dimension of the first permanent molar tooth (M1)
- Mesio-distal dimension of the second primary molar tooth (DM)

Both these sites are illustrated in Figure 3.3

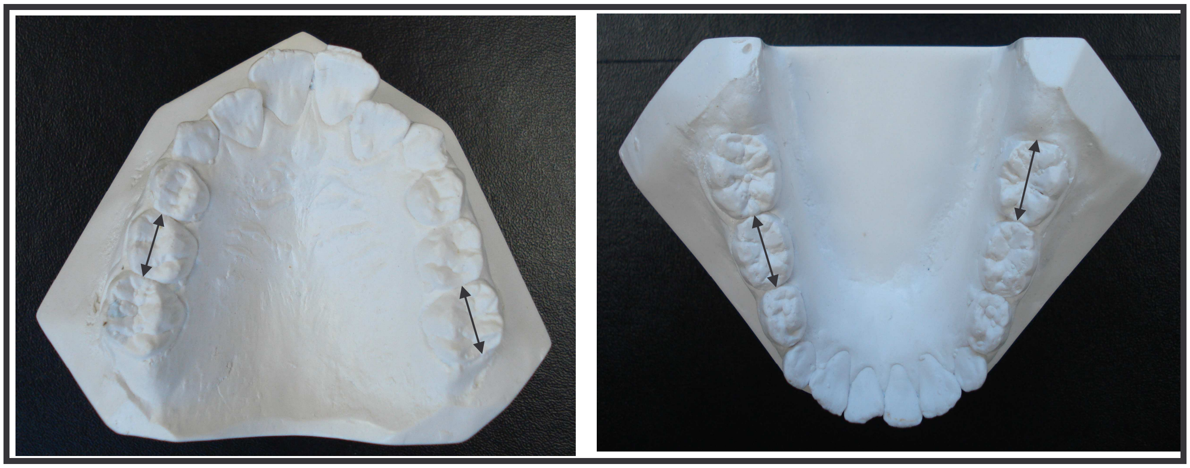


Figure 3.3– The measurement sites on the occlusal surfaces of teeth- DM is indicated on the left sides of both the maxillary study cast (left) and mandibular study cast (right). M1 is indicated on the right side of the maxillary study cast (left) and mandibular study casts (right).

Figure 3.4 – Measurement of tooth width with digital caliper

When measuring each tooth on the study casts as illustrated in figure 3.4, each measurements was taken three times, and the caliper reset at the start of each measurement.

3.2.2. Radiographs

The panoramic radiographs of the same patients corresponding to the same stage of the mixed dentition of their study casts were used. Radiographs were only chosen if the mesiodistal width of the teeth could be distinguished. One x-ray machine was used for the exposure of the radiographs: Siemens Orthophos CD (Model No D3200) in the Department of Radiology, School of Oral Health Sciences, University of the Witwatersrand.

3.2.2.1 Leica Q Win© System of Image Analysis

'Leica' is a United Kingdom based company. Leica QWin© is Leica's 'Windows' based Image Analysis toolkit which runs under the industry standard 'Microsoft Windows'. Image analysis is the science of making geometric and densitometric (measurement of density) measurements on images from any source. Image analysis first appeared in 1963 as a readily available technique. It was introduced with the Quantitative Television Microscope, which was designed by Metals Research Ltd. which later became part of Leica. Its early intention was for the quality control of micro structural measurements, but its usefulness in the biologic field soon became apparent where it was used for the measurement of the size of airspaces in the lung, as well as the counting of silver grains in autoradiographs. Since then, image analysis has expanded to the fields of anatomy through to zoology, as well as including image processing functions such as image filtering and enhancement (Leica QWin© User Guide).

Leica QWin© provides several classes of measurement, which includes the measurements of length, distance and area, which were the interactive measurements of interest to us.

3.2.2.2. Measurement parameters on the radiographs

- Panoramic radiographs were mounted onto an x-ray viewing box as seen in Figure 3.5.
- The image was edged with a square of black cardboard to reduce background glare.
- The Nikon Coolpix 990 digital camera was mounted onto a stand behind the light box as seen in Figure 3.6.
- The camera was ‘fixed’ to the stand to ensure stability while capturing the image.
- The distance of the camera from the image was fixed.
- The ‘macro’ feature of the camera was used to focus upon the image which was checked in the LCD screen before being captured. All samples were captured in this manner.
- Images were then uploaded onto the computer.

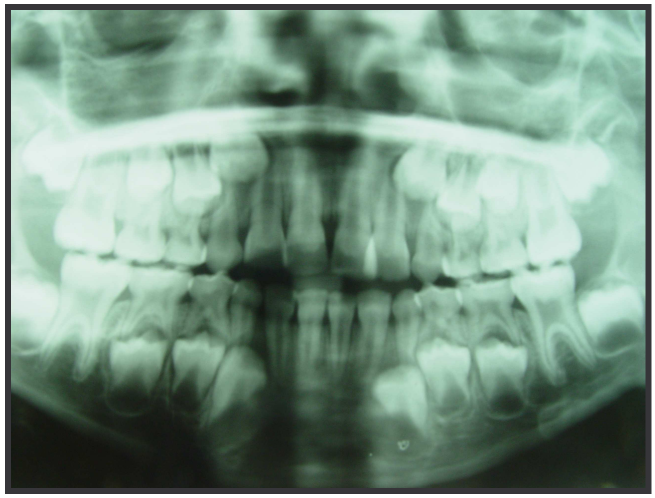


Figure 3.5 – Panorex radiograph illuminated on the viewing light box

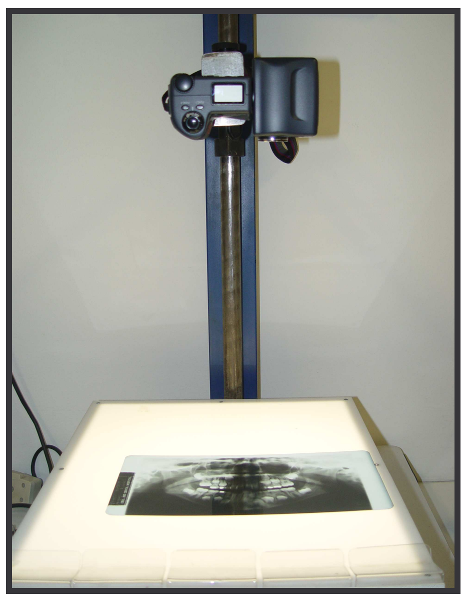


Figure 3.6– Mounted camera and radiograph on the viewing box

- The calibrated linear function of the Leica Q Win© Image Analysis System (Leica Imaging Systems, Ltd) was used to measure the radiographic images. Images were zoomed to provide better clarity during measuring. Measurement sites on the radiograph are illustrated in Figure 3.7 and detailed as follows:

Horizontal measurements:

1. Mesio-distal width of the second deciduous molar tooth (‘e’) in each arch (DM)
2. Mesio-distal width of the first permanent molar tooth (‘6’) in each arch (M1)
3. Mesio-distal width of the second premolar tooth (‘5’) follicle in its most reasonable mesiodistal dimension (P)
4. Inter-radicular distance of the ‘e’ tooth. This provided an idea of the amount of root resorption of the deciduous molar tooth (R), indicating the stage of eruption of the second premolar tooth (P).
5. Base of the ‘L’ marker (C2) for calibration purposes

Vertical measurements:

6. Cemento-enamel junction (CEJ) to the alveolar crest (AC) of the ‘e’ (DM). This additional measurement was used as a gauge to determine the degree of eruption. The additional measurement was however, not included in the statistical analysis.
7. Height of the ‘R’ marker (C1) for calibration purposes

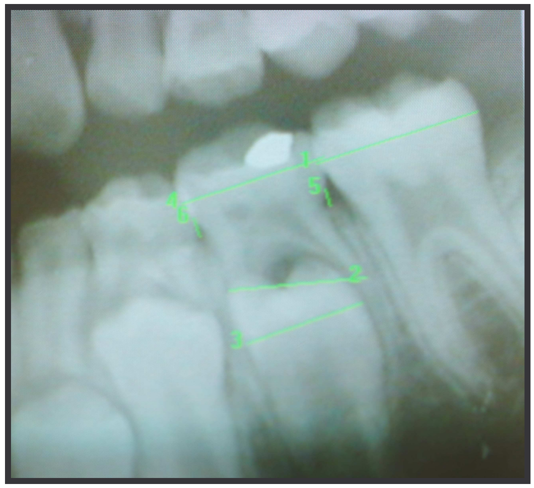


Figure 3.7- Measurement sites taken with the Leica QWin© System

The first permanent molar tooth was measured as a reference tooth. It was chosen because of its early eruption in the arch and it is present in the arch at the time of the second deciduous molar tooth. It is stable in a mesiodistal dimension.

3.2.2.3 Calibration of the Leica QWin© measuring tool

The basis of calibration of the measuring tool was to convert pixel units, which all frames are expressed as, to recognized units. A calibration factor was necessary for this. The equation used was as follows:

$$\textbf{Length (mm)} = \textbf{Length (pixels)} \times \textbf{calibration factor}$$

The calibration factor was expressed as mm/pixel. All measurement results presented by the programme were converted automatically into physical units according to the current calibration factor. Calibration was performed by enclosing an object of known dimension with a rectangular frame generated by QWin© (Leica QWin© User Guide).

Before any measurements were taken, the linear measurement tool of ‘distance’ on the Leica Q Win© programme necessitated calibration. This allowed for a standard to eliminate magnification of the image so that raw data could be adjusted to absolute measurements using a specified marker thus allowing the final measurements to be absolute regardless of visual magnification of the film.

The calibration procedure was carried out by measuring the specific dimensions of the digital or lead markers. Both the ‘height’ of the ‘R’ marker (C1) and the base of the ‘L’ marker (C2) were measured on the x-ray cassette as shown in figure 3.8. These measurements were taken with the vernier caliper. These dimensions were chosen because of the ease of identification of these dimensions and their greater repeatability. The height of C1 was measured at 5, 85 mm (average of three readings). The base of C2 was measured at 4, 08 mm, also an average of three readings. The corresponding dimensions of the markers as shown in Figure 3.9 were measured on the computer programme with the calibration factor set firstly at zero. Upon noticing the difference in readings, i.e. the actual measurement of 5.85 mm versus the computer measurement of 3.07 mm, the calibration factor was increased or decreased accordingly until the reading of the computer measurement equaled the actual measurement. In this way a calibration factor of 0.127 mm was obtained for measurements taken on the right hand side of the radiograph projected onto the computer.

Calibration factors for the left and right hand sides differed with the left hand side resulting in a calibration factor of 0.123mm.

Figure 3.8 – 'R' and 'L' digital markers on panorex cassette

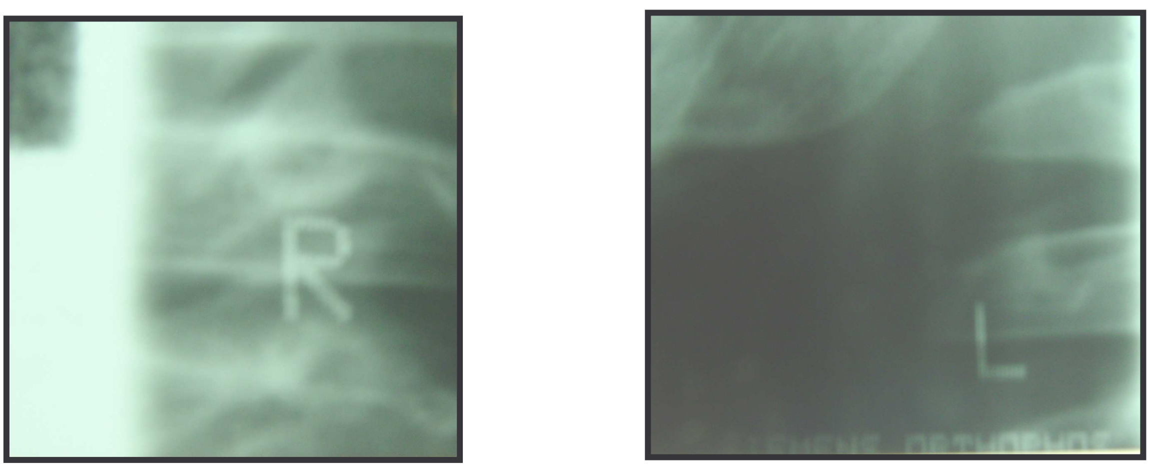


Figure 3.9 – 'R' and 'L' digital markers on panorex radiograph

Figure 3.10- Variety of lead markers: 'R' and 'L'

Calibration factors for the left and right lead markers were also determined. If a lead marker, as shown in Figure 3.10, was used on the particular radiograph, the corresponding calibration factor measured for the lead markers was used. The calibration factor also varied for the left (0.127mm) and right (0.128mm) sides. These markers were obtained from the Department of Radiology, School of Oral Health Sciences, University of the Witwatersrand, and were specific to the radiographic cassettes used at the time (www.medmac.co.za).

3.2.2.4 Measurement technique

The 'measure' icon was selected and the computer mouse used to delineate the mesiodistal width of the tooth. The value in millimeters was brought up onto the screen. At the end of each measurement, the table of measurements displayed was reset to zero, i.e. all previous measurements deleted, or the display may be cleared so that linear measurements on the screen are not superimposed or copied. Measurements were recorded to prevent loss of data and once the three measurements had been taken, the average value calculated, may be recorded.

A) <u>Intra examiner reliability - repeatability of measurements</u>

‘A dental measurement, be it linear or composite, is only as valuable as its “reliability”- the extent to which a measurement and its attendant technique are consistent. There are two very important properties of reliability: precision and accuracy’ (Kieser, 1990).

Precision refers to the repeatability of a measurement. The more precise the measurement, the more closely clustered about an average value will be the set of results. Accuracy is an estimation of how close the measured value is to the true value- how unbiased the measurement is. The relationship between the mean of a set of measurements and the true measurement, gives an idea of the accuracy of the measurement process as explained by Kieser (1990).

In order to establish the degree of reproducibility, ten repeat measurements of both the left and right digital markers, and first permanent molar tooth were taken. Measurements were taken with the

- Vernier caliper- this tool was used to measure the left and right digital markers on the actual panorex cassette and on the panoramic radiograph illuminated on the light box. On the study cast, the caliper was used for the ten repeat measurements of the first permanent molar tooth.

- Leica QWin© Image Analysis System- the digital left and right markers on the radiograph projected onto the computer was measured. The mesio-distal width of the first permanent molar in all quadrants was also measured as a comparison to the study model measurements.

In this way, the standard deviations of the true score of the measurements taken on study cast with calipers or on computer with the Leica QWin© computer image analysis system were assessed. The low standard deviation of measurements of the teeth, ranging from 0.02- 0.12, concluded a repeatable technique of measurement for both methods.

B) Co-efficient of variation

For measurements of the first permanent molar tooth on the study cast and the computer, a co-efficient of variation of a maximum value of 1.0%, and a minimum value of 0.3% has been demonstrated. These values are displayed in Table 3.1. The value of 1.0% occurred in the maxilla regarding the computer measurement with the Leica QWin© System, and the value of 0.3% occurred in the mandible regarding the caliper measurements on the study cast. The standard deviation of measurements ranged from 0.03 mm found with the study cast measurement in the mandible, to 0.11 mm for the computer measurement in the maxilla.

Table 3.1 – Mesio-distal measurements on study cast and computer of the first permanent molar tooth with left and right sides combined

Computer	n	mean	SD	range	Co-efficient of Variation
Maxilla	20	10.53	0.11	10.35-10.76	1.0%
Mandible	20	10.91	0.10	10.64-11.03	0.9%
Model	**n**	**mean**	**SD**	**range**	**Co-efficient of Variation**
Maxilla	20	10.31	0.05	10.23-10.39	0.5%
Mandible	20	10.34	0.03	10.28-10.40	0.3%

There were statistically significant readings ($P<0.0001$) at the site of measurement (study cast and computer image) and for the jaw measured, i.e. the maxilla and mandible. There was no statistical significance for the sequence of measurement, or for left or right sides ($P<0.05$). These values are displayed in Table 3.2.

Table 3.2 –General linear model (GLM) analysis for mesio-distal measurement of the left and right sides combined.

	Degrees of freedom	F value	P value
Sequence	9	0.12	0.9991
Site	1	198.82	∗<0.0001
Jaw	1	52.91	∗<0.0001
Side	1	0.04	0.8444

∗P<0.05 is statistically significant.

‘Sequence’= sequence of measurement; ‘Site’ = study cast and radiograph; ‘Jaw’ = maxilla and mandible; ‘Side’ = left and right.

The co-efficient of variation for the mesio-distal measurement of the first permanent molar on both sides with both methods of measurement, ranged from 0.2%-1.2%. All the computer measurements exhibited the higher values of co-efficient of variation, and the study cast measurement the lower values of co-efficient of variation. This was because the tooth dimension measured on the study cast was more strictly defined. The dimension of the tooth on the computer image of the radiograph allowed one more relative freedom to measure the distance between the contact points of the tooth at the most bulbous point. This area was not accessible on the study casts. These values are detailed in Table 3.3 below.

Table 3.3 – Mesio-distal measurement for first permanent molar tooth measured separated by jaw and side.

	n	x	SD	range	Co-efficient of Variation
Maxilla-left					
Computer	10	10.52	0.09	10.35-10.64	0.9%
Model	10	10.35	0.03	10.23-10.33	0.3%
Maxilla-right					
Computer	10	10.55	0.13	10.38-10.76	1.2%
Model	10	10.27	0.04	10.23-10.33	0.4%
Mandible-left					
Computer	10	10.89	0.12	10.64-11.03	1.1%
Model	10	10.35	0.02	10.31-10.39	0.2%
Mandible-right					
Computer	10	10.92	0.07	10.78-11.00	0.7%
Model	10	10.34	0.04	10.28-10.40	0.3%

The low co-efficient of variation values, i.e. 0.2%- 1.2%, verified a repeatable measurement at 1.1% of 10.55mm = 0.12mm, and 0.2% of 10.35mm = 0.21mm. These values were clinically insignificant even at the greatest co-efficient of variation value as determined by the standard deviation.

For the measurement of the left 'L' and right 'R' markers at the three different sites, the results for statistical significance are detailed in Table 3.4. The statistical significance of measurements was found only at the site of the measurement ($P<0.0001$). There was no statistical significance for the sequence of which the measurement was taken ($P=0.9704$).

Table 3.4- General linear model (GLM) analysis for length of the left marker.

	Degrees of freedom	'F' value	'P'value
Sequence	9	0.28	0.9704
Site	2	32.98	*<0.0001

*P<0.05= statistically significant

'Sequence'= sequence of measurement; 'Site' = cassette, light box or radiograph on computer

Table 3.5 details the mean values, standard deviations, range of measurements and co-efficients of variation of the measurement of the left and right markers measured at all three sites. The co-efficient of variation ranged from 0.7% for the width of the left marker on the light box, to 3.7 % for the width of the right marker on the computer. The width of the right marker on the radiograph on computer was the most difficult measurement to perform as the distance was not clear and could not be reproduced with any level of confidence.

Table 3.5 – Measurements for width and length of left and right markers measured on cassette, light box and on the computer.

	n	mean	SD	range	CV
Length- left					
Cassette	10	6.05	.06	5.97-6.14	1.0%
Lightbox	10	6.03	0.06	5.93-6.10	1.0%
Computer	10	5.79	0.08	5.66-5.92	1.4%
Width- left					
Cassette	10	4.24	0.04	4.16-4.29	0.9%
Lightbox	10	4.26	0.03	4.21-4.30	0.7%
Computer	10	3.93	0.07	3.82-4.07	1.7%
Length- right					
Cassette	10	5.97	0.12	5.85-6.30	2.0%
Lightbox	10	6.03	0.06	5.94-6.11	1.0%
Computer	10	5.92	0.09	5.72-5.92	1.5%
Width- right					
Cassette	10	3.28	0.08	3.19-3.46	2.4%
Lightbox	10	3.39	0.06	3.28-3.46	1.7%
Computer	10	3.54	0.12	3.18-3.56	3.7%

∗CV= coefficient of variation

3.3 Statistical analysis

Statistical analysis was done using SAS for Windows (version 9.1, SAS Institute Inc, Cary, N.C, USA) with statistical significance set at $P<0.05$. The analytical test used was a multivariate General Linear Models analysis on the raw data to determine significant effects of the independent variables jaw, side of the jaw, measurement site, target (study cast or radiograph) and method of measurement (vernier caliper or Leica QWin© System) on the dependent variable measurement. Differences in measurement for the different targets at the same site were calculated together with the mean values and standard deviations. The paired data was analysed using the Student's paired't' test to look for significant differences at the same measurement sites in each jaw for each target.

CHAPTER FOUR

RESULTS

4.1 Measurements

Measurements were carried out at two sites per side on each jaw, on each study cast, and at six sites per side per jaw on each radiograph. This yielded a total number of eight measurements on the study casts, and twenty four measurements on the radiographs projected onto the computer, and measured with the Leica QWin© Image Analysis System. Once the measurements were begun, it was found that there were certain sites where it was not possible to be certain about the landmarks. The difficulty in identification of landmarks on computer was due to the overlapping of structures which occurred more frequently in the maxilla as noted by Duterloo (1991). This led to fewer measurements on the targets, i.e. the study casts or projected radiographs. There was no definite different number of measurements on either target. A summary of measurements of the different sites at different targets are shown in Tables 4.1-4.6. All values are rounded to the closest second decimal point.

4.2. First permanent molar

4.2.1. Vernier caliper measurements

- The summary of measurements of the first permanent molar on the study cast is described in Table 4.1.
- Measurements were taken in millimetres.
- 30 teeth were measured on the left hand side of the study casts, and 29 on the right hand side of the study casts. This applied to the corresponding sides of both maxillary and mandibular arch measurements.

A) Maxilla

- Mean scores for teeth on the left hand side averaged 10.45 mm (SD=0.67), and 10.58 mm for teeth on the right hand side (SD=0.73).
- The standard deviation for values on the left hand side was 0.67mm, and 0.73mm on the right hand side.
- Values ranged from 9.20 mm-11.62 mm on the left side, and from 9.16 mm-12.19 mm on the right hand side.

B) Mandible

- The mean measurement for the molars on the left hand side were 10.84 mm (SD= 0.77), and right hand side was 10.88 mm (SD=0.92).
- Standard deviations for measurements on the left hand side were 0.77mm on the left and 0.92mm on the right hand sides.

- The range of values were 9.36 mm-12.09 mm on the left hand side, and 9.08 mm-12.9 mm on the right hand side

Table 4.1: Summary of measurements (mm) of first permanent molar width using the Vernier caliper on the study casts

Maxilla	**Left**	**Right**
Number	30	29
Mean	10.45	10.58
Standard deviation	0.67	0.73
Median	10.49	10.53
Minimum	9.20	9.16
Maximum	11.62	12.19
Mandible	**Left**	**Right**
Number	30	29
Mean	10.84	10.88
Standard deviation	0.77	0.92
Median	10.67	10.78
Minimum	9.36	9.08
Maximum	12.09	12.93

4.2.2 Leica QWin© measurements

In Table 4.2, the summary of measurements of the first permanent molar tooth as measured on the computer with the image analysing system is shown. The reduced number of samples in the maxilla and the mandible on both side, was due to an inability to identify the tooth accurately due to the overlapping of structures.

A) Maxilla

- The mean measurements of the first permanent molar were found to be 12.10mm on the left hand side, and 12.05mm on the right hand side.
- The standard deviation of values on the left hand side was 1.03mm and 0.95mm for values on the right hand side.
- The values ranged from 10.48 mm-14.51 mm on the left hand side, and 9.83 mm – 13.71 mm on the right hand side.

B) Mandible

- The mean measurements of the mesiodistal dimension of the first permanent molar were 13.36 mm on the left hand side, and 12.96 mm on the right hand side.
- The standard deviation for values was 1.27mm on the left hand side, and 1.11mm on the right hand side.
- The range of values was from 11.45 mm- 16.19 mm on the left hand side, and 10.73 mm- 14.86 mm for values measured on the right hand side.

The range of measurements for the first permanent molar tooth in both the maxilla and the mandible was greater on the computer at 6.36mm than on the study cast at 3.85mm. This was due to the definition of the tooth measured on the study cast in comparison with the relative freedom of the computer mouse in pin pointing the convexity of the contact points. These mesio-distal points determined the width from which the teeth were measured on the computer.

Table 4.2: Summary of measurements (mm) of first permanent molar width on panoramic radiographs using the Leica QWin© Image Analyzing System on the computer

Maxilla	**Left**	**Right**
Number	27	28
Mean	12.10	12.05
Standard deviation	1.03	0.95
Median	11.68	12.23
Minimum	10.48	9.83
Maximum	14.51	13.71
Mandible	**Left**	**Right**
Number	28	29
Mean	13.36	12.96
Standard deviation	1.27	1.11
Median	13.06	12.93
Minimum	11.45	10.73
Maximum	16.19	14.86

4.3. Second deciduous molar tooth

4.3.1 Vernier caliper measurements

Table 4.3 highlights the readings of mesio-distal tooth width of the second deciduous molar tooth measured from the study casts. A total number of 29 samples were measured for both sides and both jaws. On the right hand side of the maxilla, a maximum of thirty sets of casts were measured.

A) Maxilla

- The mean readings of the molars was found to be 8.90 mm and 8.98 mm respectively The values ranged from 7.72 mm- 9.89 mm on the left hand side, and 7.68 mm- 10.25 mm on the right side.
- The standard deviations for measurement taken on the left hand side were 0.55mm and 0.59mm on the right hand side.
- The values taken ranged from 7.72mm – 9.89mm on the left hand side, and ranged from 7.68mm – 10.25mm on the right hand side.

B) Mandible

- The mean readings for the second deciduous molar were 9.85 mm on the left hand side and 9.87 mm on the right hand side.
- The standard deviation for readings on both the left and right hand sides was 0.59mm.
- The values ranged from 8.58 mm – 10.82 mm on the left side, and 8.54 mm- 10.99 mm on the right side.

Table 4.3: Summary of measurements (mm) of second deciduous molar width using the Vernier caliper on study casts

Maxilla	**Left**	**Right**
Number	29	30
Mean	8.90	8.98
Standard deviation	0.55	0.59
Median	8.87	8.94
Minimum	7.72	7.68
Maximum	9.89	10.25
Mandible	**Left**	**Right**
Number	29	29
Mean	9.85	9.87
Standard deviation	0.59	0.59
Median	9.81	9.79
Minimum	8.58	8.54
Maximum	10.82	10.99

4.3.2 Leica QWin© measurements

Table 4.4 highlights the readings of mesio-distal tooth width of the second deciduous molar tooth measured from the radiograph projected onto the computer with the Leica QWin© Image Analyzing System. The maximum number of samples (30) was used for measurement of teeth on the left side in both the maxilla and the mandible, but a reduced number of samples were measured on the left hand sides of both the maxilla (28) and the mandible (29).

A) Maxilla

- Mean measurements of the tooth were found to be 9.78 mm on the left hand side, and 9.86 mm on the right hand side.
- The standard deviation for measurement taken on the left hand side was 1.15, and 1.09 on the right hand side.
- Values ranged from 7.5mm – 11.85mm on the left hand side, and from 7.77mm – 12.53mm on the right hand side.

B) Mandible

- Mean measurements for the second deciduous molar were found to be 11.58 mm on the left hand side, and 11.54 mm on the right hand side.
- The standard deviation of values on the left hand side was 1.26, and 1.16 on the right hand side.
- The values ranged from 8.69mm – 13.71mm on the left hand side, and 9.74mm – 13.84mm on the right hand side.

Table 4.4: Summary of measurements (mm) of second deciduous molar width on panoramic radiographs using the Leica QWin© Image Analyzing System on the computer

Maxilla	**Left**	**Right**
Number	28	30
Mean	9.78	9.86
Standard deviation	1.15	1.09
Median	9.83	9.8
Minimum	7.5	7.77
Maximum	11.85	12.53
Mandible	**Left**	**Right**
Number	29	30
Mean	11.58	11.54
Standard deviation	1.26	1.16
Median	11.61	11.47
Minimum	8.69	9.74
Maximum	13.71	13.84

4.4 Second premolar tooth

The width of the second premolar tooth was only measured on the radiograph projected onto the computer, as the unerupted tooth was not present on the study casts. The values are set out in Table 4.5.

4.4.1 Leica QWin© measurements

A) Maxilla

- A total of 27 samples were measured on the left hand side, and 29 on the right hand side.
- The mean measurements recorded on the left were 8.97mm, and 8.79mm on the right hand side.
- The standard deviation of the measurements taken on the left hand side was 1.79mm and 1.16mm on the right hand side.
- The range of values on the left hand side was from 6.54mm – 15.10mm, and 6.67mm – 10.95mm on the right hand side.

B) Mandible

- A total of 29 samples were measured on the left and 30 samples on the right hand side.
- The mean values for measurements taken on the left hand side were 9.15mm and 8.95mm on right sides.
- The standard deviation for the measurements was 1.10mm on the left hand side, and 0.99mm on the right hand side.
- Values ranged from 6.94mm – 11.44mm on the left and ranged from 6.62mm – 10.81mm on the right side.

Table 4.5: Summary of measurements (mm) of the second premolar width on panoramic radiographs using the Leica QWin© Image Analyzing System on the computer

Maxilla	**Left**	**Right**
Number Mean Standard deviation Median Minimum Maximum	27 8.97 1.79 8.70 6.54 15.10	29 8.79 1.16 8.74 6.67 10.95
Mandible	**Left**	**Right**
Number Mean Standard deviation Median Minimum Maximum	29 9.15 1.10 9.29 6.94 11.44	30 8.95 0.99 9.01 6.62 10.81

4.5 Leeway space measurements:

The leeway space measurement was calculated by subtracting the width of the second premolar, measured on the computer projected radiograph with the Leica QWin© System, from the width of second deciduous molar tooth measured with the same technique. These measurements are shown in Table 4.6.

A) Maxilla

- The total number of samples measured was 27 on the left hand side, and 29 on the right hand side.
- The mean values were calculated at 0.81 mm for the leeway space on the left hand side, and 1.08 mm for the leeway space on the right hand side.
- The standard deviation for the leeway space calculated for on the left hand side was 1.42mm and 0.69mm on the right hand side.
- Values ranged from (-) 3.95mm – 3.15mm on the left hand side, and ranged from (-) 0.40mm – 2.73mm on the right hand side.

B) Mandible

- The mean value for leeway space calculated on the left hand side was 2.43 mm and 2.59 mm on the right side.
- The standard deviation was 1.05mm on the left hand side, and 0.80mm on the right hand side.
- The range of values for leeway space on the left was (-)0.86mm – 4.39mm on the left and 1.03mm – 4.11mm on the right side.

Table 4.6: Summary of measurements (mm) of leeway space using the Leica QWin© Image Analyzing System on the computer

Maxilla	**Left**	**Right**
Number	27	29
Mean	0.81	1.08
Standard deviation	1.42	0.69
Median	0.91	1.05
Minimum	-3.95	-0.40
Maximum	3.15	2.73
Mandible	**Left**	**Right**
Number	29	30
Mean	2.43	2.59
Standard deviation	1.05	0.80
Median	2.43	2.64
Minimum	-0.86	1.03
Maximum	4.39	4.11

4.6 Mean differences between all the measurements taken

The mean differences between the measurements taken on the study casts with the vernier calipers, and those taken from the computer image of the radiograph with the Leica QWin© Image Analysis System were calculated via the General Linear Model (GLM) analysis. The statistical significance was determined by the means comparison test for paired measurements which is the Student's paired't' test.

4.6.1 First permanent molar tooth

The Student's paired't' test results for the first permanent molar tooth is seen in Table 4.7.

- A significant 'P' value for the independent variables of 'individual', 'jaw' and 'method' (P< 0.0001) was found. The independent variable of 'side' was not statistically significant (P=0.3195). A value of P< 0.05 was taken as significant.

Table 4.7 General Linear Model (GLM) results for first permanent molar width

	Degrees of freedom	F	P
Individual	29	5.35	<0.0001*
Side	1	1.00	0.3195
Jaw	1	46.02	<0.0001*
Method	1	359.60	<0.0001*

* P< 0.05 is statistically significance

4.6.2 Second deciduous molar tooth

A) Maxilla

General linear model (GLM) analysis of measurements for the second deciduous molar tooth in the maxilla is seen in Table 4.8. Separation of these values according to each jaw enabled more detailed insight into the specific values of leeway space in each jaw.

- The ‘P’ value was significant for the ‘individual’ measured and the ‘method’ of measurement (caliper or Leica QWin©), but not for the independent variable of ‘side’ (left or right).

Table 4.8 General Linear Model (GLM) results for second deciduous molar width in the maxilla

	Degrees of freedom	**F**	**P**
Individual	29	2.99	<0.0001*
Side	1	0.26	0.6137
Method	1	46.14	<0.0001*

* P< 0.05 is statistically significance

B) Mandible

- In the mandible, as seen in Table 3.9, only the ‘method’ of measurement displayed a statistical significance of P<0.0001. This value was the same as the statistical significance seen for the independent variables of ‘individual’ and ‘side’ measured in the maxilla
- The independent variable of the ‘individual’ measured had a P value of 0.0004, and the ‘side’ measured had a P value of 0.8561. These values were not statistically significant.

Table 4.9 General Linear Model (GLM) results for the second deciduous molar width in the mandible

	Degrees of freedom	F	P
Individual	29	2.60	0.0004
Side	1	0.03	0.8561
Method	1	138.54	<0.0001*

*P<0.05 is statistically significant

4.6.3 Leeway space

The analysis for leeway space calculated for each jaw is shown in Tables 4.10 and 4.11.

A) Maxilla

- The ‘P’ values were 0.1861 for the individual measured, and 0.3095 for the ‘site’ measured. These values are shown in Table 4.10, and were not statistically significant.

Table 4.10 General Linear Model (GLM) results for leeway space measurements in the maxilla

	Degrees of freedom	F	P
Individual	29	1.42	0.1861
Side	1	1.08	0.3095

P< 0.05 is statistically significance

B) Mandible

- Statistical significance was only seen in the mandible for the individual as the independent variable (P=0.0002).
- The 'side' as an independent variable displayed a 'P' value of 0.2715. The values are shown in Table 4.11.

Table 4.11 General Linear Model (GLM) results for leeway space measurements in the mandible

	Degrees of freedom	F	P
Individual	29	3.99	0.0002*
Side	1	1.26	0.2715

*P<0.05 is statistically significant

CHAPTER FIVE

DISCUSSION

The aim of this study was to determine whether the Leica QWin© System of Image Analysis was an accurate method of measuring tooth size on computerised radiographic images, enabling the calculation of leeway space. These computer-generated measurements were compared with measurements of the same teeth taken with vernier calipers on study casts. The size differential between the second deciduous molar and the unerupted second premolar tooth visible on the radiograph was used to calculate the leeway space in the arches.

5.1 Findings of the study

Both methods of measurement showed that the mandibular teeth were larger than the corresponding maxillary teeth as noted in Tables 4.1- 4.4. This finding was in keeping with the size differential of the maxillary and mandibular deciduous and permanent molar teeth as displayed in the text of Dental Anatomy and Occlusion (Kraus et al, 1969). These comparisons can be seen in the relevant tables in Appendix Five. The measurements of the teeth were not separated according to gender, and the population group of the sample was not mentioned.

The measurements of the mesio-distal dimensions of the crowns of all the teeth were greater when taken with the Leica QWin© System compared with those recorded on the study models using the vernier calipers. With the Leica QWin© System the permanent mandibular first molar tooth recorded a mean difference of measurement of 2.52mm on the left hand side and 2.08 mm on the right hand side when compared with the mean measurement for the same tooth on the same side measured with the vernier caliper. The maxillary first permanent molar tooth showed a difference of 1.65mm on the left hand side, and 1.47mm on the right hand side, whilst the mean widths of the second deciduous molar teeth recorded by computerised measurement were 1.73mm greater on the left side in the mandible and 1.67mm greater on the right hand side. In the maxilla, these values were 0.68mm on the left hand side, and 0.92mm on the right hand side. There was a wider range of measurements of the teeth taken with the Leica QWin© method than with the digital vernier calipers. These data are also displayed in Tables 4.1-4.4.

The smaller tooth widths recorded on the study casts may have been due to the restricted access for the beaks of the vernier caliper into the embrasure spaces between the plaster teeth. The linear measurements recorded of the computerised images of the teeth on panoramic x-rays with the Leica QWin© System were taken of the mesio-distal width of the tooth seen radiographically. This was from the greatest convexity of the mesial contact point of the tooth, to the corresponding distal point. These areas of contact of the teeth were not readily accessible for measurement on the study cast.

The wider range of measurements of the teeth taken with the Leica QWin© System was due to the relative freedom the operator had with the measuring tool which was the computer mouse. When each measurement was repeated, the point of the maximum curvature of the contact surface of the tooth displayed on the screen was newly discerned. This relative freedom of measurement was not available for the measurements taken on the study cast. This was reflected in the higher standard deviation of measurements of the computerised images of the teeth on panoramic x-ray films recorded with the Leica QWin© System (standard deviations of 0.95-1.79). The standard deviations of the measurements of the teeth taken on the study casts with the calipers were lower at 0.55-0.92.

The measurements of the deciduous second molar and the unerupted second premolar teeth with the Leica QWin© Image Analysis System allowed for the calculation of the leeway space. In the maxilla, the mean values of leeway space were calculated as 0.81mm on the left and 1.08mm on the right hand side. In the mandible, these values were 2.43mm on the left and 2.59mm on the right hand side. These figures are similar to those reported by Nance (1947) and by Bishara et al (1988).

5.2 Methods of measuring tooth dimension

5.2.1 Calibration for correction of measurements

In this study two types of markers on the panoramic x-rays were used to calibrate the measuring tool to ensure corrected and accurate measurements. These markers were the standard marking system used for identification of side on the radiograph. As archived records were used, the markers were identified as the only measurable constant at the time of radiographic exposure.

a) Digital markers- The letter markers ‘L’ and ‘R’ were imprinted on the cassette in which the panoramic film was housed during exposure. Ideally, a marker of known dimension, in both horizontal and vertical planes, should be placed onto the cassette at the time of exposure to calibrate the measuring tool.

b) Lead markers- These were also ‘L’ and ‘R’ markers secured to the cassette at the time of exposure of the radiograph. These markers were also carefully measured in both dimensions to calibrate the measuring tool.

The calibration of the measuring tool was specific to the type of marker on the film as well as being specific to the side of the film on which the marker was present. These markers were also used when performing the repeat measurements in order to assess the intra-examiner repeatability. The repeatability of the corrected measurements was demonstrated statistically by a low co-efficient of variation at 1.2%.

5.2.2 Comparison with other methods

Other researchers (Hunter and Priest, 1960) compared measurements of tooth size recorded with different instruments, for example,

- a pair of engineering dividers with a wheel screw adjustment
- a millimeter scale to allow readings in tenths of millimetres
- a regular Helios style sliding caliper with a Vernier scale as well as a Boley gauge.

The measurements were taken on soaped and on unsoaped study casts. The tooth width measured on the study cast was compared with the clinical measurement of the tooth taken in the mouth. It was found that measurements with the dividers were on average 0.1mm larger than those taken with the sliding calipers. The caliper measurements were found to be the most accurate of all the measurement tools used. Brooke et al (1986) compared the measurements of tooth size on study casts taken with an image analysing system (Toltec Dentiscan©, Toltec Computer Ltd., Cambridge England) with those measurements taken using a dial caliper. The study cast was placed on a calibrated stage, digitized and displayed on a monitor. The outlined periphery of each tooth was viewed occlusally, over which cross hairs were aligned and superimposed. The co-ordinates of the contact points were stored and the mesiodistal widths of the teeth were calculated. It was found that the image analysis measurements were larger than those taken directly from the study cast with dial calipers. This is in keeping with the results of the current study. Brooke et al (1986) suggested that the differences were due to the difficulty of full access into the interproximal embrasures of the plaster teeth with the beaks of the caliper in comparison with the ready identification of the contact points of the teeth which were more clearly displayed on the monitor. Mullen et al (2007) reported that the mesio-distal contact points of the teeth on the digital electronic models they measured were not always easy to identify. These digital electronic model measurements on computer were compared with measurements taken with digital calipers on study casts. Their computer measurements were corrected for magnification by using a factor calculated from the actual measurements of ball bearings and those taken on the computer images (Mullen et al, 2007).

Mok and Cooke (1998) evaluated the DigiGraph™ Workstation which uses sonic digitisation to measure the linear sizes of teeth on study casts. In this way, they attempted to prove a method of measuring teeth without using x-rays, thus reducing radiation exposure to the patient. The measurements were corrected for magnification by reference to the pre-calibrated base upon which the study cast was placed on the 'Workstation'. The teeth on the study casts were also measured directly with digital calipers. When the two sets of data were compared, the measurements did not correspond. The sonic method overestimated the size of the teeth in both the maxilla and the mandible. There was a significant difference of 50% of the tooth size between the measurements with the two systems. The authors concluded that there was a smaller standard deviation in the data derived with the caliper measurements.

Amongst these previous studies, the Digital Method of measurement of teeth on digitized study casts was used by Paredes et al (2006) in order to predict the size of unerupted teeth. The mesiodistal tooth widths were measured from the digitized study casts with a computer mouse as the measuring interface. The technique was accurate in the prediction of tooth size when the mesiodistal width of the specific reference tooth was known. Teeth in the upper arch were better predictors than those in the lower arch, and the upper central incisors were better predictors than the upper lateral incisors. The advantage of this technique was that the tooth sizes in either arch could be estimated (Paredes et al, 2006).

Khan (2006) evaluated the accuracy of the Tanaka and Johnston (1974) tables for the prediction of the mesio-distal crown widths of unerupted canines and premolar teeth when applied to a South African Black population. The four mandibular incisor teeth were measured by means of an electronic vernier caliper on 110 study casts. The predicted sizes of the canines and premolars were calculated. These teeth were also measured directly enabling a comparison between the predicted values and the actual values. Khan (2006) found that the prediction values were not applicable to his study sample. There was an under-prediction of the canines and premolars in both the maxilla and the mandible for male subjects, and an over-prediction of tooth size for female subjects, necessitating amendments to the equations. These amendments have been recommended by Khan (2006) who formulated a prediction equation for people of a mixed South African Black population.

Closest to this study, the work of Volchansky et al (2006) has shown that linear measurements of the images of teeth on panoramic radiographs could be taken in the posterior region. The study also used the Leica QWin© System of Image Analysis to measure teeth in the posterior region. For these measurements to be accurate, it was necessary that the ‘raw data’ was corrected for the specific magnification factor. A marker known in size, calculated at 0.25 inch (6.35mm), was used to calibrate the measuring tool of the computer programme. This marker was placed on the buccal surface of the upper first permanent molar of the dry skull, and was radiographically exposed at the same time as the radiograph was exposed. The marker was measured once again when the radiograph had been exposed and uploaded onto the computer. The magnification was then calculated. The study concluded that the panoramic radiographs could be used to confidently measure teeth with the Leica QWin© System in the posterior areas of the mouth provided that measurements were corrected for magnification and that the patient was correctly positioned in the focal trough at the time of radiographic exposure.

5.2.3 Problems encountered while measuring

- On the study casts the distal marginal ridge of the first permanent molar tooth was not always easily discerned. One of the reasons for this was that the definition of this margin of the tooth on the study casts was dependent upon the degree of eruption of the tooth. Another problem was that if the base of the study cast had been trimmed too close to the tooth, placement of the beak of the digital caliper at the distal margin was awkward.

- On the panoramic films, the overlapping of adjacent teeth resulted in an uncertain identification of the exact contact points of the teeth. All measurements were repeated three times, and the average value used in an attempt to reduce the variability of results.

5.2.3.1 Factors influencing accuracy of measurements

The images of teeth on radiographs should be well defined. This is essential for the accurate delineation of mesiodistal dimensions of the teeth. Criteria for selection of the study casts should include the requirement of the presence of well defined margins of all teeth to be measured. This would allow adequate access for the beaks of the digital vernier caliper or hand instrument being used. The mesio-distal landmarks on the teeth on the study casts and on the images of the teeth on the computerised x-rays should correspond. This would enable more accurate measurements of tooth size. This would eliminate the large discrepancy of tooth width measurements which was related to different mesial and distal points having been measured from on the radiographs and on the study casts.

The enlargement of the image of the tooth on the panoramic radiograph is an important factor to consider when measuring tooth size. The work of Volchansky et al (2006) has emphasized the correct positioning of the patient in the focal trough of the machine when exposing the panoramic radiograph and the importance of correcting for the magnification in the posterior region. In this study, the markers used for the correction of magnification were not placed at the same area as the tooth being measured as they were in the study by Volchansky et al (2006). In the majority of panoramic radiographs in this study, there was a notable broadening of the horizontal dimension of the teeth in the buccal segments. This was due to the incorrect patient positioning of the patient in the focal trough of the machines as explained by Duterloo (1991) and emphasized by Volchansky et al (2006). The improper positioning of the patient in the bucco-lingual dimension of the focal trough effectively increases the horizontal dimension of the images on the radiograph (Duterloo, 1991). The markers on the radiographic cassette on the left and right hand sides were not affected by this incorrect positioning of the patient. This meant that the marker was not broadened in the horizontal dimension as was the tooth in the posterior region of the radiograph. This would mean that even though the calibration factor of the measuring tool was specific to the side, more relevant to the correction of the measurements was that the marker be specific to the site on the patient and not the cassette. A single calibration factor calculated from the marker isolated at the periphery of the cassette may not have been effective in providing for the differences in magnification at different areas of the film

5.3 Future research

A longitudinal study comparing the calculated values of leeway space of a patient using the Leica QWin© measurements of teeth with the actual leeway space gained in the arches of the same patient would be valuable. This would be more definitive in determining the accuracy of the Leica QWin© Image Analysis System as a method of measuring teeth from the images of teeth on the computerised panoramic radiograph. Proper patient positioning at the time of panoramic radiographic exposure, the use of localized and measured markers on the radiograph, the correct calibration of the measuring tool of the Leica QWin© System and the standardization of the measuring points on the teeth on the study casts and the radiograph are essential areas to be noted. This would ensure that these errors that were identified in this study would be eliminated.

CHAPTER SIX

CONCLUSIONS

- When the two different methods of measurement were compared, the tooth size measurements with the Leica QWin© System were greater than those taken with the digital vernier caliper. This was thought to be due to the convexity of the mesio-distal contact point being visible on the computer images of the teeth, but not on the teeth on the study casts. The magnification of the image on the computer and the relative freedom of the measuring tool on the screen more readily allowed for the identification of the mesio-distal width of the teeth taken from the convexity of the mesio-distal contact point of the tooth.
- The differences were also due to the increased horizontal dimension of the teeth in the buccal segments of the arch on radiograph due to improper patient position during the radiographic exposure. This resulted in distorted images of the teeth.
- Mandibular teeth were larger than maxillary teeth when measured manually (digital vernier caliper) and the electronically (Leica QWin©). This was in keeping with the differences in size of the molar teeth in the mandibular and maxillary arches reported by Kraus et al (1969).
- Measurements of teeth were easier to perform using the Leica QWin© System of Image Analysis as compared with the digital calipers. This was in terms of the total time taken to measure the teeth and calculate the leeway space. The cost of the imaging analysis programme is hoped to be offset by the time saving it affords. In total, the system was simpler to use, and in keeping with technological advancements.

- The low value of intra examiner error (co efficient of variation of 0.2%- 1.2%) attests to the repeatability of the measurements. A value of 1.2% of a 10.55mm tooth measurement is 0.12mm indicating that even at the highest co-efficient of variation, the value was clinically insignificant. According to Proffit (2000), when estimating tooth size, a difference of less than 1.5mm should not be considered clinically important.
- The average leeway space in the maxilla was 0.81mm and 1.08mm for the left and right hand sides respectively, and 2.43mm and 2.59mm in the mandible for the left and right hand side respectively. This was similar to the values of 0.9mm in the maxilla and 1.8mm-1.9mm in the mandible as reported by Nance (1947) and by Bishara et al (1988).
- The leeway space calculated was larger in the mandible than in the maxilla. This has also been accepted by previous researchers (Nance, 1947; Bishara et al, 1988).

The research has shown that the proposed method of measurement of mesio-distal tooth width of erupted and unerupted teeth on panoramic x-rays taken with the Leica QWin© System was simple. In addition to the erupted teeth measured (‘6’ and ‘e’), the image of the unerupted second premolar tooth was visible on the radiograph, and its size was measurable and did not have to be predicted. The method enabled one to measure the leeway space in a manner which was relatively easy and was not time consuming. A comparison with the more traditional method of tooth size measurement with vernier calipers on the study cast did demonstrate statistically significant differences. Whilst the disparities are acknowledged, the ease with which this technique was undertaken using the standard diagnostic panoramic radiograph does make it an attractive alternative provided that accurate tooth size measurements can be recorded. This issue could be reconciled in future research taking cognisance of factors that would ensure accuracy.

These factors include

- The proper positioning of the patient within the focal trough of the machine at the time of radiographic exposure
- Accurate calibration of the measuring tool with a marker of known size that is placed at the site to be radiographed. This would enable one to correct for magnification in the buccal region of the film where the measurements would be taken.
- Use of the same mesio-distal reference points for measuring the images of the teeth on the radiographs and the teeth on the study casts.

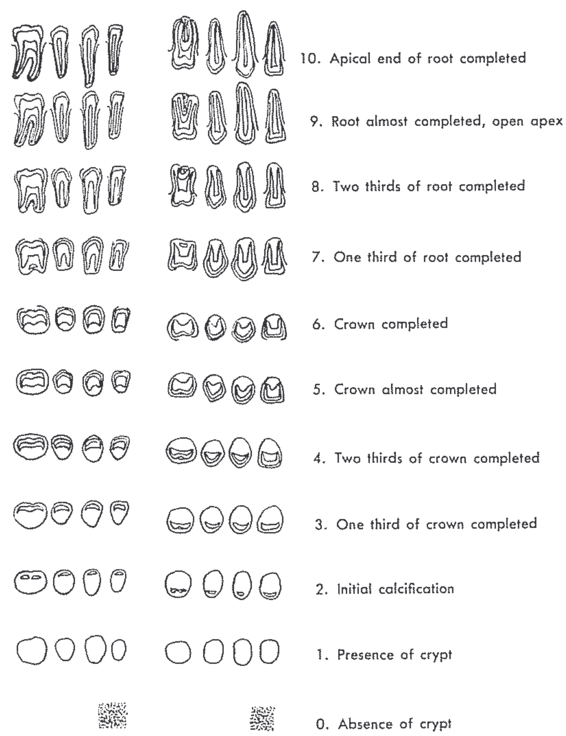
Measuring the mesio-distal widths of the images of the teeth on panoramic radiographs with the proposed method allows for a confident comparison of the calculated leeway space with the leeway space measured clinically once the corresponding teeth have erupted. This provides proof of the accuracy of the proposed method of measuring tooth size from the images of teeth on the panoramic radiographs with the Leica QWin© System.

[The author has no financial interest or gain in Leica QWin ©].

APPENDICES

Appendix One

Table A.1. Nolla's stages of tooth calcification. The radiograph is compared to the drawings and each tooth is then given a developmental score according to picture that most closely resembles (Taken from: Moyers, 1973).



Appendix Two

Table A2.1. Norms for maturation of permanent teeth for boys (Nolla). The mean stage for calcification for each tooth is shown in terms of the ten stages of calcification (Taken from: Moyers, 1973).

Age, Yr.	Mandibular Teeth (Growth Stage)								Maxillary Teeth (Growth Stage)							
	1|1	2|2	3|3	4|4	5|5	6|6	7|7	8|8	1|1	2|2	3|3	4|4	5|5	6|6	7|7	8|8
3	5.2	4.5	3.2	2.6	1.1	5.0	0.7	—	4.3	3.4	3.0	2.0	1.0	4.2	1.0	—
4	6.5	5.7	4.2	3.5	2.2	6.2	2.0	—	5.4	4.5	3.9	3.0	2.0	5.3	2.0	—
5	7.5	6.8	5.1	4.4	3.3	7.0	3.0	—	6.4	5.5	4.8	4.0	3.0	6.4	3.0	—
6	8.2	7.7	5.9	5.2	4.3	7.7	4.0	—	7.3	6.4	5.6	4.9	4.0	7.4	4.0	—
7	8.8	8.5	6.7	6.0	5.3	8.4	5.0	0.8	8.2	7.2	6.3	5.7	4.9	8.2	5.0	—
8	9.3	9.1	7.4	6.8	6.2	9.0	5.9	1.4	8.8	8.0	7.0	6.5	5.8	8.9	5.8	1.0
9	9.7	9.5	8.0	7.5	7.0	9.5	6.7	1.8	9.4	8.7	7.7	7.2	6.6	9.4	6.5	1.8
10	10.0	9.8	8.6	8.2	7.7	9.8	7.4	2.0	9.7	9.3	8.4	7.9	7.3	9.7	7.2	2.3
11	—	—	9.1	8.8	8.3	9.9	7.9	2.7	9.95	9.7	8.8	8.6	8.0	9.8	7.8	3.0
12	—	—	9.6	9.4	8.9	—	8.4	3.5	—	9.95	9.2	9.2	8.7	—	8.3	4.0
13	—	—	9.8	9.7	9.4	—	8.9	4.5	—	—	9.6	9.6	9.3	—	8.8	4.9
14	—	—	—	10.0	9.7	—	9.3	5.3	—	—	9.8	9.8	9.6	—	9.3	5.9
15	—	—	—	—	10.0	—	9.7	6.2	—	—	9.9	9.9	9.9	—	9.6	6.6
16½	—	—	—	—	—	—	10.0	7.3	—	—	—	—	—	—	10.0	7.7
17	—	—	—	—	—	—	—	7.6	—	—	—	—	—	—	—	8.0

Table A2.2. Norms for maturation of permanent teeth for girls (Nolla). The mean stage of calcification for each tooth is shown in terms of the ten stages of calcification (Taken from: Moyers)

Age, Yr.	Mandibular Teeth (Growth Stage)								Maxillary Teeth (Growth Stage)							
	$\overline{1\|1}$	$\overline{2\|2}$	$\overline{3\|3}$	$\overline{4\|4}$	$\overline{5\|5}$	$\overline{6\|6}$	$\overline{7\|7}$	$\overline{8\|8}$	$\underline{1\|1}$	$\underline{2\|2}$	$\underline{3\|3}$	$\underline{4\|4}$	$\underline{5\|5}$	$\underline{6\|6}$	$\underline{7\|7}$	$\underline{8\|8}$
3	5.3	4.7	3.4	2.9	1.7	5.0	1.6	—	4.3	3.7	3.3	2.6	2.0	4.5	1.8	—
4	6.6	6.0	4.4	3.9	2.8	6.2	2.8	—	5.4	4.8	4.3	3.6	3.0	5.7	2.8	—
5	7.6	7.2	5.4	4.9	3.8	7.3	3.9	—	6.5	5.8	5.3	4.6	4.0	6.9	3.8	—
6	8.5	8.1	6.3	5.8	4.8	8.1	5.0	—	7.4	6.7	6.2	5.6	4.9	7.9	4.7	—
7	9.3	8.9	7.2	6.7	5.7	8.7	5.9	1.8	8.3	7.6	7.0	6.5	5.8	8.7	5.6	—
8	9.8	9.5	8.0	7.5	6.6	9.3	6.7	2.1	9.0	8.4	7.8	7.3	6.6	9.3	6.5	2.1
9	10.0	9.9	8.7	8.3	7.4	9.7	7.4	2.3	9.6	9.1	8.5	8.1	7.4	9.7	7.2	2.4
10	—	10.0	9.2	8.9	8.1	10.0	8.1	3.2	10.0	9.6	9.1	8.7	8.1	10.0	7.9	3.2
11	—	—	9.7	9.4	8.6	—	8.6	3.7	—	10.0	9.5	9.3	8.7	—	8.5	4.3
12	—	—	10.0	9.7	9.1	—	9.1	4.7	—	—	9.8	9.7	9.3	—	9.0	5.4
13	—	—	—	10.0	9.4	—	9.5	5.8	—	—	10.0	10.0	9.7	—	9.5	6.2
14	—	—	—	—	9.7	—	9.7	6.5	—	—	—	—	10.0	—	9.7	6.8
15	—	—	—	—	10.0	—	9.8	6.9	—	—	—	—	—	—	9.8	7.3
16	—	—	—	—	—	—	10.0	7.5	—	—	—	—	—	—	10.0	8.0
17	—	—	—	—	—	—	—	8.0	—	—	—	—	—	—	—	8 7

Appendix Three

Table A.3.1 Percentage of ultimate root length by ages in boys (Taken from: Moyers, 1973)

Age	Canine		First Premolar		Second Premolar		First Molar		Second Molar	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
5 yrs	3.75	5.16					26.37	8.78		
6 yrs	9.38	5.36					53.25	17.78		
7 yrs	19.10	7.97	1.58	7.31			68.45	16.86		
8 yrs	32.41	11.39	12.89	9.60	4.92	9.81	78.00	10.84	7.34	10.03
9 yrs	44.91	15.03	27.91	15.61	17.61	16.86	86.99	7.60	17.35	13.82
10 yrs	60.90	15.06	44.17	18.77	30.34	16.86	90.85	6.87	34.08	17.51
11 yrs	76.56	12.44	59.96	20.13	47.61	24.12	92.34	5.76	54.09	20.94
12 yrs	87.32	9.01	78.62	16.07	63.92	23.20	94.63	3.79	68.13	20.23
13 yrs	95.59	4.82	91.52	8.59	83.16	18.84	96.71	2.74	88.49	14.15
14 yrs	96.81	5.59	97.31	5.14	93.38	10.12	96.74	3.19	95.51	6.95
15 yrs	97.13	3.02	96.07	7.94	97.71	4.19	98.21	2.41	97.65	2.74
16 yrs	98.99	2.01	99.73	.54	100.00	0.00	95.67	6.99	99.19	1.61

Table A.3.2.Percentages of ultimate root length by ages in girls (Taken from: Moyers, 1973)

Age	Canine		First Premolar		Second Premolar		First Molar		Second Molar	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
5 yrs	8.15	5.44					35.86	14.79		
6 yrs	16.64	13.30					49.30	16.54		
7 yrs	27.78	12.43	8.27	7.83	1.92	10.30	69.73	9.60	4.58	9.84
8 yrs	43.95	13.83	22.19	11.13	13.56	14.32	78.73	9.71	15.28	12.41
9 yrs	62.50	13.36	37.61	15.65	25.76	18.22	87.11	7.95	31.36	19.99
10 yrs	76.44	15.21	58.71	19.92	41.04	20.94	92.54	6.07	43.18	22.19
11 yrs	89.36	10.24	74.41	17.99	63.32	25.75	95.48	4.08	65.18	22.38
12 yrs	94.55	7.31	87.40	14.34	81.63	21.90	98.32	2.33	85.09	22.46
13 yrs	98.13	4.34	96.63	7.01	92.86	14.98	97.98	2.33	91.29	14.23
14 yrs	97.26	1.91	95.41	6.71	92.19	13.02	98.86	1.22	95.45	5.18
15 yrs	99.60	.72	99.76	.36	98.06	2.74	98.00	2.86	96.69	8.10

Appendix Four

Table A.4.1. Percentages of eruption achieved at each age for boys (Taken from: Moyers, 1973).

Age	Canine	First Premolar	Second Premolar	First Molar	Second Molar
5 yrs	0.00	0.00	0.00	0.00	0.00
6 yrs	.28	0.00	0.00	18.98	0.00
7 yrs	5.21	4.72	4.42	39.70	5.83
8 yrs	12.21	12.23	7.06	52.30	8.62
9 yrs	24.04	20.62	14.07	56.70	14.79
10 yrs	38.21	33.11	21.97	60.30	22.86
11 yrs	61.13	49.93	38.23	65.01	39.01
12 yrs	75.15	64.74	48.64	68.92	51.83
13 yrs	79.85	76.32	68.16	72.08	67.71
14 yrs	88.80	88.51	87.00	84.74	85.96
15 yrs	90.94	92.18	94.02	89.89	91.52
16 yrs	94.58	95.15	95.76	97.58	98.58
17 yrs	100.00	100.00	100.00	100.00	100.00

Table A.4.2. Percentages of eruption achieved at each age for girls (Taken from: Moyers, 1973).

Age	Canine	First Premolar	Second Premolar	First Molar	Second Molar
5 yrs	0.00	0.00	0.00	10.08	0.00
6 yrs	5.12	4.66	1.57	38.98	3.78
7 yrs	10.48	7.89	3.46	64.65	8.84
8 yrs	23.79	18.49	10.11	74.80	14.73
9 yrs	45.17	32.10	18.49	78.03	21.82
10 yrs	63.43	51.96	32.54	82.91	33.98
11 yrs	80.38	69.97	53.73	85.83	56.91
12 yrs	90.50	82.84	65.95	86.69	73.85
13 yrs	96.68	97.51	86.38	95.04	91.62
14 yrs	98.73	97.46	92.43	94.96	89.32
15 yrs	100.00	100.00	100.00	100.00	100.00

Appendix Five

Table A.5.1.Average mesio-distal widths of the mandibular permanent molar teeth (Taken from: Kraus et al, 1969).

THE MANDIBULAR MOLARS

Size and Eruption

Mandibular Molars	Crown Height	Mesiodistal Crown Diameter	Labiolingual Crown Diameter	Tooth Length	Age at Eruption
	mm	*mm*	*mm*	*mm*	*yr*
First	7.5	11.0	10.5	21.5	6
Second	7.0	10.5	10.5	20.0	12
Third	7.0	10.0	9.5	18.0	18+

Table A.5.2. Average mesio-distal widths of the maxillary permanent molar teeth (Taken from: Kraus et al, 1969).

MAXILLARY MOLARS

Size and Eruption

Maxillary Molars	Crown Height	Mesiodistal Crown Diameter	Bucco-lingual Crown Diameter	Tooth Length	Age at Eruption
mm	*mm*	*mm*	*mm*	*mm*	*yr*
First	7.5	10.0	11.0	19.5	6
Second	7.0	9.0	11.0	18.0	12
Third	6.5	8.5	10.0	17.5	18+

Table A.5.3.Average mesio-distal widths of the deciduous molar teeth in the maxilla and in the mandible (Taken from: Kraus et al, 1969).

THE MOLARS

Size and Eruption

	Crown Height	Mesio-distal Crown Diameter	Bucco-lingual Crown Diameter	Tooth Length	Age at Eruption
	mm	*mm*	*mm*	*mm*	*mo*
Maxillary molars					
First molar	5.1	7.3	8.5	15.2	12–16
Second molar	5.7	8.2	10.0	17.5	20–30
Mandibular					
First molar	6.0	7.7	7.0	15.8	12–16
Second molar	5.5	9.9	8.7	18.8	20–30

Appendix Six

Table A6.1- Proposed probability tables for black subjects of African descent for predicting the mesiodistal widths of the unerupted maxillary canine and premolar teeth (Taken from: Schirmer and Wiltshire, 1997).

Percentile (%) $\Sigma\ \overline{21}\vert 12$	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	21.7	21.9	22.1	22.3	22.4	22.6	22.8	23.1	23.3	23.5	23.8	24.0	24.3
85	21.5	21.7	21.9	22.1	22.3	22.5	22.8	23.0	23.2	23.4	23.7	23.9	24.2
75	21.4	21.6	21.8	22.1	22.3	22.5	22.7	22.9	23.2	23.4	23.6	23.9	24.1
65	21.3	21.5	21.8	22.0	22.2	22.4	22.7	22.9	23.1	23.4	23.6	23.8	24.1
50	21.2	21.4	21.7	21.9	22.1	22.4	22.6	22.9	23.1	23.3	23.6	23.8	24.0
35	21.1	21.3	21.6	21.8	22.1	22.3	22.6	22.8	23.0	23.3	23.5	23.7	24.0
25	21.0	21.3	21.5	21.8	22.0	22.3	22.5	22.8	23.0	23.3	23.5	23.7	23.9
15	20.9	21.2	21.4	21.7	22.0	22.2	22.5	22.7	23.0	23.2	23.4	23.7	23.9
5	20.7	21.0	21.3	21.6	21.9	22.1	22.4	22.7	22.9	23.1	23.4	23.6	23.8
Females													
95	20.4	20.6	20.8	21.1	21.3	21.6	21.8	22.1	22.4	22.7	23.0	23.4	23.7
85	20.1	20.4	20.7	20.9	21.2	21.5	21.7	22.0	22.3	22.6	22.9	23.3	23.6
75	20.0	20.3	20.6	20.8	21.1	21.4	21.7	22.0	22.3	22.6	22.9	23.2	23.5
65	19.9	20.2	20.5	20.8	21.0	21.3	21.6	21.9	22.2	22.5	22.8	23.1	23.5
50	19.8	20.1	20.4	20.7	21.0	21.3	21.6	21.9	22.2	22.5	22.8	23.1	23.4
35	19.6	19.9	20.2	20.6	20.9	21.2	21.5	21.8	22.1	22.4	22.7	23.0	23.3
25	19.5	19.8	20.2	20.5	20.8	21.1	21.5	21.8	22.1	22.4	22.7	23.0	23.2
15	19.4	19.7	20.0	20.4	20.7	21.1	21.4	21.7	22.0	22.3	22.6	22.9	23.2
5	19.1	19.5	19.9	20.2	20.6	20.9	21.3	21.6	22.0	22.3	22.5	22.8	23.1

Table A6.2- Proposed probability tables for black subjects of African descent for predicting the mesiodistal widths of the unerupted mandibular canine and premolar teeth (Taken from: Schirmer and Wiltshire, 1997).

Percentile (%) $\Sigma\ \overline{21}\vert 12$	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	22.3	22.5	22.7	22.9	23.2	23.4	23.7	24.0	24.3	24.6
85	21.4	21.6	21.9	22.1	22.3	22.6	22.8	23.1	23.4	23.6	23.9	24.2	24.5
75	21.3	21.5	21.8	22.0	22.3	22.5	22.8	23.0	23.3	23.6	23.9	24.1	24.4
65	21.2	21.4	21.7	21.9	22.2	22.5	22.7	23.0	23.3	23.5	23.8	24.1	24.4
50	21.0	21.3	21.6	21.9	22.1	22.4	22.7	22.9	23.2	23.5	23.8	24.0	24.3
35	20.9	21.2	21.5	21.8	22.0	22.3	22.6	22.9	23.2	23.4	23.7	24.0	24.3
25	20.8	21.1	21.4	21.7	22.0	22.3	22.6	22.9	23.1	23.4	23.7	23.9	24.2
15	20.7	21.0	21.3	21.6	21.9	22.2	22.5	22.8	23.1	23.4	23.6	23.9	24.1
5	20.5	20.8	21.1	21.5	21.8	22.1	22.4	22.7	23.0	23.3	23.5	23.8	24.0
Females													
95	20.6	20.8	21.0	21.2	21.4	21.6	21.9	22.1	22.3	22.6	22.9	23.2	23.6
85	20.3	20.6	20.8	21.0	21.3	21.5	21.8	22.0	22.3	22.5	22.8	23.1	23.4
75	20.2	20.5	20.7	20.9	21.2	21.4	21.7	22.0	22.2	22.5	22.8	23.1	23.4
65	20.1	20.4	20.6	20.9	21.1	21.4	21.6	21.9	22.2	22.5	22.7	23.0	23.3
50	20.0	20.2	20.5	20.8	21.0	21.3	21.6	21.9	22.1	22.4	22.7	22.9	23.2
35	19.8	20.1	20.4	20.7	21.0	21.2	21.5	21.8	22.1	22.4	22.6	22.9	23.1
25	19.7	20.0	20.3	20.6	20.9	21.2	21.5	21.8	22.0	22.3	22.6	22.8	23.1
15	19.6	19.9	20.2	20.5	20.8	21.1	21.4	21.7	22.0	22.3	22.5	22.8	23.0
5	19.3	19.7	20.0	20.4	20.7	21.0	21.3	21.6	21.9	22.2	22.4	22.7	22.9

REFERENCES

Adeyemi TA, Isiekwe MC. (2003). Comparing permanent tooth sizes (mesio-distal) of males and females in a Nigerian population. West African Journal of Medicine 22(3):219-21.

Al-Dashti AA, Cook PA, Curzon ME. (2005). A comparative study on methods of measuring mesiodistal tooth diameters for interceptive orthodontic space analysis. European Journal of Paediatric Dentistry 6(2):97-104.

Al Khadra BH. (1993). Prediction of the size of unerupted canines and premolars in a Saudi Arab population. American Journal of Orthodontics and Dentofacial Orthopedics 104:369-72.

Al Tamimi T, Hashim HA. (2005). Bolton tooth size ratio revisited. World Journal of Orthodontics (6)3; 289-295.

Altherr ER, Koroluk LD, Phillips C. (2007). Influence of sex and ethnic tooth size differences on mixed dentition space analysis. American Journal of Orthodontics and Dentofacial Orthopedics 132:332-9.

Anderson AA. (2005). Dentition and occlusion development in African American children: mesio-distal diameters and tooth size ratios of primary teeth. Paediatric Dentistry 27(2):121-8.

Angle EH. (1899). Classification of malocclusion. Dental Cosmos 41:248-64; 350-7.

Ballard ML, Wylie WL. (1947). Mixed dentition case analysis estimating size of unerupted permanent teeth. American Journal of Orthodontics and Oral Surgery 33:754-9.

Barber T. Personal Communication with Moyers, cited in Moyers (1973).

Basaran G, Selek M, Hamam O, et al. (2006). Intermaxillary Bolton tooth size discrepancy among different malocclusion groups. Angle Orthodontist 76(1):26-30.

Baume LJ. (1950). Physiologic tooth migration and its significance for the development of the occlusion. II. The biogenesis of the accessional dentition. Journal of Dental Research 29:331.

Bell A, Ayoub AF, Siebert P. (2003). Assessment of the accuracy of a three dimensional imaging system for archiving dental study models. Journal of Orthodontics 30:219-23.

Bishara SE, Staley RN. (1984). Mixed dentition mandibular arch length analysis: a step by step approach using the revised Hixon Oldfather prediction method. American Journal of Orthodontics 86:130-135.

Bishara SE, Hoppens BJ, Jakobsen JR, et al. (1988). Changes in the molar relationship between the primary and permanent dentitions: a longitudinal study. American Journal of Orthodontics and Dentofacial Orthopedics 93(1):19-28.

Bishara SE, Jakobsen JR. (1998). Comparison of two non radiographic methods of predicting permanent tooth size in the mixed dentition. American Journal of Orthodontics and Dentofacial Orthopedics 114(5):573-6.

Bishara SE. (2001). Textbook of Orthodontics. W.B Saunders Company, Philadelphia, Pennsylvania.

Black GV. (1902). Descriptive anatomy of the human teeth. Philadelphia: SS White Dental Manufacturing.

Bolton WA. (1958). Disharmony in tooth size and its relation to the analysis and treatment of malocclusion. Angle Orthodontist 28:113-30.

Brennan MM, Gianelly AA. (2000). The use of the lingual arch in the mixed dentition to resolve incisor crowding. American Journal of Orthodontics and Dentofacial Orthopedics 117(1):81-5.

Brook AH, Pitts NB, Yau F, et al. (1986). An image analysis system for the determination of tooth dimensions from study casts: comparison with manual measurements of mesio-distal diameter. Journal of Dental Research 65(3):428-31.

Carey CW. (1949). Linear arch dimension and tooth size. An evaluation of the bone and dental structures in cases involving the possible reduction of dental units in treatment. American Journal of Orthodontics 35:762-75.

Cassidy KM, Hams EF, Tolley EA, et al. (1998). Gender influence on dental arch form in orthodontic patients. The Angle Orthodontist 68(5):445-54.

Champagne M. (1992). Reliability of measurements from photocopies of study models. Journal of Clinical Orthodontics 26:648-50.

Clauss WJ. (1955). An evaluation of analyses in the mixed dentition. Thesis, Department of Orthodontics, University of Michigan, Ann Arbor.

Cohen M. (1959). Recognition of the developing Malocclusion, Dental Clinics of North America 6:299-311.

De Paula S, Ameida MAO, Lee PCF. (1995). Prediction of mesiodistal diameter of unerupted lower canines and premolars using 45° cephalometric radiography. American Journal of Orthodontics and Dentofacial Orthopedics 107:309-14.

Diagne F, Diop-Ba K, Ngom PI, et al. (2003). Mixed dentition analysis in a Senegalese population: elaboration of prediction tables. American Journal of Orthodontics and Dentofacial Orthopedics 73:314-8.

Duterloo H.S. (1991). An atlas of dentition in childhood- Orthodontic diagnosis and panoramic radiology. Wolfe Publishing Ltd.

Ferguson FS, Macko DJ, Sonnenberg EM, et al. (1978). The use of regression constants in estimating tooth size in a Negro population. American Journal of Orthodontics 73:68-72.

Flores-Mir C, Bernabè E, Camus C, et al. (2003). Prediction of mesiodistal canine and premolar width in a sample of Peruvian adolescents. Orthodontics and Craniofacial; Research 6:173-6.

Gardner RB. (1979).A comparison of four methods of predicting arch length. American Journal of Orthodontics 75(4):387-98.

Gianelly AA. (1969). Diagnosis of incipient malocclusions. Journal of American Dental Association 79:658-61, 1969.

Gianelly AA. (1995). Leeway space and the resolution of crowding in the mixed dentition. Seminars in Orthodontics 1(3):188-94.

Griewe PW. (1949). Tooth size and symmetry in the human dentition. Thesis, University of Iowa Dental Library.

Hixon EH, Oldfather RE. (1958). Estimation of the sizes of unerupted cuspid and bicuspid teeth. Angle Orthodontist 28(4):236-40.

Hollinger JO, Lorton L, Krantz W, et al. (1984). A clinical and laboratory comparison of irreversible hydrocolloid impression techniques. Journal of Prosthetic Dentistry 51: 304-9.

Huckaba GW. (1964). Arch size analysis and tooth size prediction. Dental Clinics of North America 431.

Howes AE. (1947). Case analysis and treatment planning based upon the relationship of the tooth material to its supporting bone. American Journal of Orthodontics and Oral Surgery 33:499-533.

Hunter WS, Priest WR. (1960). Errors and discrepancies in measurement of tooth size. Journal of Dental Research 39(2):405-14.

Jaksic N, Scepan I, Glisic B, et al (2002). Mesiodistal size of deciduous teeth in subjects with unilateral cleft lip and palate. Orthodontic Craniofacial Research 5(1):17-21.

Jaroontham J, Godfrey K. (2000). Mixed dentition space analysis in a Thai population. European Journal of Orthodontics 22:127-34.

Kabban M, Fearne J, Jovanovski V, et al. (2001). Tooth size and morphology in twins. International Journal of Pediatric Dentistry 11(5):333-9.

Khalaf K, Elcock C, Smith RE, et al. (2005). Fluctuating dental asymmetry of multiple crown variables measured by an image analysis system. Archives of Oral Biology 50:249-53.

Khan MI. (2006). Tooth width predictions in a sample of Black South Africans. Masters dissertation, University of Limpopo.

Kieser JA. (1990). Human Adult Odontometrics (Cambridge Studies in Biological Anthropology; 4) Cambridge University Press, Cambridge.

Kraus BS, Jordan RE, Abrams L. A study of the masticatory system. Dental Anatomy and occlusion. The Williams and Wilkins Company, Baltimore, 1969.

Lee-Chan S, Jacobsen BN, Chwa KH, et al. (1998). Mixed dentition analysis for Asian Americans. American Journal of Orthodontics and Dentofacial Orthopedics. 113(3):293-9.

Leica Q Win© User Guide. Leica Imaging Systems Ltd. Clifton Road, Cambridge, CB1 3QH, England.

McDonald F, Ireland AJ. (1998). Diagnosis of the Orthodontic Patient. Oxford University Press.

www.medmac.co.za/catalogue

Melgaço CA, de Sousa Araújo MT, de Oliveira Ruellas AC. (2007). Mandibular permanent first molar and incisor width as predictor of mandibular canine and premolar width. American Journal of Orthodontics and Dentofacial Orthopedics 132:340-5.

Mok KHY, Cooke MS. (1998). Space analysis: a comparison between sonic digitization (DigiGraph™Workstation) and the digital caliper. European Journal of Orthodontics 20:653-61.

Moorrees CFA, Reed RB. (1964). Correlations among crown diameters of human teeth. Archives of Oral Biology 9:685.

Moorrees CFA, Chadha JM. (1965). Available space for incisors during dental development. A growth study based on physiological age. Angle Orthodontist 35:12-22.

Moyers RE. (1973). Handbook of Orthodontics 3rd Edition, Year Book Medical Publishers.

Moyers RE, van der Linden FPGM, Riolo ML, et al. (1976). Standards of Human Occlusal Development. Monograph #5 Craniofacial Growth Series. Ann Arbor MI: Centre of Human Development, University of Michigan.

Moyers RE. (1988). Handbook of Orthodontics, 4th Edition, Year Book Medical Publishers Inc.

Mullen SR, Martin CA, Ngan P, et al. (2007). Accuracy of space analysis with ‘e’ models and plaster models. American Journal of Orthodontics and Dentofacial Orthopedics 132(3):36-52.

Nance HN. (1947). The limitations of orthodontic treatment I: Mixed dentition diagnosis and treatment. American Journal of Orthodontics and Oral Surgery 33(4):177-241 April.

Neff CW. (1949). Tailored occlusion with the anterior co-efficient. American Journal of Orthodontics 35:309-14.

Nolla C. (1960). Development of the permanent teeth. Journal of Dentistry for Children 27:254.

Paredes V. (2003). Desarollo de un metodo digital para la medicióny predicción de tamaños dentarios: applicciones para determiner alteraciones del indice de Bolton. Thesis, University of Valencia.

Paredes V, Gandia JL, Cibrian R. (2006) Determination of Bolton tooth size ratios by digitisation and comparison with the traditional method. European Journal of Orthodontics 28:120-5.

Proffit WR. (2000). Contemporary Orthodontics, 3rd edition. Mosby.

Quimby M, Vig K, Rashid R, et al. (2004). The accuracy and reliability of measurements made on computer based digital models. Angle Orthodontist 74:298-303.

Schirmer UR, Wiltshire WA. (1997). Manual and computer aided space analysis: a comparative study. American Journal of Orthodontics and Dentofacial Orthopedics, 112(6):676-80.

Schirmer UR, Wiltshire WA. (1997). Orthodontic probability tables for Black patients of African descent: Mixed dentition analysis. American Journal of Orthodontics and Dentofacial Orthopedics 112: 545-51.

Schwartz GT. (2005). Sexual dimorphism in modern human permanent teeth. American Journal of Physical Anthropology 128 (2):312-7.

Staley RN, Hoag JF. (1978). Prediction of the mesiodistal widths of maxillary permanent canines and premolars. American Journal of Orthodontics 73(2):169- 77.

Staley RN, Shelley TH, Martin JF. (1979). Prediction of lower canine and premolar widths in the mixed dentition. American Journal of Orthodontics 76(3):300-9.

Staley RN, Kerber PE. (1980). A revision of the Hixon-Oldfather mixed dentition prediction method. American Journal of Orthodontics 78(3):296-302.

Staley RN, Hu P, Hoag JF. (1983). Prediction of the combined right and left canine and premolar widths in both arches of the mixed dentition. Pediatric Dentistry 5:57-60.

Staley RN, O'Gorman TW, Hoag JF, et al. (1984). Prediction of the widths of unerupted canines and premolars. Journal of the American Dental Association 108:185-90.

Tanaka MM, Johnston LE. (1974). The prediction of the size of unerupted canines and premolars in a contemporary orthodontic population. Journal of the American Dental Association 88:798-801.

Tomasetti JJ, Taloumis LJ, Denny JM, et al. (2001). A comparison of 3 computerised Bolton tooth size analyses with a commonly used method. Angle Orthodontist 71(5):351-7.

Tootla R, Fayle S.A. (2003). Comparison of two methods of space prediction in the mixed dentition. Pediatric Dentistry 25(4):350-6.

Volchansky A, Cleaton-Jones P, Drummond S, et al. (2006). Technique for linear measurement on panoramic and periapical radiographs: A pilot study. Quintessence International, 37(3): 191-7.

Wheeler RC. (1961). A textbook of dental anatomy and physiology. Philadelphia: WB Saunders.

http://en.wikipedia.org/wiki/Caliper

Yen CH. (1991). Computer aided space analysis. Journal of Clinical Orthodontics 25:236-8.

Yuen KK, Tang EL, So LL. (1998). Deciduous tooth size standards for American Blacks. Journal of Tennessee Dental Association 72:30-3.

Zilberman O, Huggare JA, Parikakis KA. (2003). Evaluation of the validity of tooth size and arch width measurements using conventional and 3-D virtual orthodontic models. The Angle Orthodontist 73(3):301-6.

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TO WHOM IT MAY CONCERN:

Waiver: This certifies that the following research does not require clearance from the Human Research Ethics Committee (Medical).

Investigator: **Dr NF Green-Thompson Student number 9501733T**

Project title: **Measuring and predicting leeway space in the mixed dentition on panoramic xrays using computer imaging analysis.**

Reason: This research uses stored radiographs and models approved for such use in the Department of Orthodontics, Class Clearance 27/7/90 Prof W Evans.

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