# THE RELIABILITY AND ACCURACY OF CBCT IN MEASURING DIAMETER OF UNERUPTED POSTERIOR TEETH

by

CELIA E. FENELL, D.D.S.

Submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry

Thesis Advisor: Sebastian Baumgaertel, D.M.D., M.S.D.

Case Western Reserve University

School of Dental Medicine

Department of Orthodontics

December 11, 2013

# DEDICATION

To my parents for their unwavering love and support.

TABLE OF CONTENTS

DEDICATION.....ii

TABLE OF CONTENTS.....iii

LIST OF TABLES.....iv

ABSTRACT.....v

REVIEW OF THE LITERATURE.....1

REFERENCES FOR REVIEW OF THE LITERATURE.....21

STATEMENT OF THESIS.....24

MANUSCRIPT.....25

REFERENCES FOR MANUSCRIPT.....37

FIGURES FOR MANUSCRIPT.....40

TABLES FOR MANUSCRIPT.....43

APPENDICES

A. IRB APPROVAL.....44

B. TABLES.....45

LIST OF TABLES

1. Abbreviations.....47
2. Measurements from CBCT (unerupted teeth) – Input 1..48
3. Measurements from CBCT (unerupted teeth) – Input 2..49
4. Measurements from Casts (erupted teeth) – Input 1...50
5. Measurements from Casts (erupted teeth) – Input 2...51
6. Assessment of normal distribution of teeth of interest.....52

THE RELIABILITY AND ACCURACY OF CBCT IN MEASURING DIAMETER OF UNERUPTED POSTERIOR TEETH

Abstract

by

CELIA E. FENELL

In the mixed dentition, the space available for unerupted canines and premolars is an important variable for future treatment considerations. This study aimed to investigate the reliability and accuracy of diameter measurements of permanent posterior unerupted teeth on cone-beam computed tomography (CBCT) reconstructions.

Seventeen subjects had been scanned with dental CBCT during the mixed dentition stage and plaster casts fabricated from alginate impressions were made at a later timepoint during the permanent dentition. The greatest mesiodistal diameter of unerupted canines and premolars were measured on the CBCT reconstructions. The same measurements were made on plaster casts on the erupted teeth using a high-precision digital caliper.

Reliability was assessed using the intraclass correlation coefficient, and accuracy was assessed using the paired Student t-test and Wilcoxon signed-ranks test. Both the CBCT and digital caliper (DC) measurements were reliable ($r>0.80$). The CBCT measurements generally underestimated the true values, which was statistically significant for only mandibular first premolars. CBCT measurements were accurate to 0.12mm.

Levels of reliability for all measurements were acceptable and significant differences between CBCT and DC measurements were found only for mandibular first premolars. Because the detected differences cannot be considered clinically significant, CBCT can be used to measure the mesiodistal diameter of unerupted teeth.

# REVIEW OF THE LITERATURE

An accurate diagnosis of orthodontic problems is critical to a successful treatment plan. Orthodontic records consisting of extra- and intra-oral photographs, dental casts, and radiographs are tools for diagnosis. Study models provide the clinician an opportunity to make measurements and quantify different forms of malocclusions. Plaster casts fabricated from alginate impressions are true to anatomic form and can be employed to make accurate dental measurements outside of the patient's mouth (Zilberman et al. 2003; Quimby et al. 2004).

One of the diagnostic parameters in the mixed dentition with greatest variability is the difference between the size of unerupted canines and premolars and the space available for them in the mandibular arch (Hixon and Oldfather 1958). The difference in size of the succedaneous teeth and permanent teeth can result in excess space within the arch, commonly referred to as

leeway space. The primary molars are on average larger than the premolars, and the primary canine is smaller than its permanent counterpart (Black 1897). Mixed dentition analyses aim to predict the size of the unerupted posterior permanent teeth even though great variability can exist. A reliable and accurate method to evaluate required space for the permanent teeth in the mixed dentition can aid in decision making and predicting future orthodontic needs of a patient: need for serial extraction, space maintenance or regaining, eruption guidance, or observation without any treatment.

Traditionally, space analyses predicted the size of the unerupted canines and premolars. These methods utilize measurements of erupted teeth, measurements of unerupted teeth from radiographs, or a combination of measurements of erupted teeth and unerupted teeth from radiographs, but these methods all come with inherent inaccuracies.

Nance (1947) studied the space occupied by primary and permanent teeth which was one of the first attempts to predict how much space is necessary for the permanent teeth to erupt into the arches. Fine-pointed dividers measured the primary teeth on dental casts and the widths

recorded on cards. These measures were compared to the space the permanent teeth would occupy by measuring the unerupted teeth in their crypts on a full-mouth series of radiographs.

Radiographic technique can introduce distortion or inaccuracies into the films. The x-rays must pass directly through the contacts points of the teeth being filmed, resulting in no overlapping of the teeth in the images produced. When a permanent tooth could not be accurately measured in a film due to position of the crypt, Nance referred to G.V. Black's tables of average mesiodistal crown widths. Below are the figures published by Black (1897)

| Mandibular Deciduous Teeth | mm |
|---|---|
| Average mesiodistal crown width of a canine | 5.0 |
| First molar | 7.7 |
| Second molar | 9.9 |
| Total | 22.6 |
| **Mandibular Permanent Teeth** | **mm** |
| Average mesiodistal crown width of a canine | 6.9 |
| First premolar | 6.9 |
| Second premolar | 7.1 |
| Total | 20.9 |
| Difference | 1.7 |

Ballard and Wylie (1947) attempted to supplement Nance's method. The mesiodistal widths of all mandibular permanent teeth from first molar to first molar for 441 individuals were measured on plaster casts that had all fully erupted permanent incisors, canines, premolars, and first molars. Measurements were made to the nearest one-quarter millimeter. The mean sum of the canines and premolars was determined, as well as the mean sum of the four mandibular permanent incisors, for each individual. The mean width of the mandibular permanent first molar was also determined.

The coefficient correlation of +0.64 indicated a positive relationship between the mean sum of the four mandibular permanent incisors and the mean sum of the permanent canines and premolars on one side. Although not extremely high, practical applications were thought to be possible. Thus, a formula was developed to predict the sum of the mesiodistal widths of the canines and premolars when another variable was known (the sum of the width of the four mandibular permanent incisors). Ballard and Wylie created a predictive graph for ease of use.

It was hypothesized that the width of the mandibular permanent first molar might improve accuracy of the

prediction of the sum of the canines and premolars. The coefficient correlation of the mandibular permanent first molar with the sum of the canines and premolars on one side was calculated. The coefficient correlation of the sum of the mandibular permanent first molar and the four permanent mandibular incisors with the sum of the canines and premolars on one side was also calculated. New prediction formulas employing the relationship of the mandibular permanent first molar with the sum of the mesiodistal width of the canine and premolar did not prove to be more accurate than the prediction formula based on the sum of the four mandibular permanent incisors alone. The more complicated prediction formula did not improve prediction of the sum of the unerupted teeth.

Ballard and Wylie compared the accuracy of the estimates from the predictive chart and radiographic measurements employing Nance's method to the actual sum of the mesiodistal width of the canine and premolars. The use of radiographs on average tend to overestimate the sum of the canines and premolars by 10.5 percent or 2.2mm per side, and the predictive graph on average by 2.6 percent or 0.6mm per side with error in either direction.

Hixon and Oldfather (1958) attempted to develop a more efficient procedure to predict the size of the unerupted canines and premolars to aid in the analysis of the mixed dentition. Combined widths of the permanent canines and premolars were correlated with varying combinations of measurements of the primary canines and molars and the permanent incisors. The measurements of the primary canines and molars and the permanent incisors were made on plaster casts where the teeth were present and erupted. The measurements of the permanent canines and premolars were made on periapical films with the primary canines and molars present and erupted and the permanent canines and premolars present but unerupted.

Hixon and Oldfather's study included forty-one subjects and the teeth on casts and films were repeated. After the product-moment correlation established the reliability of the cast and film measurements, the Pearson product-moment correlation coefficients were calculated for varying combinations of teeth. Combined widths of the permanent canines and premolars correlated most highly with the cast widths of the permanent incisors plus the film widths of the permanent first and second premolars having an r value of 0.88. The sum of

the mesiodistal diameters of the primary canines and molars on casts had the lowest correlation with the combined widths of permanent canines and premolars. Similar to a previous study (Ballard and Wylie 1947), the coefficient correlation of +0.69 indicated a positive relationship between the sum of the widths of the four permanent mandibular incisors on casts and the sum of the widths of the permanent canines and premolars after eruption.

A predictive table of measured values and estimated tooth size was produced for clinical application. The technique requires a measured value which is the sum of the maximum mesiodistal diameter of one mandibular permanent central incisor and lateral incisor and the mesiodistal diameter of the unerupted first and second premolars measured on an intraoral film on the same side as the incisors. The estimates should be accurate within 1.7mm per side for 99% of cases, within 1.1mm per side for 95% of cases, and 0.6mm per side for 68% of cases.

Although there is a strong correlation, the data are only valid if the periapical films are taken with a 16-inch cone. Hixon and Oldfather achieved their goal of reducing prediction error compared to Nance's method of

simply measuring the permanent canines and premolars directly on an intraoral film.

Hixon and Oldfather (1958) also analyzed the difference between the widths of the permanent canines and premolars compared to the widths of the primary canines and molars in the mandibular arch. Leeway space ranged from 0.1-4.4mm per side, indicating in some patients there was almost no change in size of teeth overall to about a 9mm difference per arch. This is similar to earlier findings (Nance 1947) of 0-4mm of leeway space available per side after the eruption of the permanent canines and premolars. This confirms the variability in tooth size between individuals and difficulty in using predictive measures for unerupted canines and premolars in an accurate mixed dentition analysis. If severe crowding is present in the mixed dentition, knowing there will be virtually no leeway space or up to 8.8mm of leeway space could impact the proposed treatment plan.

A revised method of Hixon and Oldfather (Bishara and Staley 1984) averaged the values on the right and left sides of the mandibular arch of each subject. This method decreased the standard error of estimates compared to the

original prediction equation. Although more accurate, the method was only tested in subjects of Caucasian descent.

Further simplifying mixed dentition analyses, Moyers (1988) derived the size of the unerupted canines and premolars from the sizes of the permanent teeth already erupted into the arch. His method can be completed intraorally, or with the use of dental casts. The method does not require the use of any radiographs. Similar to other methods (Ballard and Wylie 1947), the sum of mesiodistal width of the permanent mandibular incisors was used to predict the sum of the mesiodistal width of the maxillary and mandibular canines and premolars.

Probability charts for males and females were created at different confidence intervals to predict the combined widths of unerupted canines and premolars in both arches. The only measurement that has to be obtained is the width of the four permanent mandibular incisors, but reference to a table and choosing a level of probability is necessary. If choosing a high confidence level (95%), most individuals will have a combined width of canines and premolars that will be equal to or less than the value estimated. The 75% confidence level is most commonly used clinically. Moyers' regression

equations, nor the sample from which they were calculated, have been reported in the literature (Tanaka and Johnston 1974).

Following Moyers, additional attempts to simplify the prediction of the size of unerupted canines and premolars have been made (Tanaka and Johnston 1974). Mesiodistal widths of all permanent mandibular incisors, canines, and premolars were measured on 506 dental casts of orthodontic patients. Simple linear regression equations were calculated from the data. Instead of referencing prediction tables as in Moyers' analysis, half the width of the mandibular incisors plus 11.0mm for the maxillary arch and plus 10.5mm for the mandibular arch are used to produce results in a comparable approximation to that of Moyers' tables at the 75 percentile level of the space required for the permanent canine and premolars.

Other attempts to improve accuracy and simplify the mixed dentition analysis have also been made. A linear regression equation to predict the sum of the unerupted posterior teeth utilizing only the width of the mandibular left first premolar on 45 degree oblique radiography was formulated after the sum of the

mesiodistal widths of the unerupted mandibular canine and premolars on one side of the lower arch and on both sides of the lower arch was correlated with its width (Martinelli et al. 2005). Correlations were similar to that of Hixon and Oldfather. Only a single measurement is necessary to employ this technique and predict the sum of the mesiodistal width of all six unerupted canines and premolars.

Kaplan et al. (1977) compared the accuracy of the three different methods utilized by Hixon and Oldfather, Moyers, and Tanaka and Johnston. Subjects were selected from the longitudinal growth study of the Child Study Clinic at the School of Dentistry, University of Oregon Health Sciences Center. A total of 104 (51 female and 53 male) subjects were studied. Subjects had dental study casts and periapical radiographs available from the mixed dentition with unerupted mandibular first and second premolars. Dental casts taken several years later with mandibular permanent incisors, canines, and first and second premolars erupted were available as well. Measurements necessary to perform the three prediction methods were obtained, and 20% of the measurements were randomly repeated two weeks following the initial data

collection. Predicted values were calculated for the three mixed dentition analyses, including several confidence intervals of Moyers' analysis.

Analysis did not identify any statistically significant differences between gender and between the right and left sides of the mouth. Paired t-tests assessed the differences between the actual and predicted values for each method. Histograms demonstrated the distribution of the mean differences among the three methods. The Hixon-Oldfather method had the least mean difference between actual and predicted values of the sum of mesiodistal widths, but had a slight tendency to underestimate (0.15mm). The correlation coefficient of 0.88 was very similar to that of Hixon and Oldfather in their initial analysis. The distribution was normal, indicating the method was free of any bias.

The Moyers and Tanaka-Johnston methods overestimated on average and distribution was weighted heavily to over-predicting in more than 95% of the cases. Moyers' 95% confidence interval had the greatest mean difference (-2.06mm) and his 65% confidence interval had the least mean difference (-0.76mm). The Tanaka-Johnston method was between Moyers' 65%-75% confidence intervals. A simple

regression equation was applied to the data to further improve predictions and eliminate or reduce the under-prediction present in Hixon and Oldfather's analysis. It appears that the inclusion of the radiographic measurements in Hixon and Oldfather's analysis was the key to the increased accuracy when compared to Moyers' and the Tanaka-Johnston methods. Although Hixon and Oldfather under-predicted actual tooth mass, a more conservative approach is prudent, as over-prediction could lead to unnecessary treatment of orthodontic problems.

The accuracy of the methods of Nance, Hixon and Oldfather, Moyers, and Tanaka and Johnston has also been compared by others (Gardner 1979). Again, the Hixon-Oldfather method had the least mean difference between actual and predicted values of the sum of mesiodistal widths, and had a slight tendency to underestimate by 0.5mm. Nance's prediction method overestimated by 3.0mm. At 75% level of probability, Moyers' overestimated by 1.7mm and Tanaka-Johnston by 1.1mm. Combining the four methods in any manner did not improve the accuracy of the predictions. Sex of the patient did not seem to affect

the accuracy of the prediction in this study (Gardner 1979).

Bishara and Jakobsen (1998) compared two non-radiographic methods: Tanaka and Johnston and the Boston University prediction. The Boston University method uses the sum of the width of the mandibular primary canines and twice the width of the mandibular first primary molars. Student *t*-tests, although not specifically mentioned, were used to determine significant differences between right and left sides for males and females and between males and females. No significant differences were found between the right and left sides, and hence, values were averaged. Significant differences were found between male and female subjects. Males had larger mesiodistal crown widths than females. The Tanaka-Johnston prediction overestimated tooth size and the Boston University prediction generally underestimated tooth size.

In general, statistically significant differences have not been found between right and left sides of the dental arch (Kaplan et al. 1977; Bishara and Jakobsen 1998; Pancherz and Schäffer 1999; Legovic et al. 2003; Melgaco et al. 2007; Bherwani and Fida 2011). Symmetry

between right and left sides exists in most cases. Although there is a consensus that a great deal of symmetry exists between right and left sides, the evidence for sex differences is equivocal. The effect of sex on the accuracy of predictions of the sum of the unerupted canines and premolars is ambiguous. Sex did not appear to affect the accuracy of the predictions in some studies (Kaplan et al. 1977; Gardner 1979; Pancherz and Schäffer 1999; Bherwani and Fida 2011). Mesiodistal widths, however, were found to be greater in males than in females and did affect predictions (Legovic et al. 2003; Melgaco et al. 2007, Philip et al. 2010).

Since mixed-dentition analyses were developed from a study sample of Northern European descent, it has been hypothesized that there may be ethnic differences. Altherr et al. (Altherr et al. 2007) evaluated the Tanaka-Johnston method of prediction in black and white subjects. It was found that the Tanaka-Johnston analysis overestimated the mesiodistal widths in white females and underpredicted most in the mandibular arch of black males (Altherr et al. 2007). This investigation suggests again that sex, as well as ethnicity, might play a role in traditional mixed-dentition analyses. New linear

regression equations have been developed to account for ethnic variations in different populations (Lee-Chan et al. 1998; Nourallah et al. 2002; Altherr et al. 2007; Philip et al. 2010; Bherwani and Fida 2011; Allesandri Bonetti et al. 2011).

Simple linear and multiple linear regression equations continue to be proposed to improve upon previous methods of prediction. Various predictors have been used. New methods attempted to simplify the prediction process or account for sex and ethnic differences amongst populations (Nourallah et al. 2002; Altherr et al. 2007; Melgaco et al. 2007; Philip et al. 2010; Bherwani and Fida 2011; Allesandri Bonetti et al. 2011).

Error appears to be present within all mixed dentition analyses. Currently, periapical radiographs are not routinely taken on young children in the early mixed dentition stage and the production of accurate radiographs used for diagnostic purposes are highly technique sensitive. Widely used mixed dentition analyses, such as Moyers and Tanaka-Johnston methods, tend to overestimate the sum of the mesiodistal widths of the buccal segment of teeth. These methods were also

developed with Caucasian children, and therefore adjustments need to be made for variations amongst different ethnic groups. Although the method of Moyers and Tanaka and Johnston are most widely used clinically, radiographic correlation methods have been found to be more precise than those that only employ mesiodistal widths of erupted teeth for prediction (Gardner 1979; Kaplan et al. 1977).

With the advent of cone-beam computed tomography and its introduction in dentistry in 2001, a wealth of information is currently available. The possibility of increasing accuracy and eliminating the effects of certain variables, such as sex and ethnicity, in the prediction of the mesiodistal diameter of the permanent canines and premolars is now conceivable. Cone-beam computed tomography data can be reconstructed into three-dimensional volumetric- and two-dimensional images and the resultant images require no adjustment for magnification. Studies have established the reliability and accuracy of linear facial and dental measurements on volumetric images produced from scans of dry skulls (Stratemann et al. 2007; Berco et al. 2009; Baumgaertel et al. 2009).

Nguyen (Nguyen et al. 2011) attempted to establish the reliability and accuracy of measuring the mesiodistal diameter of unerupted teeth from CBCT data in two- and three-dimensional reconstructions. Extracted teeth were implanted in Aquasil Putty Mix to simulate the density of bone, and the twenty-five extracted teeth were measured before being implanted in the putty material. The models with implanted extracted teeth were scanned and reconstructions made. Two CBCT software programs, InVivoDental and CBWorks, and three different viewing methods were used to make measurements from CBCT data. A section view and a volume view were used with InVivoDental, and a volume render mode was used with CBWorks. Measurements for the three CBCT methods and the physical method with a digital caliper were repeated three times one week apart, by two investigators, to establish intra-relater reliability and inter-relater reliability, respectively. Reliability was established for both investigators individually using the intra-class correlation coefficient for all four methods of measurement. Pearson's correlations were used to assess agreement between investigators, which is not the most appropriate test. Instead, authors could have used

intraclass correlation coefficient like they did for individual reliability.

Pearson's correlation coefficients compared the mean values of CBCT methods to the mean values of the physical method of measurement. CBWorks Volume Render view was the most reliable method of CBCT measurement between investigators, but InVivo Sections view was the most accurate when compared to physical measurement. A high correlation (0.94-0.98) was found between the CBCT measurements and the extracted teeth, but the widths were slightly underestimated.

Although a good attempt, live subjects were not used and bone and supporting tissues were simply simulated. Roots of deciduous teeth and varying density of bone could affect the measurements if made from reconstructed CBCT data of live subjects. The small sample size of twenty-five extracted teeth consisted only of premolars and molars, not canines. Different morphology of teeth have the potential to affect the reliability and accuracy of measurements made. A paired Student t-test might have been more appropriate to assess the accuracy of the measurements made on CBCT images compared to the true value.

Efforts to determine the reliability and accuracy of measuring the mesiodistal diameter of unerupted posterior teeth on CBCT reconstructions of live subjects appear to be lacking. If reliable and accurate measurements on uerupted posterior teeth can be made on CBCT reconstructions, predictive methods can be supplemented and/or replaced with true values to aid the development of a treatment plan when a CBCT scan is indicated for an individual patient.

REFERENCES

Alessandri Bonetti G, Verganti S, Zanarini M, Bonetti S, Gatto MR. Mixed dentition space analysis for a northern Italian population: new regression equations for unerupted teeth. Prog Orthod 2011;12:94-9.

Altherr ER, Koroluk LD, Phillips C. Influence of sex and ethnic tooth-size differences on mixed-dentition space analysis. Am J Orthod Dentofacial Orthop 2007;132:332-9.

Ballard ML, Wylie WL. Mixed dentition case analysis-estimating size of unerupted permanent teeth. Am J Ortho & Oral Surg 1947;33:754-9.

Baumgaertel S, Palomo JM, Palomo L, Hans MG. Reliability and accuracy of cone-beam computed tomography dental measurements. Am J Orthod Dentofacial Orthop 2009;136:19-25.

Berco M, Rigali PH, Miner RM, DeLuca S, Anderson NK, Will LA. Accuracy and reliability of linear cephalometric measurements form cone-beam computed tomography scans of a dry human skull. Am J Orthod Dentofacial Orthop 2009;136:17.e1-9.

Bherwani AK, Fida M. Development of a prediction equation for the mixed dentition in a Pakistani sample. Am J Orthod Dentofacial Orthop 2011;140:626-32.

Bishara SE, Staley RN. Mixed-dentition mandibular arch length analysis: A step-by-step approach using the revised Hixon-Oldfather prediction method. Am J Orthod 1984;86:130-5.

Black GV. Descriptive anatomy of the human teeth, 4th ed. Philadelphia, SS White Mfg Co 1897;16.

Gardner RB. A comparison of four methods of predicting arch length. Am J Orthod 1979;75:387-98.

Hixon EH, Oldfather RE. Estimation of the sizes of unerupted cuspid and bicuspid teeth. Angle Orthod 1958;28:236-40.

Kaplan RG, Smith CC, Kanarek PH. An analysis of three mixed dentition analyses. J Dent Res 1977;56:1337-43.

Lee-Chan S, Jacobson BN, Chwa KH, Jacobson RS. Mixed dentition analysis for Asian-Americans. Am J Orthod Dentofacial Orthop 1998;113:293-9.

Legovic M, Novosel A, Legovic A. Regression equations for determining mesiodistal crown diameters of canines and premolars. Angle Orthod 2003;73: 314-8.

Lima Martinelli F, Martinelli de Lima E, Rocha R, Souza Tirre-Araujo M. Prediction of lower permanent canine and premolars width by correlation methods. Angle Orthod 2005;75:805-8.

Melgaco CA, de Sousa Araújo MT, de Oliveira Ruellas AC. Mandibular permanent first molar and incisor width as predictor of mandibular canine and premolar width. Am J Orthod Dentofacial Orthop 2007;132:340-5.

Moyers RE. Handbook of orthodontics, 4th ed. Chicago, Year Book Medical Publishers 1988;235-9.

Nance HN. The limitations of orthodontic treatment in mixed dentition diagnosis and treatment. Am J Ortho & Oral Surg 1947;33:177-223.

Nguyen E, Boychuk D, Orellana M. Accuracy of cone-beam computed tomography in predicting the diameter of unerupted teeth. Am J Orthod Dentofacial Orthop 2011;140:e59-66.

Nourallah AW, Gesch D, Khordaji MN, Splieth C. New regression equations for predicting the size of unerupted canines and premolars in a contemporary population. Angle Orthod 2002;72:216-21.

Pancherz H, Schäffer C. Individual-based prediction of the size of the supporting zones in the permanent dentition. J Orofac Orthop 1999;60: 227-35.

Philip NI, Prabhakar M, Arora D, Chopra S. Applicability of the Moyers mixed dentition probability tables and new prediction aids for a contemporary population in India. Am J Orthod Dentofacial Orthop 2010;138:339-45.

Quimby ML, Vig KWL, Rashid RG, Firestone AR. The accuracy and reliability of measurements made on computer-based digital models. Angle Orthod 2004;74:298-303.

Stratemann SA, Huang JC, Maki K, Hatcher DC. Comparison of cone beam computed tomography imaging with physical measures. Dentomaxillofac Radiol 2008;37:80-93.

Tanaka MM, Johnston LE. The prediction of the size of unerupted canines and premolars in a contemporary orthodontic population. J Am Dent Assoc 1974;88:798-801.

Zilberman O, Huggare JA, Parikakis KA. Evaluation of the validity of tooth size and arch width measurements using conventional and three-dimensional virtual orthodontic models. Angle Orthod 2003;73:301-6.

## STATEMENT OF THESIS

The objective of this study is to investigate the reliability and accuracy of diameter measurements of permanent posterior unerupted teeth on cone-beam computed tomography (CBCT) reconstructions.

It is hypothesized that there is no difference between the mesiodistal diameter of unerupted permanent teeth measured on volumetric images generated with the CB MercuRay imaging unit and the corresponding erupted permanent teeth measured physically with digital calipers on plaster casts fabricated from alginate impressions.

# THE RELIABILITY AND ACCURACY OF CBCT IN MEASURING DIAMETER OF UNERUPTED POSTERIOR TEETH

Authors: Celia E. Fenell DDS[a]

Sena Narendran DDS, DDPHRCS, MSc[b]

J. Martin Palomo DDS, MSD[c]

Sebastian Baumgaertel DMD, MSD[d]

a – Resident, Department of Orthodontics, Case Western Reserve University, Cleveland, OH

b – Associate Professor, Department of Community Dentistry, Case Western Reserve University, Cleveland, OH

c – Associate Professor and Program Director, Department of Orthodontics, Case Western Reserve University, Cleveland, OH

d – Clinical Associate Professor, Department of Orthodontics, Case Western Reserve University, Cleveland, OH

Corresponding author/reprint requests to:
Sebastian Baumgaertel, DMD, MSD
Case Western Reserve University
School of Dental Medicine
Department of Orthodontics
10900 Euclid Ave.
Cleveland, OH 44106

ABSTRACT

**Introduction:** In the mixed dentition, the space available for unerupted canines and premolars is an important variable for future treatment considerations. This study aimed to investigate the reliability and accuracy of diameter measurements of permanent posterior unerupted teeth on cone-beam computed tomography (CBCT) reconstructions. **Subjects and Methods:** Seventeen subjects had been scanned with dental CBCT during the mixed dentition stage and plaster casts fabricated from alginate impressions were made at a later timepoint during the permanent dentition. The greatest mesiodistal diameter of unerupted canines and premolars were measured on the CBCT reconstructions. The same measurements were made on plaster casts on the erupted teeth using a high-precision digital caliper. Reliability was assessed using the intraclass correlation coefficient, and accuracy was assessed using the paired Student t-test and Wilcoxon signed-ranks test. **Results:** Both the CBCT and digital caliper (DC) measurements were reliable ($r>0.80$). The CBCT measurements generally underestimated the true values, which was statistically significant for only mandibular first premolars. CBCT measurements were accurate to 0.12mm. **Conclusions:** Levels of reliability for all measurements were acceptable and significant differences between CBCT and DC measurements were found only for mandibular first premolars. Because the detected differences cannot be considered clinically significant, CBCT can be used to measure the mesiodistal diameter of unerupted teeth.

**Introduction:**

An accurate diagnosis of orthodontic problems is critical to a successful treatment plan. In the mixed dentition, the space available for unerupted canines and premolars is an important determinant for future treatment considerations. The primary molars are on average larger than the premolars, and the primary canine is smaller than its permanent counterpart.[1] Mixed dentition analyses aim to predict the size of the unerupted posterior permanent teeth even though great variability can exist.

Orthodontic records including radiographs and dental casts are tools for diagnosis. Study models provide the clinician an opportunity to make measurements and quantify different forms of malocclusions. Plaster casts fabricated from alginate impressions are true to anatomic form and can be employed to make accurate dental measurements outside of the patient's mouth.[2,3] A reliable and accurate method to evaluate required space for the permanent teeth in the mixed dentition can aid in decision making and predicting future orthodontic needs of a patient: need for serial extraction, space maintenance or regaining, eruption guidance, or observation without any treatment. Traditionally, space analyses predicted the size of the unerupted canines and premolars. These methods utilize measurements of erupted teeth,[4-6] measurements of unerupted teeth from radiographs,[1,7] or a combination of measurements of erupted teeth and unerupted teeth from radiographs,[8,9] but these methods all come with inherent inaccuracies.

Until now, only one study[10] has attempted to establish the accuracy of measuring the mesiodistal diameter of unerupted teeth from cone-beam computed tomography (CBCT) data in two- and three-dimensional reconstructions. Unerupted teeth were simulated by extracted teeth and bone was simulated by a putty material. There was a high correlation between the measurements made on CBCT and the direct measurements of extracted teeth, but the CBCT measurements were slightly less than the direct measurements. Efforts to determine the reliability and accuracy of measuring the mesiodistal diameter of unerupted posterior teeth on CBCT reconstructions of live subjects appear to be lacking. If reliable and accurate measurements of uerupted posterior teeth can be made on CBCT reconstructions, predictive methods can be supplemented and/or replaced with true values to aid the development of a treatment plan when a CBCT scan is indicated for an individual patient. The purpose of this study is to investigate the reliability and accuracy of measuring the greatest mesiodistal diameter of unerupted canine, first premolar, and second premolar teeth on three-dimensional reconstructions generated from CBCT scans of live subjects.

**Materials and Methods:**

The Institutional Review Board at Case Western Reserve University (CWRU), Cleveland, OH approved the study. The study sample included CBCT data and plaster casts of 17 subjects (11 female, 6 male) treated in the orthodontic clinics at the

CWRU School of Dental Medicine. We set the power of the study to be 0.90 and alpha to be 0.05, which resulted in a sample size of 21 teeth.

The following inclusion criteria were applied: all subjects who presented for Phase I orthodontic treatment with at least one quadrant of unerupted permanent posterior teeth (canine, first premolar, and second premolar) who had CBCT scans using the Hitachi CB MercuRay Volumetric Digital Imaging Unit (Hitachi Medical, Tokyo, Japan); all of the above subjects who subsequently presented for Phase II orthodontic treatment with either initial of final plaster casts fabricated from alginate impressions with the same quadrant (as above) of permanent posterior teeth fully erupted. The mixed dentition records were taken at ages ranging from 7 years 1 month to 12 years 3 months (mean, 8 years 11 months). The permanent dentition records were taken at ages ranging from 11 years 4 months to 16 years 0 months (mean 12 years 7 months).

Subjects with the following criteria were excluded: craniofacial abnormalities; radiographic evidence of osseous pathological processes; obvious abnormalities affecting the formation of enamel or dentin, or the form of the teeth, including fractures of the erupted permanent posterior teeth (canine, first premolar, second premolar); proximal carious lesions or proximal restorations of the permanent posterior teeth (canine, first premolar, second premolar) determined radiographically or photographically; interproximal reduction of any permanent teeth if final records were to be used determined from clinical treatment chart entries; damaged, distorted, or non-locatable Phase II plaster casts.

All scans were taken at the Craniofacial Imaging Center at the CWRU School of Dental Medicine, using the custom settings of 2 mA, 120 kVp, and a 12-inch field of view.[11,12] Image data for each patient consisted of 512 slices, with isometric voxels sized 0.3777 mm. Image resolution was 1024 x 1024 pixels and 12 bits per pixel (4096 greyscale). Scans were taken with patients seated with head in the natural position and teeth in maximum intercuspation, which was done at the end of the exhalation period when the patient was not swallowing.

The software Dolphin Imaging 11.5 Premium (Patterson Dental, St. Paul, MN) was used for image processing. The unerupted posterior teeth were manually segmented from the volume in a Volume Render mode using the "Volume Sculpting" option and the "Free Form" tool (Figure 1). The magnification and orientation were adjusted to view the unerupted teeth from the occlusal aspect. The histogram function was used to achieve optimal opacity and blend out undesired background as much as possible (Figure 2). The "Digitize/Measurement" option and the "Line" tool were used to measure the mesiodistal diameter to the nearest 0.1mm (Figure 3). Measurements on the casts were made using a high-precision digital caliper calibrated to the nearest 0.01mm (Digimatic Caliper CD-6 in CX, Mitutoyo America, Plymouth, MI). The greatest mesiodistal diameter from the mesial anatomic contact point to the distal anatomic contact point of each tooth perpendicular to the long axis was recorded for both CBCT and plaster cast measurements. Data were entered into a Microsoft Office 2007 Excel spreadsheet (Microsoft Corp., Redmont, WA), then

exported to Statistical Package for Social Sciences (IBM/SPSS, Chicago, IL), and data were analyzed using the latter.

All measurements for the CBCT and digital caliper (DC) methods were repeated at least 2 weeks apart by a single operator. Intraclass correlation coefficient assessed intra-operator reliability for both methods. The mean of the two recordings from each subject was used to evaluate the results. Shapiro-Wilk test assessed distribution characteristics of both the CBCT and DC data. Accuracy was assessed by comparing the measurements from the CBCT volumes with direct measurements made on the plaster casts with digital calipers. The paired Student t-test and the Wilcoxon signed-ranks test determined any differences between the CBCT and DC measurements of the same teeth, for normally distributed data and data with a lack of normal distribution, respectively. The Bonferonni correction was applied to offset the effects of multiple comparisons.

**Results:**

The Shapiro-Wilk test revealed a lack of normal distribution in the data. The CBCT and DC measurements were not normally distributed for the maxillary canine, the mandibular sum of widths, all sum of widths, and overall (138 teeth).

The intraclass correlation coefficient was above 0.80 for both CBCT and DC measurements, indicating acceptable intraoperator reliability (Table I). However, reliability of CBCT measurements of mandibular first premolars was the lowest of all teeth of interest.

Comparisons between CBCT and DC measurements with the paired Student t-test and the Wilcoxon signed-ranks test revealed statistically significant differences for the mandibular first premolars and for any teeth of interest that included the mandibular first premolars (Table II). Mean differences between CBCT and DC measurements were small. The CBCT measurements were generally lower than the DC measurements except for maxillary and mandibular canines. CBCT measurements were accurate to the 0.12mm.

**Discussion:**

The goal of this study was to assess the reliability and accuracy of diameter measurements of unerupted permanent posterior teeth on volumetric CBCT images. The same measurements were made on plaster casts fabricated from alginate impressions true to anatomic form. Both methods proved to be reliable, consistent with previous results.[2,3,10] Although reliable, CBCT measurements slightly underestimated the true value of the mesiodistal diameters of erupted teeth. These findings were similar to Nguyen et al.[10] who showed measurements using CBCT were on average of 0.4mm less than the true value. In the study by Nguyen and co-workers, bone, supporting tissues, and unerupted teeth were simulated by implanting extracted teeth in a putty material. An isolated tooth placed in a consistent material may not accurately depict an unerupted tooth in a live subject. Our study used image data of real live orthodontic patients and hence investigated a pragmatic state where bone

was of varying density and roots of deciduous teeth and adjacent teeth could be in close proximity.

The difference between the CBCT and DC measurements for the mandibular first premolar was statistically significant. The CBCT measurements of the mandibular first premolar were of acceptable reliability, but the lowest of all teeth in the study. These two findings might indicate it was difficult to precisely identify the mesial and distal anatomic contact points of mandibular first premolars versus other teeth using CBCT. From the occlusal view, maxillary premolars tend to be more oblong or rectangular, whereas mandibular premolars are more square.[13] The crown morphology, in combination with the variables previously mentioned (bone, roots, adjacent teeth) could have contributed to the difference between CBCT and DC measurements.

The partial volume effect is one consideration when the general underestimation of the mesiodistal widths of the unerupted teeth with CBCT is examined. The partial volume effect is an artifact that appears when a scanner is unable to differentiate between two structures if a voxel lies at the junction of two structures. A voxel can only display one degree of intensity so when a voxel is at the junction of enamel and bone, the processor tries to average out the two densities or structures, and information is lost. If there is a high threshold value, smaller objects than the actual can be created.[14]

Although CBCT generally underestimated the true widths, CBCT overestimated the maxillary and mandibular canine widths when compared to the

measurements with the DC. In the maxillary arch, the canine is typically the last tooth of interest to erupt. The distal of the canine is just coronal to the cemento-enamel junction of the maxillary first premolar under the mesiodistal height of contour of the premolar. This makes it very difficult to segment the mesial of maxillary first premolar from the distal of the maxillary canine. This does not affect the measurement of the first premolar because the crown of the first premolar is further coronal already because it is the first to erupt of the three teeth.

The crown of the mandibular canine is sometimes at the level of the CEJ of the mandibular lateral incisors. This makes it very difficult to segment the two dense areas from each other. The roots of the permanent lateral incisors in both arches also make measurements of the canines more difficult. When using the histogram function to blend out undesired background, the roots of the permanent teeth are in close proximity to the crown of the canines. This proximity of the lateral root to the crown of the incisor could have contributed to the overestimation as well. In order to measure the teeth, a fine balance with the histogram function to allow clear delineation of the tooth of interest must be achieved, but this sometimes results in more background noise being present.

Regression equations based on correlations of groups of teeth tend to over- and under-estimate the actual values.[5,6,] Although there is a consensus that a great deal of symmetry exists between right and left sides,[9,15-18] the evidence for sex differences is equivocal. The effect of sex on the accuracy of predictions of the sum of the unerupted canines and premolars is ambiguous. Sex did not appear to affect the

accuracy of the predictions in some studies.[15,18,19] Mesiodistal widths, however, were found to be greater in males than in females and did affect predictions.[16,17,20]

Since widely used mixed-dentition analyses[5,6] have been developed from a study sample of those of Northern European descent, it has been hypothesized that there may be ethnic differences. Altherr et al.[21] evaluated the Tanaka-Johnston analysis on black and white subjects. It was found that the Tanaka-Johnston analysis overestimated the mesiodistal widths in white females and underpredicted most in the mandibular arch of black males. New linear regression equations have been developed to account for ethnic variations in different populations.[18,20-24]

With the advent of CBCT and its introduction in dentistry, a wealth of information is currently available. The possibility of increasing accuracy and eliminating variables, such as sex and ethnicity, in the prediction of the mesiodistal diameter of the permanent canines and premolars to complete a mixed dentition analysis is now conceivable. CBCT data can be reconstructed into three-dimensional volumetric- and two-dimensional images and the resultant images require no adjustment for magnification. Studies have established the reliability and accuracy of linear facial and dental measurements on volumetric images produced from scans of dry skulls.[25-27]

According to the position statement by the American Academy of Oral and Maxillofacial Radiology,[28] CBCT is a useful aide/adjunct in the diagnosis of impacted teeth. The mesiodistal diameter of bilaterally impacted teeth could be measured to develop a definitive treatment plan (extraction, uncovering, and traction).

Although statistically significant differences were found between CBCT and DC measurements, the mean differences are not substantial enough to be clinically significant. Mixed dentition analyses could be more precise due to the elimination of differences due to sex and ethnicity, with the use of CBCT.

**Conclusions:**

Acceptable levels of reliability indicate that CBCT can be used to measure the mesiodistal diameter of unerupted permanent posterior teeth; detected differences were minimal and not clinically significant. CBCT may be superior to other established methods as it is less sensitive when it comes to inaccuracies introduced by gender and ethnicity and is accurate to the 0.12mm.

**References:**


1. Black GV. Descriptive anatomy of the human teeth, 4th ed. Philadelphia, SS White Mfg Co 1897;16.

2. Zilberman O, Huggare JA, Parikakis KA. Evaluation of the validity of tooth size and arch width measurements using conventional and three-dimensional virtual orthodontic models. Angle Orthod 2003;73:301-6.

3. Quimby ML, Vig KWL, Rashid RG, Firestone AR. The accuracy and reliability of measurements made on computer-based digital models. Angle Orthod 2004;74:298-303.

4. Ballard ML, Wylie WL. Mixed dentition case analysis-estimating size of unerupted permanent teeth. Am J Ortho & Oral Surg 1947;33:754-9.

5. Moyers RE. Handbook of orthodontics, 4th ed. Chicago, Year Book Medical Publishers 1988;235-9.

6. Tanaka MM, Johnston LE. The prediction of the size of unerupted canines and premolars in a contemporary orthodontic population. J Am Dent Assoc 1974;88:798-801.

7. Nance HN. The limitations of orthodontic treatment in mixed dentition diagnosis and treatment. Am J Ortho & Oral Surg 1947;33:177-223.

8. Hixon EH, Oldfather RE. Estimation of the sizes of unerupted cuspid and bicuspid teeth. Angle Orthod 1958;28:236-40.

9. Bishara SE, Staley RN. Mixed-dentition mandibular arch length analysis: A step-by-step approach using the revised Hixon-Oldfather prediction method. Am J Orthod 1984;86:130-5.

10. Nguyen E, Boychuk D, Orellana M. Accuracy of cone-beam computed tomography in predicting the diameter of unerupted teeth. Am J Orthod Dentofacial Orthop 2011;140:e59-66.

11. Kwong J, Palomo JM, Landers MA, Figueroa A, Hans MG. Image quality produced by different CBCT settings. Am J Orthod Dentofac Orthoped 2008;133:317-27.

12. Palomo, JM, Rao PS, Hans MG. Influence of CBCT exposure conditions on radiation dose. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;105:773-82.

13. Scheid RC. Woelfel's dental anatomy: its relevance to dentistry, 7th ed. Philadelphia, Lippincott Williams & Wilkins 2007;197.

14. Halazaonetis, DJ. Commentary. Am J Orthod Dentofacial Orthop 2009;136: 25-8.

15. Kaplan RG, Smith CC, Kanarek PH. An analysis of three mixed dentition analyses. J Dent Res 1977;56:1337-43.

16. Legovic M, Novosel A, Legovic A. Regression equations for determining mesiodistal crown diameters of canines and premolars. Angle Orthod 2003;73:314-8.

17. Melgaco CA, de Sousa Araújo MT, de Oliveira Ruellas AC. Mandibular permanent first molar and incisor width as predictor of mandibular canine and premolar width. Am J Orthod Dentofacial Orthop 2007;132:340-5.

18. Bherwani AK, Fida M. Development of a prediction equation for the mixed dentition in a Pakistani sample. Am J Orthod Dentofacial Orthop 2011;140:626-32.

19. Gardner RB. A comparison of four methods of predicting arch length. Am J Orthod 1979;75:387-98.

20. Philip NI, Prabhakar M, Arora D, Chopra S. Applicability of the Moyers mixed dentition probability tables and new prediction aids for a contemporary population in India. Am J Orthod Dentofacial Orthop 2010;138:339-45.

21. Altherr ER, Koroluk LD, Phillips C. Influence of sex and ethnic tooth-size differences on mixed-dentition space analysis. Am J Orthod Dentofacial Orthop 2007;132:332-9.

22. Lee-Chan S, Jacobson BN, Chwa KH, Jacobson RS. Mixed dentition analysis for Asian-Americans. Am J Orthod Dentofacial Orthop 1998;113:293-9.

23. Nourallah AW, Gesch D, Khordaji MN, Splieth C. New regression equations for predicting the size of unerupted canines and premolars in a contemporary population. Angle Orthod 2002;72:216-21.

24. Alessandri Bonetti G, Verganti S, Zanarini M, Bonetti S, Gatto MR. Mixed dentition space analysis for a northern Italian population: new regression equations for unerupted teeth. Prog Orthod 2011;12:94-9.

25. Stratemann SA, Huang JC, Maki K, Hatcher DC. Comparison of cone beam computed tomography imaging with physical measures. Dentomaxillofac Radiol 2008;37:80-93.

26. Berco M, Rigali PH, Miner RM, DeLuca S, Anderson NK, Will LA. Accuracy and reliability of linear cephalometric measurements form cone-beam

computed tomography scans of a dry human skull. Am J Orthod Dentofacial Orthop 2009;136:17.e1-9.

27. Baumgaertel S, Palomo JM, Palomo L, Hans MG. Reliability and accuracy of cone-beam computed tomography dental measurements. Am J Orthod Dentofacial Orthop 2009;136:19-25.

28. American Academy of Oral and Maxillofacial Radiology. Clinical recommendations regarding use of cone beam computed tomography in orthodontic treatment. Position statement by the American Academy of Oral and Maxillofacial Radiology. Oral Surg Oral Med Pathol Oral Radiol 2013;116:238-57.

**Figures:**

Figure 1. CBCT volume before segmentation of the unerupted teeth

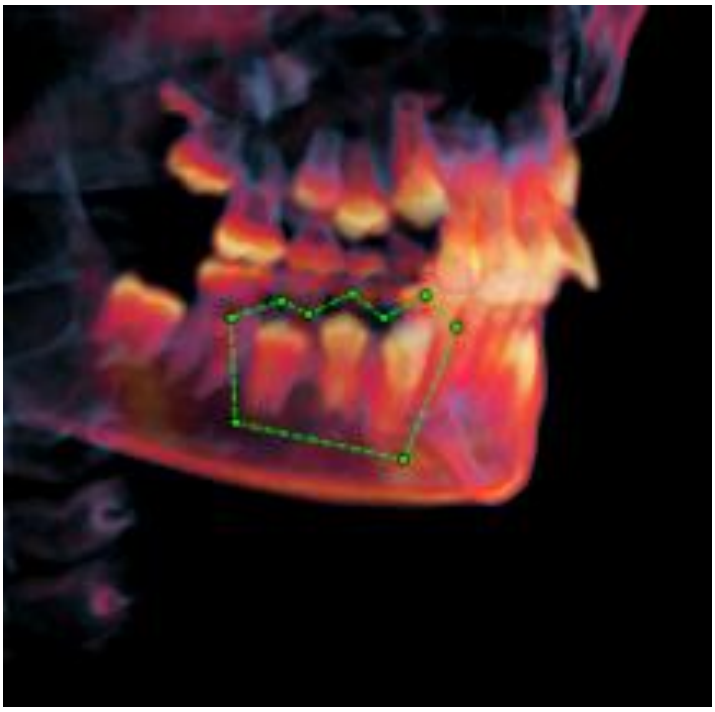


Figure 2. CBCT volume after segmentation of the unerupted teeth and use of the histogram function

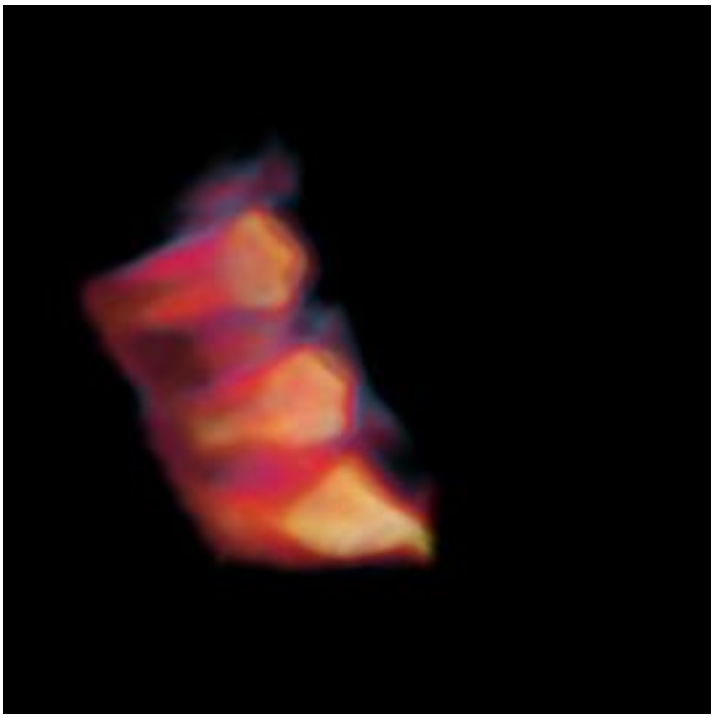
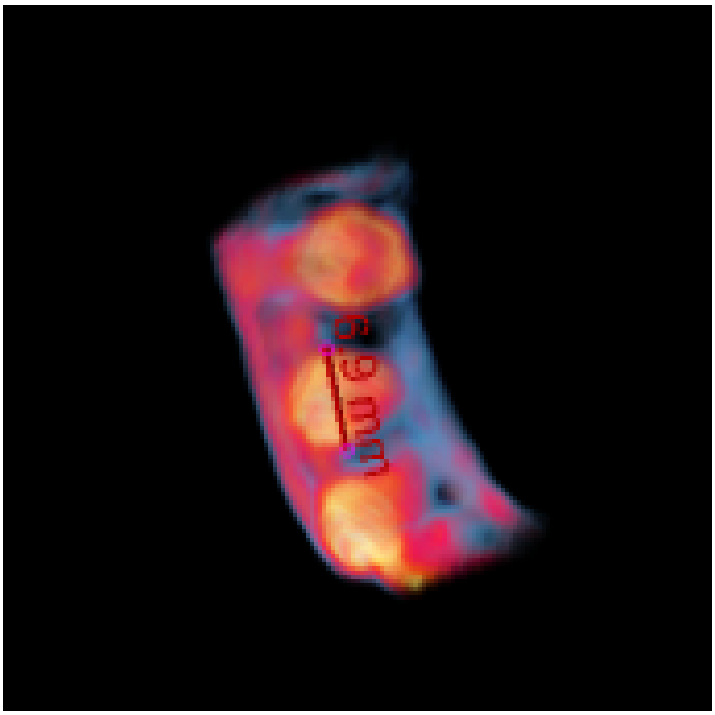


Figure 3. CBCT volume after adjustment of magnification and orientation to measure the unerupted teeth from the occlusal aspect



## Tables:

Table I. Evaluation of intraoperator reliability for CBCT and DC measurements

| | CBCT | DC |
|---|---|---|
| *Measurement (mm)* | *r* | *r* |
| Maxillary canine | 0.961 | 0.995 |
| Maxillary first premolar | 0.948 | 0.989 |
| Maxillary second premolar | 0.904 | 0.995 |
| Mandibular canine | 0.914 | 0.996 |
| Mandibular first premolar | 0.830 | 0.993 |
| Mandibular second premolar | 0.904 | 0.995 |
| Overall | 0.954 | 0.997 |

Table II. Differences in mesiodistal diameter of CBCT and DC measurements

| | CBCT | DC | | CBCT-DC | | |
|---|---|---|---|---|---|---|
| *Measurement (mm)* | *Mean ± SD* | *Mean ± SD* | *Test* | Δ *Mean ± SD* | *P* | *P** |
| Maxillary first premolar (n=21) | 7.08 ± 0.40 | 7.15 ± 0.35 | T | -0.07 ± 0.19 | 0.096 | NS |
| Maxillary second premolar (n=21) | 6.61 ± 0.45 | 6.66 ± 0.45 | T | -0.05 ± 0.14 | 0.088 | NS |
| Mandibular canine (n=25) | 6.79 ± 0.34 | 6.75 ± 0.33 | T | 0.03 ± 0.14 | 0.249 | NS |
| Mandibular first premolar (n=25) | 7.08 ± 0.30 | 7.20 ± 0.35 | T | -0.12 ± 0.12 | 0.000 | * |
| Mandibular second premolar (n=25) | 7.05 ± 0.43 | 7.13 ± 0.44 | T | -0.08 ± 0.15 | 0.008 | NS |
| Maxillary sum of widths (n=21) | 21.52 ± 1.19 | 21.61 ± 1.10 | T | -0.09 ± 0.28 | 0.161 | NS |
| Maxillary canine (n=21) | 7.84 ± 0.56 | 7.80 ± 0.51 | W | 0.04 ± 0.13 | 0.289 | NS |
| Mandibular sum of widths (n=25) | 20.91 ± 0.87 | 21.09 ± 0.84 | W | -0.17 ± 0.25 | 0.004 | * |
| All sum of widths (n=46) | 21.19 ± 1.06 | 21.33 ± 0.99 | W | -0.13 ± 0.26 | 0.000 | * |
| Overall (n=138) | 7.06 ± 0.55 | 7.12 ± 0.54 | W | -0.04 ± 0.15 | 0.000 | * |

T, paired Student t-test; W, Wilcoxon signed-ranks test

*P**, *P* value after Bonferroni correction; *, significant; NS, not significant

APPENDIX A

**NOTICE OF APPROVAL**

CWRU IRB Protocol Number: **IRB-2013-364**

Protocol Title: ***The Reliability and Accuracy of Diameter Measurements of Unerupted Posterior Teeth***

Responsible Investigator (RI): **Juan Palomo**

RI Department: **Orthodontics**

Type of Review: **Expedited**

Risk Level: **Minimal**

Vulnerable Population(s): **Children**

**Approval Date: 04/01/2013**

**CONTINUING REVIEW DEADLINE: 03/17/2014**

**EXPIRATION DATE: 03/31/2014**

APPENDIX B

TABLE 1.--Abbreviations

| | |
|---|---|
| u | Unerupted – CBCT – mesiodistal width (mm) |
| e | Erupted – Digital Caliper – mesiodistal width (mm) |
| 4 | Maxillary right second premolar |
| 5 | Maxillary right first premolar |
| 6 | Maxillary right canine |
| 11 | Maxillary left canine |
| 12 | Maxillary left first premolar |
| 13 | Maxillary left second premolar |
| 20 | Mandibular left second premolar |
| 21 | Mandibular left first premolar |
| 22 | Mandibular left canine |
| 27 | Mandibular right canine |
| 28 | Mandibular right first premolar |
| 29 | Mandibular right second premolar |

TABLE 2.--Measurements from CBCT (unerupted teeth) – Input 1

| Subject | Sex | Race | Age at T1 | Age at T2 | u4 | u5 | u6 | u11 | u12 | u13 | u20 | u21 | u22 | u27 | u28 | u29 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CO217 | F | AA | 101 | 144 | . | . | . | 7.9 | 7.7 | 6.7 | 7.2 | 7.8 | 6.4 | . | . | . |
| GE62 | M | C | 123 | 147 | . | . | . | . | . | . | 6.4 | 6.6 | 7.1 | 6.9 | 6.8 | 6.7 |
| GO120 | F | C | 122 | 160 | 7.1 | 6.9 | 7.8 | 7.8 | 7.2 | 7.3 | . | . | . | . | . | . |
| GR149 | F | C | 93 | 137 | . | . | . | 7.6 | 6.8 | 6.2 | 6.7 | 6.9 | 6.6 | 6.6 | 7 | 6.5 |
| GR180 | M | C | 123 | 157 | 7.1 | 7.5 | 8.9 | 9 | 7.4 | 6.9 | . | . | . | 7.6 | 7.6 | 7.7 |
| GR191 | F | C | 105 | 146 | 6.6 | 7.6 | 7.6 | 7.3 | 7.5 | 6.4 | 7.1 | 7.4 | 6.6 | 6.4 | 7.3 | 7.2 |
| KE88 | M | C | 92 | 151 | . | . | . | . | . | . | 7.3 | 7.3 | 7 | 7.2 | 7.4 | 7.4 |
| MA296 | F | C | 121 | 179 | . | . | . | . | . | . | 6.8 | 7.1 | 6.6 | 6.5 | 6.9 | 6.7 |
| MA306 | F | C | 111 | 160 | . | . | . | 7.3 | 7.2 | 6.4 | 6.8 | 6.9 | 7.1 | . | . | . |
| MO191 | M | C | 120 | 150 | . | . | . | . | . | . | 6.7 | 6.7 | 6.6 | . | . | . |
| NA42 | F | C | 113 | 139 | 7.3 | 7.5 | 8 | 7.9 | 7.3 | 6.7 | 7.7 | 7.1 | 7 | 6.4 | 7.2 | 7.4 |
| OE1 | F | Asian | 106 | 166 | 7.1 | 7.6 | 8.5 | . | . | . | 7.8 | 7.7 | 7.3 | 7.4 | 7.5 | 7.6 |
| RO217 | F | C | 97 | 137 | 6.6 | 7 | 7.5 | 7.5 | 7 | 7 | 7.1 | 7.1 | 6.7 | 7 | 7 | 7.1 |
| RO259 | M | C | 112 | 137 | . | . | . | 8.5 | 6.9 | 6.7 | . | . | . | . | . | . |
| SH118 | M | C | 99 | 149 | 6 | 6.9 | 7.2 | 7.7 | 7 | 5.7 | 7 | 7.1 | 6.6 | 6.9 | 6.6 | 6.2 |
| SF2 | F | C | 99 | 192 | 6.1 | 6.9 | 8 | 7.5 | 6.5 | 6.5 | 6.9 | 6.8 | 6.8 | 6.5 | 6.8 | 7.1 |
| YO34 | F | C | 86 | 145 | 6.2 | 6.5 | 7.1 | 7.3 | 6.4 | 6.2 | 6.8 | 6.5 | 6.8 | . | . | . |

TABLE 3.--Measurements from CBCT (unerupted teeth) – Input 2

| Subject | Sex | Race | Age at T1 | Age at T2 | u4 | u5 | u6 | u11 | u12 | u13 | u20 | u21 | u22 | u27 | u28 | u29 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CO217 | F | AA | 101 | 144 | . | . | . | 8 | 7.6 | 7.1 | 7.4 | 7.6 | 6.1 | . | . | . |
| GE62 | M | C | 123 | 147 | . | . | . | . | . | . | 6.4 | 7.1 | 6.9 | 6.9 | 6.5 | 6.3 |
| GO120 | F | C | 122 | 160 | 7 | 7.3 | 7.8 | 7.9 | 7 | 7.4 | . | . | . | . | . | . |
| GR149 | F | C | 93 | 137 | . | . | . | 7.5 | 6.8 | 5.9 | 6.7 | 7 | 6.1 | 6.4 | 6.9 | 6.5 |
| GR180 | M | C | 123 | 157 | 6.6 | 7.8 | 9 | 9.2 | 7.5 | 6.8 | . | . | . | 7.6 | 7.5 | 7.8 |
| GR191 | F | C | 105 | 146 | 6.9 | 7.7 | 7.3 | 7.6 | 7.2 | 6.8 | 6.8 | 7.2 | 6.7 | 6.4 | 7.3 | 7 |
| KE88 | M | C | 92 | 151 | . | . | . | . | . | . | 7.1 | 7.3 | 7.2 | 7 | 7.2 | 7.3 |
| MA296 | F | C | 121 | 179 | . | . | . | . | . | . | 7.2 | 7.1 | 7 | 6.5 | 6.8 | 6.8 |
| MA306 | F | C | 111 | 160 | . | . | . | 7.5 | 7 | 6.9 | 6.7 | 6.7 | 7 | . | . | . |
| MO191 | M | C | 120 | 150 | . | . | . | . | . | . | 7.1 | 7.1 | 6.4 | . | . | . |
| NA42 | F | C | 113 | 139 | 7.2 | 7.4 | 8 | 8.3 | 7.1 | 6.8 | 7.5 | 7 | 6.7 | 6.2 | 6.8 | 8.1 |
| OE1 | F | Asian | 106 | 166 | 7.2 | 7.7 | 8.8 | . | . | . | 7.9 | 7.3 | 7.3 | 7.3 | 7.7 | 7.5 |
| RO217 | F | C | 97 | 137 | 6.7 | 6.9 | 7.6 | 7.4 | 6.9 | 6.7 | 7.2 | 7.2 | 6.9 | 6.9 | 7.5 | 7.5 |
| RO259 | M | C | 112 | 137 | . | . | . | 8.6 | 6.9 | 6.3 | . | . | . | . | . | . |
| SH118 | M | C | 99 | 149 | 6.1 | 6.7 | 7.8 | 7.5 | 6.8 | 5.5 | 6.9 | 6.9 | 6.7 | 6.5 | 6.9 | 6.6 |
| SF2 | F | C | 99 | 192 | 6.4 | 6.6 | 7.8 | 7.4 | 6.4 | 6.3 | 6.8 | 6.9 | 6.7 | 6.6 | 6.7 | 6.9 |
| YO34 | F | C | 86 | 145 | 6 | 6.4 | 7 | 7.2 | 6.5 | 6 | 6.6 | 6.7 | 6.7 | . | . | . |

TABLE 4.--Measurements from Casts (erupted teeth) – Input 1

| Subject | Sex | Race | Age at T1 | Age at T2 | e4 | e5 | e6 | e11 | e12 | e13 | e20 | e21 | e22 | e27 | e28 | e29 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CO217 | F | AA | 101 | 144 | . | . | . | 8.06 | 7.75 | 7.01 | 7.28 | 7.93 | 6.27 | . | . | . |
| GE62 | M | C | 123 | 147 | . | . | . | . | . | . | 6.4 | 6.95 | 7.21 | 7.07 | 6.82 | 6.42 |
| GO120 | F | C | 122 | 160 | 7.31 | 7.25 | 7.64 | 7.65 | 7.35 | 7.29 | . | . | . | . | . | . |
| GR149 | F | C | 93 | 137 | . | . | . | 7.57 | 6.93 | 6.17 | 6.69 | 7.19 | 6.41 | 6.39 | 7.21 | 6.75 |
| GR180 | M | C | 123 | 157 | 6.95 | 7.18 | 8.84 | 8.93 | 7.41 | 7.04 | . | . | . | 7.46 | 7.53 | 7.79 |
| GR191 | F | C | 105 | 146 | 6.54 | 7.5 | 7.45 | 7.45 | 7.55 | 6.57 | 7.29 | 7.63 | 6.52 | 6.56 | 7.56 | 7.29 |
| KE88 | M | C | 92 | 151 | . | . | . | . | . | . | 7.55 | 7.45 | 7.21 | 7.13 | 7.57 | 7.48 |
| MA296 | F | C | 121 | 179 | . | . | . | . | . | . | 6.99 | 7.06 | 6.43 | 6.39 | 7.05 | 6.95 |
| MA306 | F | C | 111 | 160 | . | . | . | 7.64 | 7.21 | 6.59 | 6.9 | 6.79 | 7.06 | . | . | . |
| MO191 | M | C | 120 | 150 | . | . | . | . | . | . | 6.99 | 6.91 | 6.52 | . | . | . |
| NA42 | F | C | 113 | 139 | 7.41 | 7.39 | 8.12 | 8.08 | 7.43 | 7.01 | 7.8 | 7.09 | 6.52 | 6.46 | 7.14 | 7.78 |
| OE1 | F | Asian | 106 | 166 | 7.03 | 7.68 | 8.59 | . | . | . | 7.62 | 7.75 | 7.16 | 7.19 | 7.68 | 7.61 |
| RO217 | F | C | 97 | 137 | 6.74 | 7.11 | 7.44 | 7.39 | 7.08 | 6.73 | 7.37 | 7.43 | 6.82 | 6.79 | 7.42 | 7.4 |
| RO259 | M | C | 112 | 137 | . | . | . | 8.24 | 7.23 | 6.58 | . | . | . | . | . | . |
| SH118 | M | C | 99 | 149 | 5.87 | 6.7 | 7.56 | 7.57 | 6.88 | 5.82 | 6.61 | 7.09 | 6.77 | 6.68 | 6.75 | 6.51 |
| SF2 | F | C | 99 | 192 | 6.39 | 6.55 | 7.55 | 7.6 | 6.54 | 6.3 | 7.07 | 6.85 | 6.73 | 6.5 | 6.82 | 7.07 |
| YO34 | F | C | 86 | 145 | 6.32 | 6.75 | 7.14 | 7.18 | 6.79 | 6.2 | 6.7 | 6.58 | 6.7 | . | . | . |

TABLE 5.--Measurements from Casts (erupted teeth) – Input 2

| Subject | Sex | Race | Age at T1 | Age at T2 | e4 | e5 | e6 | e11 | e12 | e13 | e20 | e21 | e22 | e27 | e28 | e29 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CO217 | F | AA | 101 | 144 | . | . | . | 7.99 | 7.75 | 6.92 | 7.34 | 7.9 | 6.25 | . | . | . |
| GE62 | M | C | 123 | 147 | . | . | . | . | . | . | 6.44 | 6.91 | 7.17 | 7.01 | 6.76 | 6.39 |
| GO120 | F | C | 122 | 160 | 7.22 | 7.09 | 7.8 | 7.83 | 7.24 | 7.25 | . | . | . | . | . | . |
| GR149 | F | C | 93 | 137 | . | . | . | 7.64 | 6.89 | 6.12 | 6.76 | 7.2 | 6.33 | 6.44 | 7.16 | 6.75 |
| GR180 | M | C | 123 | 157 | 6.93 | 7.3 | 8.76 | 8.92 | 7.48 | 6.94 | . | . | . | 7.41 | 7.4 | 7.77 |
| GR191 | F | C | 105 | 146 | 6.57 | 7.49 | 7.4 | 7.38 | 7.47 | 6.6 | 7.2 | 7.54 | 6.54 | 6.51 | 7.5 | 7.21 |
| KE88 | M | C | 92 | 151 | . | . | . | . | . | . | 7.47 | 7.43 | 7.22 | 7.15 | 7.51 | 7.49 |
| MA296 | F | C | 121 | 179 | . | . | . | . | . | . | 6.95 | 7.08 | 6.45 | 6.36 | 7.19 | 6.83 |
| MA306 | F | C | 111 | 160 | . | . | . | 7.58 | 7.08 | 6.69 | 6.96 | 6.71 | 7.04 | . | . | . |
| MO191 | M | C | 120 | 150 | . | . | . | . | . | . | 6.96 | 6.92 | 6.45 | . | . | . |
| NA42 | F | C | 113 | 139 | 7.46 | 7.41 | 8.09 | 8.13 | 7.45 | 6.94 | 7.8 | 7.04 | 6.58 | 6.44 | 7.15 | 7.79 |
| OE1 | F | Asian | 106 | 166 | 7.01 | 7.7 | 8.69 | . | . | . | 7.66 | 7.64 | 7.13 | 7.23 | 7.65 | 7.57 |
| RO217 | F | C | 97 | 137 | 6.85 | 7.18 | 7.39 | 7.38 | 7.13 | 6.82 | 7.4 | 7.42 | 6.77 | 6.79 | 7.46 | 7.5 |
| RO259 | M | C | 112 | 137 | . | . | . | 8.3 | 7.18 | 6.59 | . | . | . | . | . | . |
| SH118 | M | C | 99 | 149 | 5.84 | 6.77 | 7.52 | 7.54 | 6.85 | 5.77 | 6.7 | 7.16 | 6.83 | 6.7 | 6.71 | 6.48 |
| SF2 | F | C | 99 | 192 | 6.41 | 6.56 | 7.61 | 7.62 | 6.55 | 6.3 | 7.12 | 6.8 | 6.72 | 6.48 | 6.79 | 7.09 |
| YO34 | F | C | 86 | 145 | 6.27 | 6.79 | 7.14 | 7.23 | 6.85 | 6.28 | 6.77 | 6.66 | 6.7 | . | . | . |

Table 6.--Assessment of normal distribution of teeth of interest

| | CBCT | | DC | |
|---|---|---|---|---|
| Measurement (mm) | *P* | *Sig* | *P* | *Sig* |
| Maxillary canine | 0.021 | * | 0.019 | * |
| Maxillary first premolar | 0.118 | NS | 0.613 | NS |
| Maxillary second premolar | 0.660 | NS | 0.784 | NS |
| Mandibular canine | 0.699 | NS | 0.066 | NS |
| Mandibular first premolar | 0.338 | NS | 0.411 | NS |
| Mandibular second premolar | 0.381 | NS | 0.319 | NS |
| Overall | 0.001 | * | 0.028 | * |
| Maxillary sum of widths | 0.426 | NS | 0.093 | NS |
| Mandibular sum of widths | 0.032 | * | 0.034 | * |
| All sum of widths | 0.023 | * | 0.005 | * |

*Significant at $P \leq 0.05$; *Sig*, significance; NS, not significant