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Accuracy of Unsegmented CBCT in Mesial-Distal Tooth Measurements

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Accuracy of Unsegmented CBCT in Mesial-Distal Tooth Measurements

by

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A Thesis submitted in partial satisfaction of
the requirements for the degree of
Master of Science in Orthodontics and Dentofacial Orthopedics

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September 2011

Each person whose signature appears below certifies that this thesis in his/her opinion is adequate, in scope and quality as a thesis for the degree of Master of Science.

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CONTENTS

Approval Page . . . iii

Acknowledgements . . . iv

Contents . . . v

Figures . . . vii

Tables . . . viii

Abbreviations . . . ix

Abstract . . . x

Chapter

1. Introduction . . . 1
   - Statement of the Problem . . . 1
   - Hypothesis . . . 2
2. Review of the Literature . . . 3
   - CBCT Uses in Dentistry . . . 3
   - CBCT Measurement Accuracy . . . 5
   - CBCT Hardware and Software Used in Previous Studies . . . 6
   - Model Measurements . . . 7
3. Materials and Method . . . 8
   - Statistical Analysis . . . 14
4. Results . . . 17
   - Reliability . . . 17
   - Intraclass Correlation . . . 17
   - Box-Whisker Plots . . . 18
5. Discussion . . . 25
   - Statistical Significance . . . 25
   - Clinical Significance . . . 25
   - Differences Between Dolphin and OsiriX . . . 26
   - CBCT MPR Measurements . . . 28
   - CBCT Pano Measurements . . . 29
   - Accuracy . . . 29
   - Standardization . . . 30

Conclusions 30
References 32

Appendices

A. Main Data 35
B. Reliability Data 54
C. Python Script to Extract XYZ Points 61

FIGURES

Figure		Page
1	Modified Digital Caliper Beaks.	9
2	Method 1: CBCT MPR - CephalometriX™ Plugin using MPR View.	10
3	Method 2: CBCT Detailed Pano - OsiriX (Maxilla).	12
4	Method 2: CBCT Detailed Pano - OsiriX (Mandible).	12
5	Method 3: CBCT Detailed Pano - Dolphin (Maxilla).	13
6	Method 3: CBCT Detailed Pano - Dolphin (Mandible).	13
7	Method 4: CBCT Simple Pano - OsiriX.	15
8	Method 5: CBCT Simple Pano - Dolphin.	15
9	Result: CBCT MPR - CephalometriX	20
10	Result: CBCT Detailed Pano - OsiriX	21
11	Result: CBCT Detailed Pano - Dolphin	22
12	Result: CBCT Simple Pano - OsiriX	23
13	Result: CBCT Simple Pano - Dolphin	24
14	Cut Line: CBCT Simple Pano OsiriX	27
15	Cut Line: CBCT Simple Pano - Dolphin	27
16	Difference in Length Between an Arc (s) and a Chord (a).	27

TABLES

Table Page

1 Summary of Measurement Methods 16

2 Reliability - Cronbach's Alpha 17

3 Overall Intraclass Correlation with Model Measurements 19

4 Upper vs. Lower / Anterior vs. Posterior Intraclass Correlation 19

ABBREVIATIONS

2D	Two-dimensional
3D	Three-dimensional
CBCT	Cone-beam Computed Tomography
DICOM	Digital Imaging and Communications in Medicine
ICC	Intra-class correlation
MD	Mesial-Distal
MPR	Multi-planar Reconstruction

ABSTRACT OF THE THESIS

Accuracy of Unsegmented CBCT in Mesial-Distal Tooth Measurements

by

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Master of Science, Graduate Program in Orthodontics and Dentofacial Orthopedics
School of Dentistry, September 2011
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Introduction: Cone-beam computed tomography (CBCT) scans may be used to measure mesial-distal (MD) tooth width for orthodontic diagnosis and treatment planning.

Purpose: The objective of this study was to determine if MD tooth measurements from unsegemented CBCT scans in the axial, sagittal, and coronal planes or from a panoramic reconstruction correlate and agree with respective measurements made on study models.

Material and Methods: Using stone models of 30 subjects, reference MD tooth measurements were made using digital calipers. From CBCT scans, five different methods of measuring MD width were used and compared to the reference: (1) points chosen from orthogonal planar views using a custom plugin for OsiriX, (2) points chosen from a simple panoramic image made in OsiriX and (3) Dolphin, and finally, (4) points from a detailed panoramic image made in OsiriX and (5) Dolphin.

Statistical Analysis: An Intra-class correlation (ICC) was used to compare resulting MD measurements from the five different measurement methods to the model measurements. Ten subjects were re-measured for reliability using Cronbach's Alpha. Box-whisker plots were used to visualize results.

Results: At a statistically significant level, measurements made from reconstructed panoramic films and from orthogonal planar views show high correlation and agreement with reference measurements. A detailed panoramic cut line produced more accurate measurements than a simple cut line. Anterior tooth measurements were more variable.

Conclusions: MD tooth widths can be accurately measured from CBCT scans. Care must be taken in how panoramic slices are constructed and how the data is measured.

CHAPTER ONE

INTRODUCTION

Statement of the Problem

Mesial-distal (MD) measurements of teeth on diagnostic stone models have been used in orthodontics for almost a century. In the process of diagnosis, these measurements are commonly used to determine arch form, tooth size discrepancy, arch length deficiencies, and band sizes. The evolution of computers and radiographic technology has produced new methods of measuring the dentition. Combined with powerful software, cone-beam computed tomography (CBCT) scans provide the information needed to measure MD tooth widths.

Linear measurements of MD tooth width can be made from CBCT scans in two dimensional (2D) views without dental segmentation or three-dimensional (3D) rendering. To this point, there have been no known published studies that look at accuracy of 3D measurements of dental dimension from unsegmented CBCT in the fully erupted permanent dentition. The clinician that has access to CBCT data for a patient may be able to use MD measurements for diagnosis and treatment planning.

The primary objective of this study was to determine if MD tooth measurements from unsegemented CBCT scans in the axial, sagittal, and coronal planes or panoramic reconstructions can be as accurate as measurements taken off of study models. A secondary objective was to test an efficient method to collect three-dimensional coordinates of MD contact points of teeth which in turn may allow creation of computer aided tools to analyze and quantify topics such as arch length, arch form, and curve of spee in the process of treatment planning.

Hypothesis

The null hypothesis in this study was: Measurements of MD tooth widths on unsegmented CBCT data in a multi planar reconstruction (MPR) or reconstructed panoramic slice do not correlate or agree with corresponding reference model measurements.

The alternative hypothesis was: There is significant correlation and agreement in measurements of MD tooth widths on unsegmented CBCT data in a MPR or reconstructed panoramic and reference model measurements.

CHAPTER TWO

REVIEW OF THE LITERATURE

CBCT Uses in Dentistry

Many human anatomical features relating to dentistry have been measured with CBCT. Most studies have examined bony landmarks. These include anatomical sites marked with gutta percha[1], metal spheres[2] or simply chosen off of scans[3,4,5,6,7,8,9,10,11]. Reasons for measuring bony landmarks include implant placement[3,4,2,12], or more closely related to orthodontics, cephalometric analysis[5,6,7,8,9,13,10,11].

Fewer studies look at measurements of the dentition. Hayasaki et al.[14] investigated many dental measurements including arch form, arch length, arch perimeter, crown height, curves of spee and Wilson, the sphere of Monson, cusp height, incisal level, intercanine width, intermolar width, interpremolar width, midline deviation, overbite, overjet, tooth angulation, tooth inclination, and tooth thickness. This study, however, was performed on models, not with CBCT data. One study that did look at dentition with CBCT was by Baumgaertel et al.[15]. In this study, CBCT data was segmented to include only alveolar bone and dentition. Measurements were taken off a surfaced 3D image. MD measurements as well as intercanine and intermolar widths were taken using a view that was perpendicular to the occlusal plane. Thus, the contact points were chosen in two dimensions.

Sakabe et al.[16] measured MD tooth width of unerupted teeth in three dimensions from two-dimensional projections. This study had a small sample size ($n = 10$) and only looked at supernumeraries planned for extraction in the anterior median maxillary region. No known studies have identified MD contact points in the fully erupted dentition in this manner on unsegmented CBCT data for the purpose of diagnosis.

An excellent study was performed by Peck et al.[17] in which a reconstructed panoramic radiograph was created from CBCT data and root angulation was compared to that of models as well as on conventional panoramic radiograph. The reconstructed CBCT panoramic slice produced very accurate results when compared to direct measurements on models while the conventional panoramic was found to be unreliable, especially in canine and premolar regions. This study provides a good basis for use of the panoramic slice technique to measure MD widths of the dentition. Bouwens et al.[18] also showed the inaccuracy of conventional panoramics in measurements of root angulation.

Two studies measured dental-related volumes from CBCT. Liu et al.[19] determined that the resulting volumes of segmented teeth from CBCT scans do not match actual volumes. In another study[20] the measurement of an extraction socket volume was determined to be accurate.

Finally, one study looked at a new method of visualizing and measuring the dentogingival unit[21] using CBCT. In this study, the authors discuss taking measurements of the dentogingival unit, but do not quantify how accurate their method is. CBCT has also been used to calculate root curvature radius in a reliable and reproducable manner[22].

Not all studies involving measurements taken from CBCT scans were done on human anatomy. Many used manufactured synthetic objects of known dimension called phantoms[7,23,1,12,24,25]. These studies have measured linear accuracy, volumetric accuracy, contrast, and resolution. One study compared values of the various commercially available CBCT systems on the contrast and linear measurements of phantoms[25].

CBCT Measurement Accuracy

There are several methods that are commonly used to check accuracy of measurements taken on CBCT data. The best way to check accuracy is to measure the object that has been scanned directly. Most studies use some sort of digital caliper to directly measure the subject of interest[14,3,2,5,6,7,8,1,24,9,13,10]. Sometimes, the type of measurement dictates the device used to directly measure the object of interest. For example, angles are sometimes measured with an angle tool[5].

In the case of phantoms, the manufactured object is usually of known dimension and therefore can be compared to CBCT measurements directly.

For studies that look at volume, two methods were reviewed in the literature. When looking at extraction socket volume, an alginate impression has been used to reproduce the socket volume and a water displacement technique is then used to determine volume[20]. When looking at accuracy of segmented tooth volumes, a comparative displaced water volume from the actual tooth is used[19].

There is no definitive conclusion to the question of if CBCT measurements are accurate for linear measurements. Although most studies agree that CBCT measurements are clinically accurate, many have found that CBCT measurements underestimate real-world dimensions[2,8,12,24,13,15] while one paper reviewed found it overestimates real-world dimensions[16].

In order to view CBCT data as one three-dimensional unit, a 3D reconstruction must be performed. Grauer et al.[26] state that caution must be used in measurements taken from a rendered volume. More accurate measurements can be obtained from a stack of two-dimensional (2D) images.

When segmentation is done on CBCT data, a range of radiodensity values for the tissue of interest are defined and used to extract the data of interest. In a dataset, individual units of information are known as voxels, representing a 3D volume. This is a natural progression from the more commonly used term in 2D, the pixel. Each voxel has a value associated with it, based on radiographic tissue density, that can be numerically excluded or included in the segmentation process. This works nicely in areas where the tissue of interest has dramatically different radiographic densities than surrounding tissues. In the case of the dentition, however, adjacent teeth and the bony housing make automatic segmentation difficult due to similar radiographic densities.

The ability to segment out dental tissues from CBCT data is a worthy endeavor indeed. Segmentation allows distinct visualization of teeth in relationship to jaw tissues is helpful in diagnosis and treatment planning in any dental setting. Segmentation of dental tissues has proven to be difficult and inaccurate[19]. The process of separating out dental structures involves some degree of human decision making. This can be time consuming and/or expensive. When segmentation occurs, there is a possibility for error based on the paritial volume effect[15]. This occurs because each voxel processed must either belong to the structure of interest or a tangential structure. This is due to the fact that instead of being a continuous spectrum of data, voxels represent a grid. This is similar to how a computer screen represents curves. At the pixel level, the curve is really a series of squares, not a continuous curve. The smaller the pixel size, or in our case, the voxel size is, the smaller the magnitude of error will be. For the reasons above, it would be useful to know if accurate mesial-distal tooth measurements could be made from unsegmented CBCT data.

CBCT Hardware and Software Used in Previous Studies

Most commercially available CBCT systems have been used in research. These include the ICat[7,23,24,9,13,10,25,21,19], Accuitomo[4,25,20], Galileos[1], Lightspeed Plus (A conventional medical CT)[4], Mercuray[8,25,15], Newtom[3,2,5,6,8,12,25,11], and Somatom (A conventional medical CT)[1,25]. Most studies focus on one machine, while some analyze multiple machines[8,25].

All systems require some sort of software to manage the resulting data from a scan. In most cases, the end product is a set of Digital Imaging and Communications in Medicine (DICOM) files that any number of software packages can read. Once a CBCT scan is done, software is used to view the DICOM files. There are a variety of packages that are found in the literature to analyze dental related measurements. Of these, the two most popular appear to be Amira[6,8,1,19] and Dolphin Imaging[7,9,13,11], however many other packages are found including Accurex[24], Analyze[27], CB Works[8,15], DentaScan[4], EasyGuide[3], Livewire,[20], Maxilim[23], the Newtom Software / NNT[2,5,6], Vitrea[10], and Xoran[27].

No known studies have been published on dental-related topics utilizing the open-source program OsiriX.

Model Measurements

A paper by Hunter and Priest[28] serves as a baseline for how to measure models. The authors describe the process as lining up the beaks of calipers along the long axis of the tooth to be measured. Measurements of certain teeth such as maxillary molars, lateral incisors, and mandibular incisors are difficult to measure due to tooth morphology. In these cases, a buccal or lingual approach with calipers is often used. We hypothesize that measurements on CBCT data may improve this. Additionally, this study discusses the measurement difference between soaped and non-soaped casts. The difference appears to be insignificant, although it does likely add dimension to measurements.

CHAPTER THREE

MATERIALS AND METHOD

Thirty CBCT image sets and corresponding stone model sets (used as a reference) were randomly selected from the Loma Linda University graduate orthodontic clinic. The CBCT scans were taken for orthodontic diagnosis with Newtom 3G hardware using a 12-inch field of view and a 0.4 mm voxel size. DICOM datasets were exported out of NNT software without secondary reconstruction. Patient enrollment impressions taken with alginate and subsequently poured in stone were used for direct measurements. Models were trimmed and soaped by a professional orthodontic laboratory. Measurements were taken of each tooth up to and including the first molar: 12 teeth in each arch for a total of 24 teeth per patient. Patients were chosen based on the following criteria:

1. Fully erupted dentition (All incisors, canines, first and second premolars, and first molars)
2. No restorations on mesial or distal surfaces of teeth to be measured
3. No visual signs of distortion on models
4. No obvious radiographic artifacts or patient movement in CBCT data

One reference model measurement method and five CBCT measurement methods were used to measure MD tooth width. The reference measurement made directly on models with digital calipers (Cen-Tech® 4-inch Digital Caliper Model 47256) with beaks modified to measure interproximally (Figure 1). This was done in a fashion similar to that of Hunter and Priest[28] whereby MD tooth width was estimated with the points of calipers

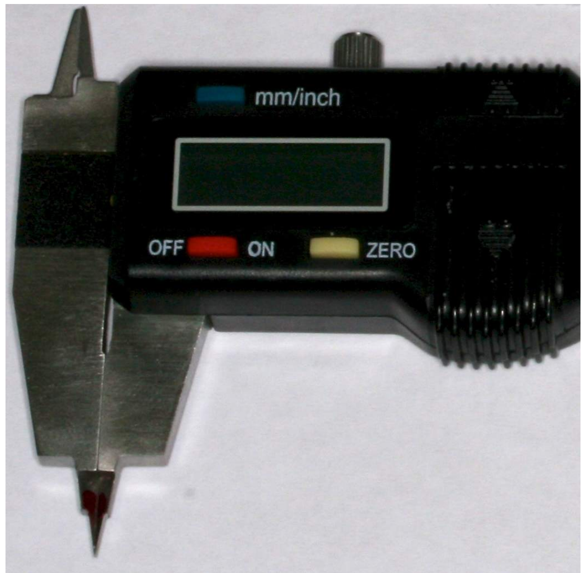

Fig 1. Modified Digital Caliper Beaks.

parallel to the long axis of the crown at normal contact areas. When this was not possible, a buccal or lingual approach was used.

The first CBCT tooth width measurement method used a custom plugin for OsiriX called CephalometriX™. This plugin used a MPR view which allowed contact points to be selected in sagittal, coronal, and axial views simultaneously. A computer script written in the Python language was used to extract the resulting x,y,z coordinates of selected contact points to calculate MD widths using the distance formula:

$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2}$$

Sakabe et al.[16] discuss a method to measure tooth widths on CBCT data using the X, Y, and Z planes to line the tooth up. Similarly, our method involved navigation through axial, sagittal, and coronal planes until the proper location was found and verified in all three planes. An example is shown in Figure 2. The red dot represents the contact point chosen and was visible in each plane of space. To select the proper location, each plane was navigated until the desired contact point area was identified. Placing or moving the

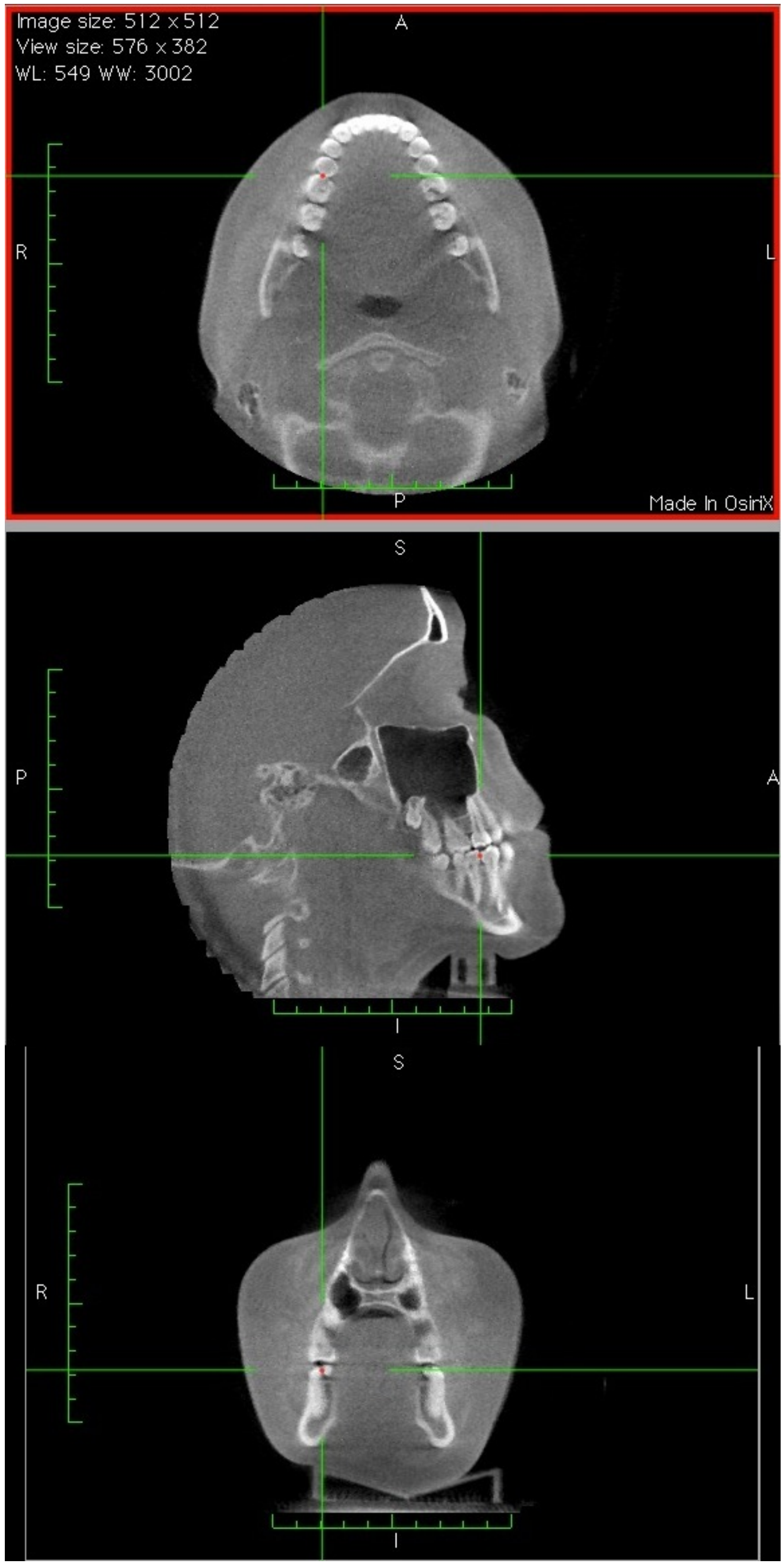

Fig 2. Method 1: CBCT MPR - CephalometriX™ Plugin using MPR View.

red dot in any plane of space also moved it in the other planes of space accordingly.

In order to accurately pick each contact point independent of an adjacent tooth, two passes were made, each using a customized analysis within the CephalometriX™ plugin. The first pass selected MD points on the odd numbered teeth, i.e. #3, #5 etc. proceding through the quadrants in the order of the universal numbering system. The second pass selected MD points on the remaining even numbered teeth.

The remaining methods are more common in the clinical environment because they easily done using available CBCT viewing software. The second method was done in OsiriX v. 3.3.2 32-bit by making a panoramic cut that traced the trough through the apparent MD contact points in the axial view. In defining the trough for the panoramic cut, a node for the curve was placed at each contact point. If teeth were severely rotated or displaced out of the arch form, an average position was chosen. For this method, two cut-lines were necessary, one produced from MD contact points of the maxillary teeth and the second from MD contact points of the mandibular teeth. MD tooth width measurements were produced from the respective panoramic image (adjusted for optimal trough thickness and contrast) by picking the contact points in the occlusal-gingival dimension. The third method was similar to the second but using Dolphin Imaging v. 11.0.03.41 Premium, with the exception that the software was used to re-orient the dataset such that the occlusal plane was leveled. Examples of methods 2 and 3 can be found in Figures 3 to 6.

The fourth method was done in OsiriX using a panoramic cut that approximated a common, general arch form (Figure 7). It did not model exact MD contact points in the axial view. The panoramic cut was done at the axial level where upper and lower incisors are both visible as would be done most often to produce a panoramic view. By convention, the general panoramic arch form was chosen by marking the central fossa in the 2nd molar area, the canines, and the central incisors. As before, two passes were made

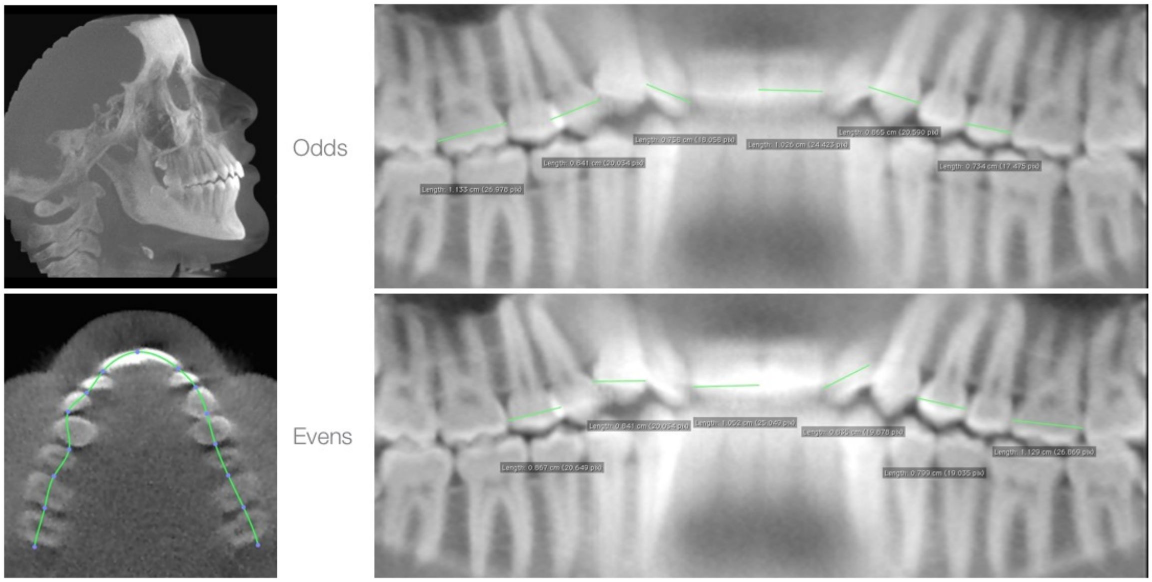

Fig 3. Method 2: CBCT Detailed Pano - OsiriX (Maxilla).

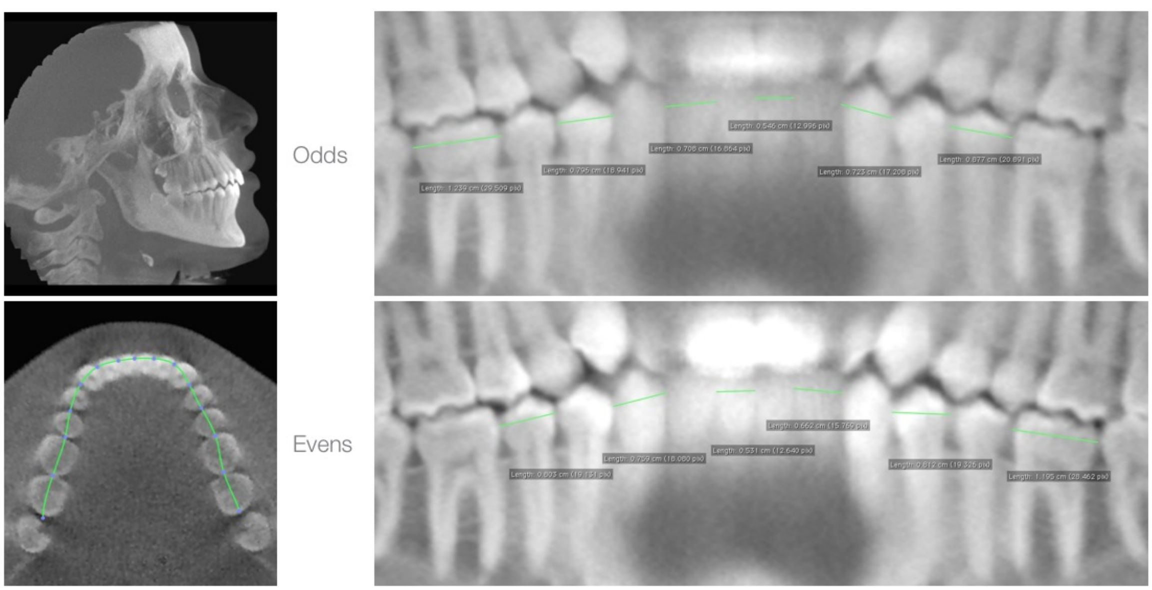

Fig 4. Method 2: CBCT Detailed Pano - OsiriX (Mandible).

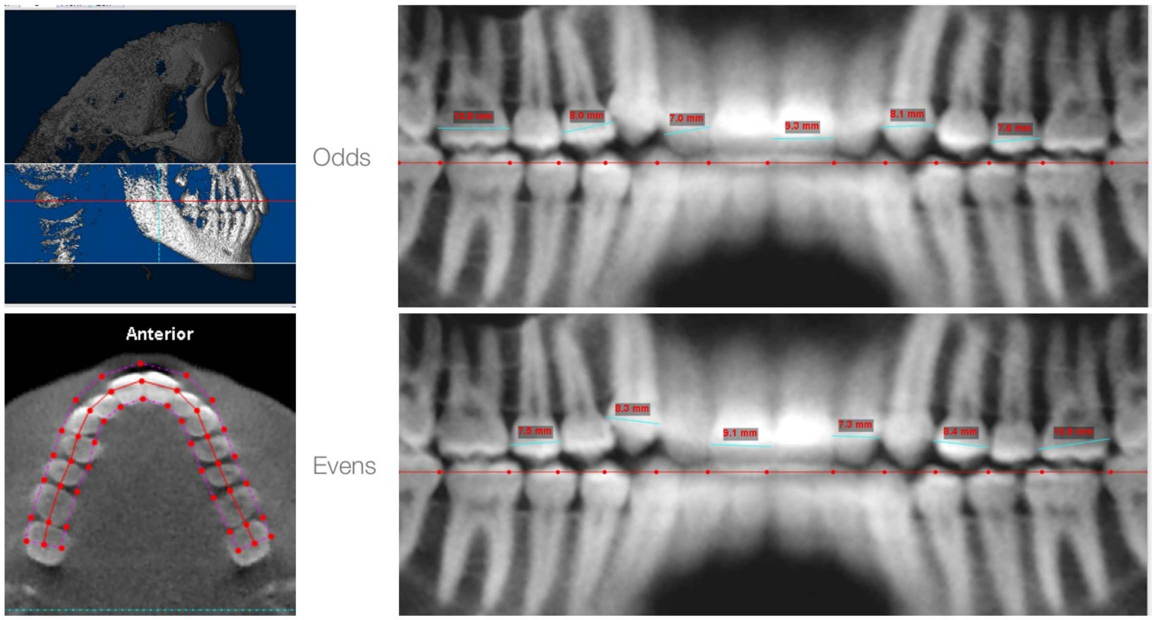

Fig 5. Method 3: CBCT Detailed Pano - Dolphin (Maxilla).

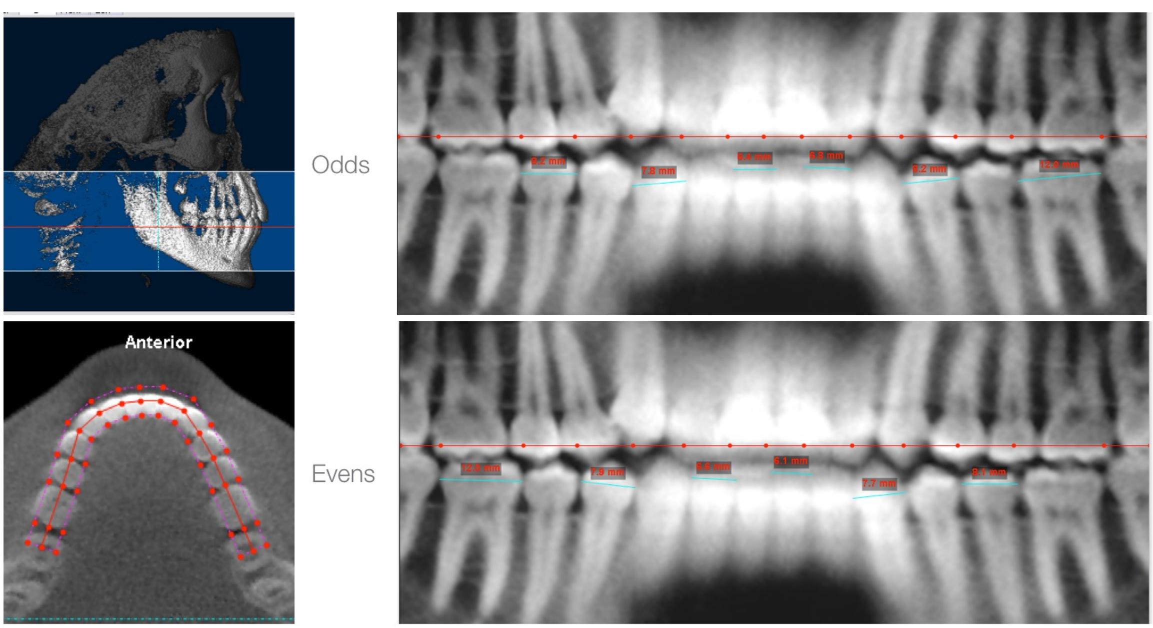

Fig 6. Method 3: CBCT Detailed Pano - Dolphin (Mandible).

off of each resulting panoramic to measure odd numbered teeth and even numbered teeth separately. as before, MD tooth width measurements were produced from the respective panoramic image (adjusted for optimal trough thickness and contrast) by picking the contact points in the occlusal-gingival dimension. The fifth method was similar to the fourth but using Dolphin Imaging, with the exception that the dolphin software was used to re-orient the dataset such that the occlusal plane was leveled. An example of method 5 can be found in Figure 8.

A summary of the five measurement methods can be found in Table 1. In all software measurements, either Dolphin Imaging version 11.0.03.41 Premium or OsiriX version 3.3.2 32-bit were used. Screenshots of measurements were saved where applicable to check for accuracy. Measurements were recorded in a spreadsheet made using Numbers™software by Apple™.

Statistical Analysis

Raw data was exported from the Numbers™spreadsheet and imported into the SAS v. 9.2[29], SPSS v. 18[30] and R v. 2.10.1[31] software packages for statistical analysis. Intra-class correlations (ICC) were run in SPSS and SAS to check for correlation and agreement of each modality with model measurements. Specifically, agreement was checked between model measurements and the five different modalities as a whole, and split up by region, including upper vs. lower and anterior vs. posterior.

Ten randomly selected subjects were reevaluated in SPSS and SAS to quantify measurement method reliability using Cronbach's alpha. Box-whisker plots were made using R to visualize differences between each method and the model measurements.

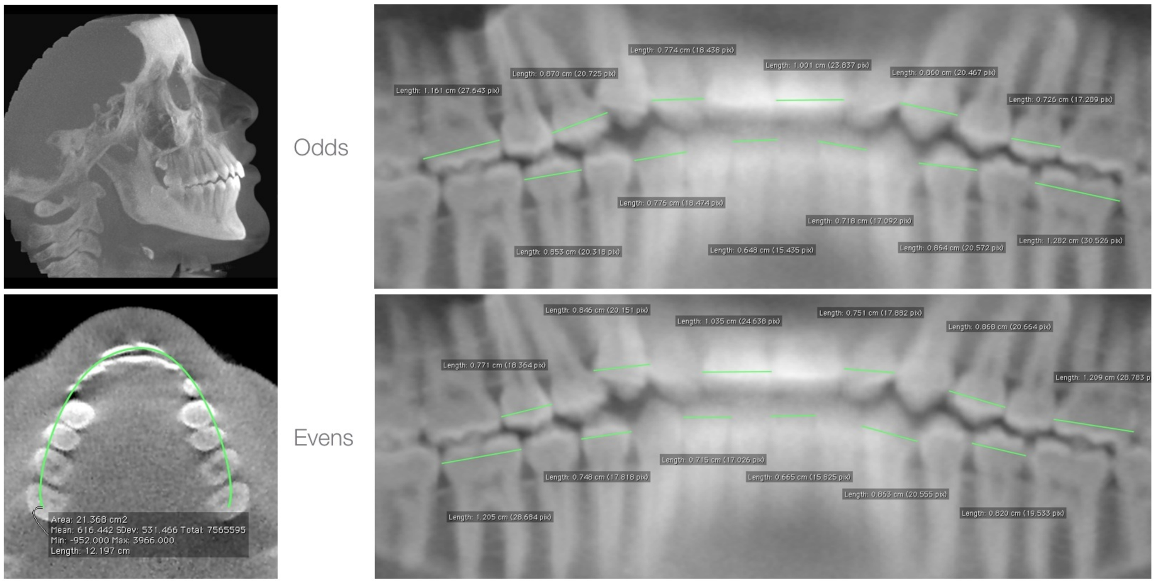

Fig 7. Method 4: CBCT Simple Pano - OsiriX.

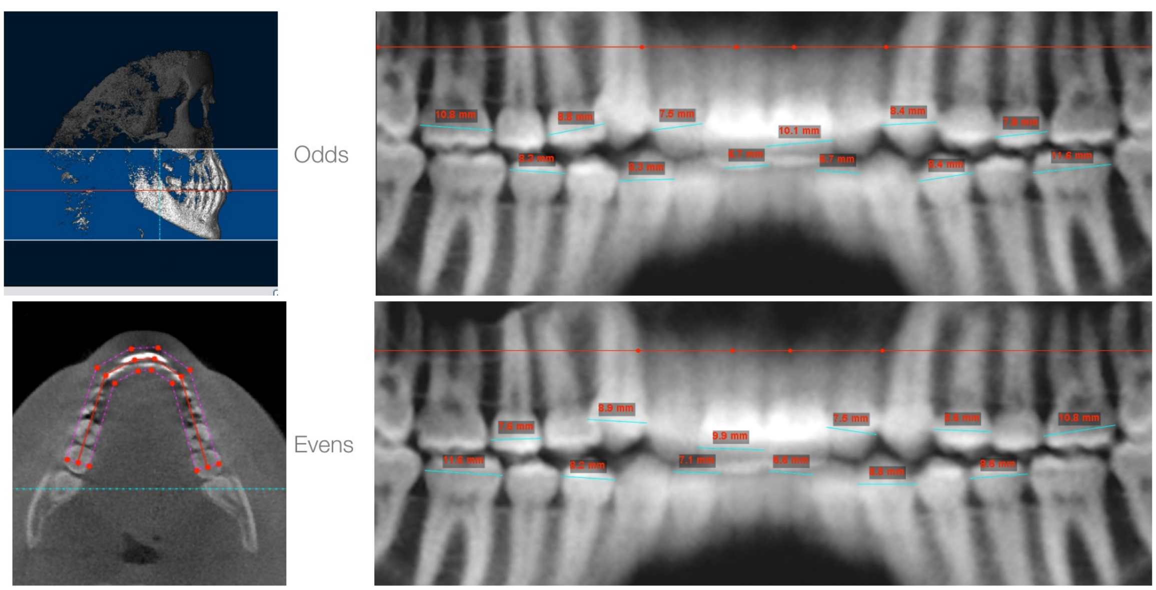

Fig 8. Method 5: CBCT Simple Pano - Dolphin.

Table 1. Summary of Measurement Methods

Measurement Method	Explanation	Software
Reference: Models	Measurements of MD dimensions using digital calipers	N/A
1.CBCT MPR	MPR measurements	OsiriX / CephalometriX™
2.CBCT Detailed Pano	Pano measurements, slice through MD contact points in axial view	OsiriX
3.CBCT Detailed Pano		Dolphin
4.CBCT Simple Pano	Pano measurements, slice using a generalized arch form	OsiriX
5.CBCT Simple Pano		Dolphin

CHAPTER FOUR

RESULTS

Reliability

The coefficients of Cronbach's alpha are shown in Table 2 and show high reliability.

Table 2. Reliability - Cronbach's Alpha

Measurement Method	Cronbach's Alpha
CBCT Detailed Pano - Dolphin	0.985
CBCT Detailed Pano - OsiriX	0.977
CBCT MPR	0.976
CBCT Simple Pano - Dolphin	0.972
CBCT Simple Pano - OsiriX	0.958

Intraclass Correlation

At a statistically significant level, the ICC test shows that each measurement method correlates and agrees well with model measurements. Table 3 illustrates the ICC results and shows the best correlation with CBCT Detailed Pano - Dolphin, followed by CBCT MPR, CBCT Detailed Pano - OsiriX, CBCT Simple Pano - Dolphin, and finally CBCT Simple Pano - OsiriX. The confidence intervals demonstrate that if we were to run the study 100 times, 95% of the time this interval would contain the ICC value.

In Table 4 the data is segmented into upper / lower arches and anterior / posterior segments. In all measurement methods the posterior teeth show higher ICC values than the anterior teeth. When comparing upper and lower arches, most modalities had similar ICC values with the exception of the anterior segments of the Simple Pano modalities. In Dolphin, the lower anteriors had a lower ICC value than the upper anteriors while OsiriX had a lower ICC value for the upper anterior than the lower anterior.

Box-Whisker Plots

Graphically, we can visualize the results in box-whisker plots shown in Figures 9 to 13. Each box-whisker plot shows the distribution of the differences from the respective measurement method to the model measurements. It is easy to see that the detailed pano modalities in either Dolphin or OsiriX showed better precision and accuracy around the reference model measurements than the simple pano modalities. Additionally, the CBCT MPR method showed high precision and accuracy around the reference model measurements. The box-whisker plots confirm the ICC results in Tables 3 and 4.

Table 3. Overall Intraclass Correlation with Model Measurements

Measurement Method	Single Measures ICC	95% Confidence Interval Lower Bound	Upper Bound	F Test Sig
CBCT Detailed Pano - Dolphin	0.968	0.956	0.977	0.000
CBCT MPR	0.954	0.941	0.964	0.000
CBCT Detailed Pano - OsiriX	0.953	0.938	0.964	0.000
CBCT Simple Pano - Dolphin	0.944	0.928	0.956	0.000
CBCT Simple Pano - OsiriX	0.919	0.897	0.936	0.000

Table 4. Upper vs. Lower / Anterior vs. Posterior Intraclass Correlation

Region and Method	Single Measures ICC	95% Confidence Interval Lower Bound	Upper Bound	F Test Sig
Upper Anterior				
CBCT Detailed Pano - Dolphin	0.840	0.523	0.930	0.000
CBCT MPR	0.791	0.656	0.864	0.000
CBCT Detailed Pano - OsiriX	0.827	0.655	0.907	0.000
CBCT Simple Pano - Dolphin	0.829	0.700	0.901	0.000
CBCT Simple Pano - OsiriX	0.628	0.274	0.802	0.000
Lower Anterior				
CBCT Detailed Pano - Dolphin	0.849	0.759	0.907	0.000
CBCT MPR	0.804	0.670	0.883	0.000
CBCT Detailed Pano - OsiriX	0.755	0.568	0.859	0.000
CBCT Simple Pano - Dolphin	0.702	0.389	0.845	0.000
CBCT Simple Pano - OsiriX	0.726	0.562	0.831	0.000
Upper Posterior				
CBCT Detailed Pano - Dolphin	0.981	0.968	0.989	0.000
CBCT MPR	0.971	0.941	0.985	0.000
CBCT Detailed Pano - OsiriX	0.971	0.952	0.982	0.000
CBCT Simple Pano - Dolphin	0.960	0.934	0.976	0.000
CBCT Simple Pano - OsiriX	0.954	0.925	0.972	0.000
Lower Posterior				
CBCT Detailed Pano - Dolphin	0.979	0.965	0.987	0.000
CBCT MPR	0.971	0.951	0.982	0.000
CBCT Detailed Pano - OsiriX	0.969	0.949	0.982	0.000
CBCT Simple Pano - Dolphin	0.980	0.963	0.988	0.000
CBCT Simple Pano - OsiriX	0.943	0.876	0.971	0.000

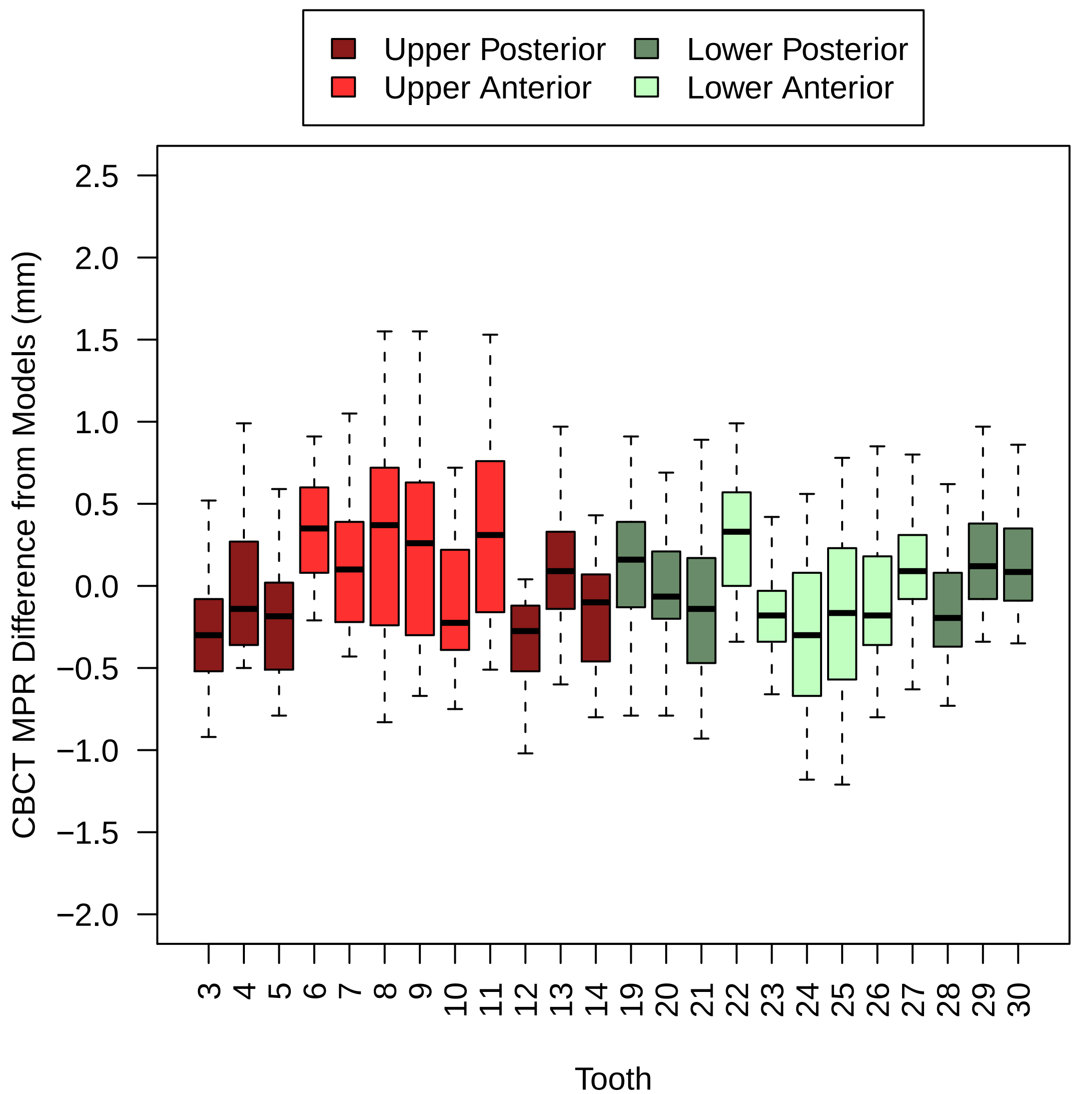

Fig 9. Result: CBCT MPR - CephalometriX

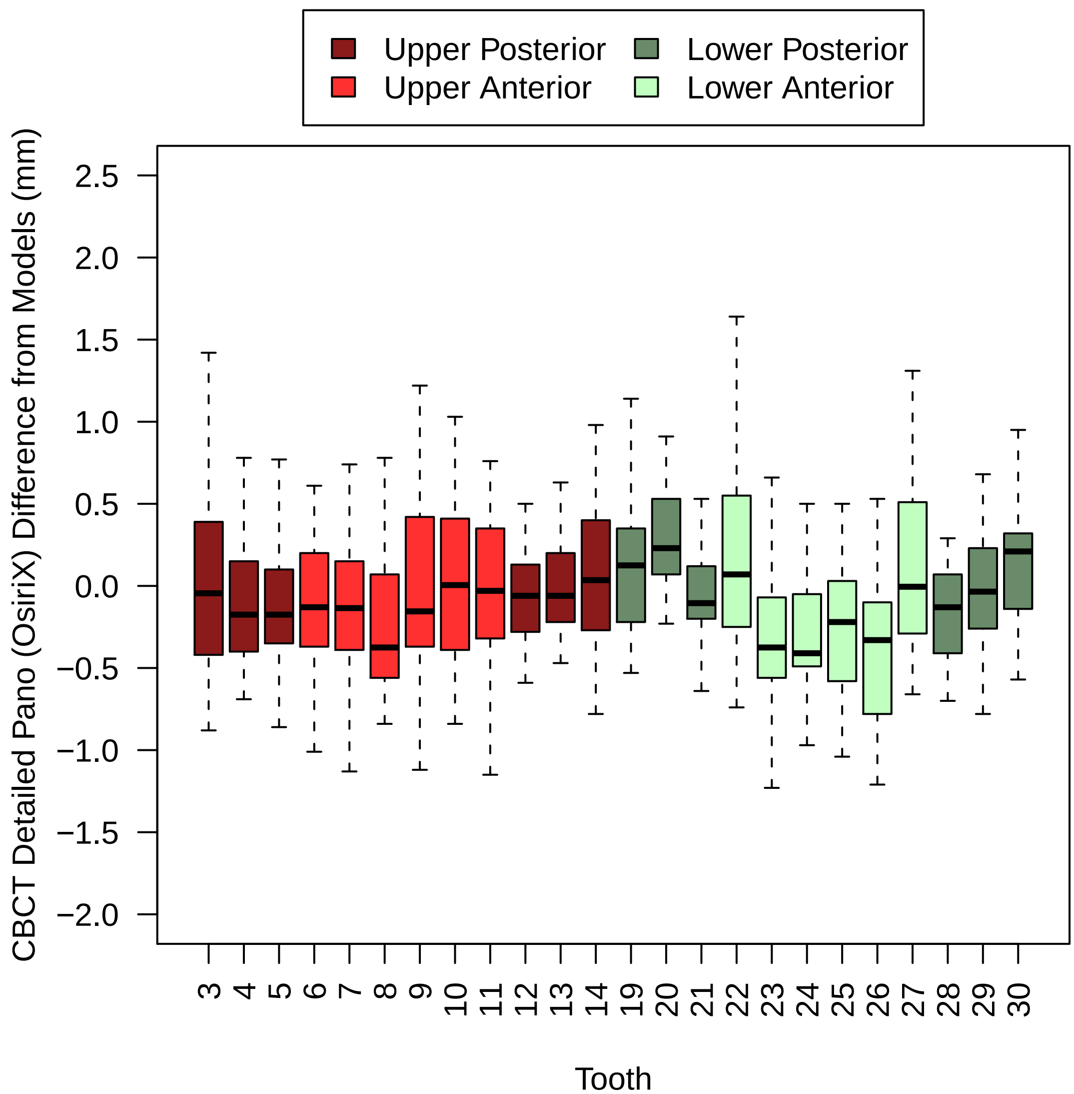

Fig 10. Result: CBCT Detailed Pano - OsiriX

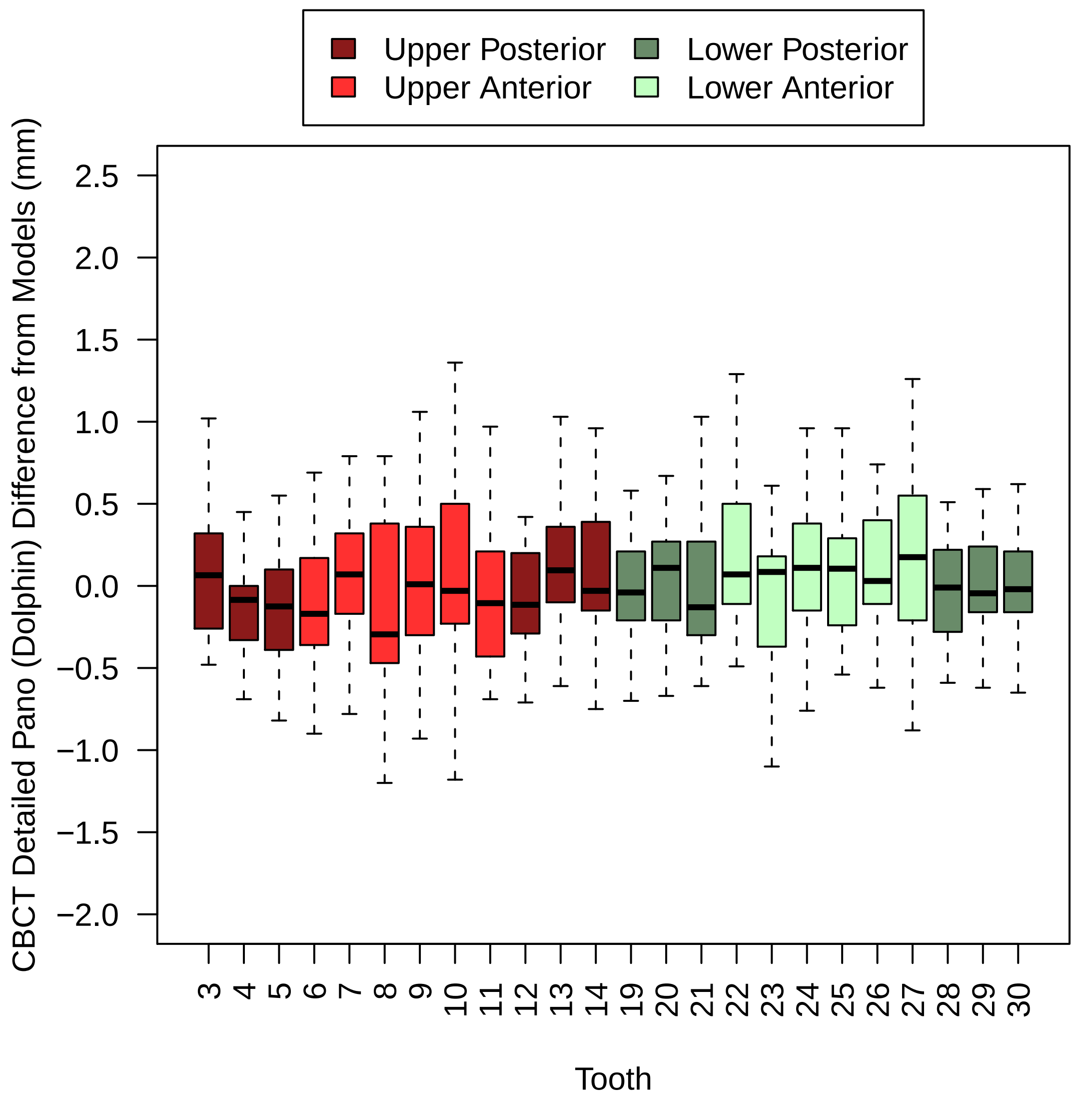

Fig 11. Result: CBCT Detailed Pano - Dolphin

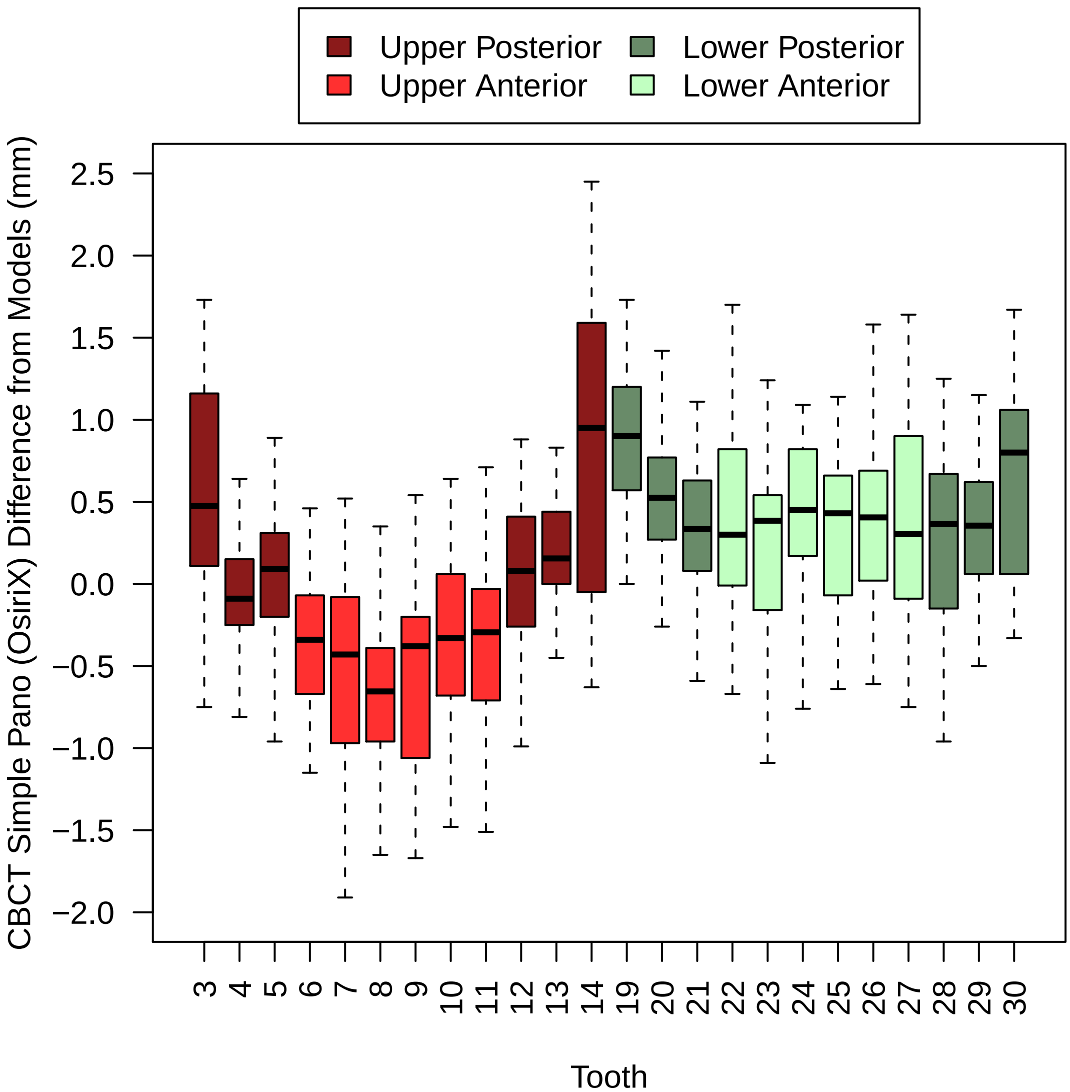

Fig 12. Result: CBCT Simple Pano - OsiriX

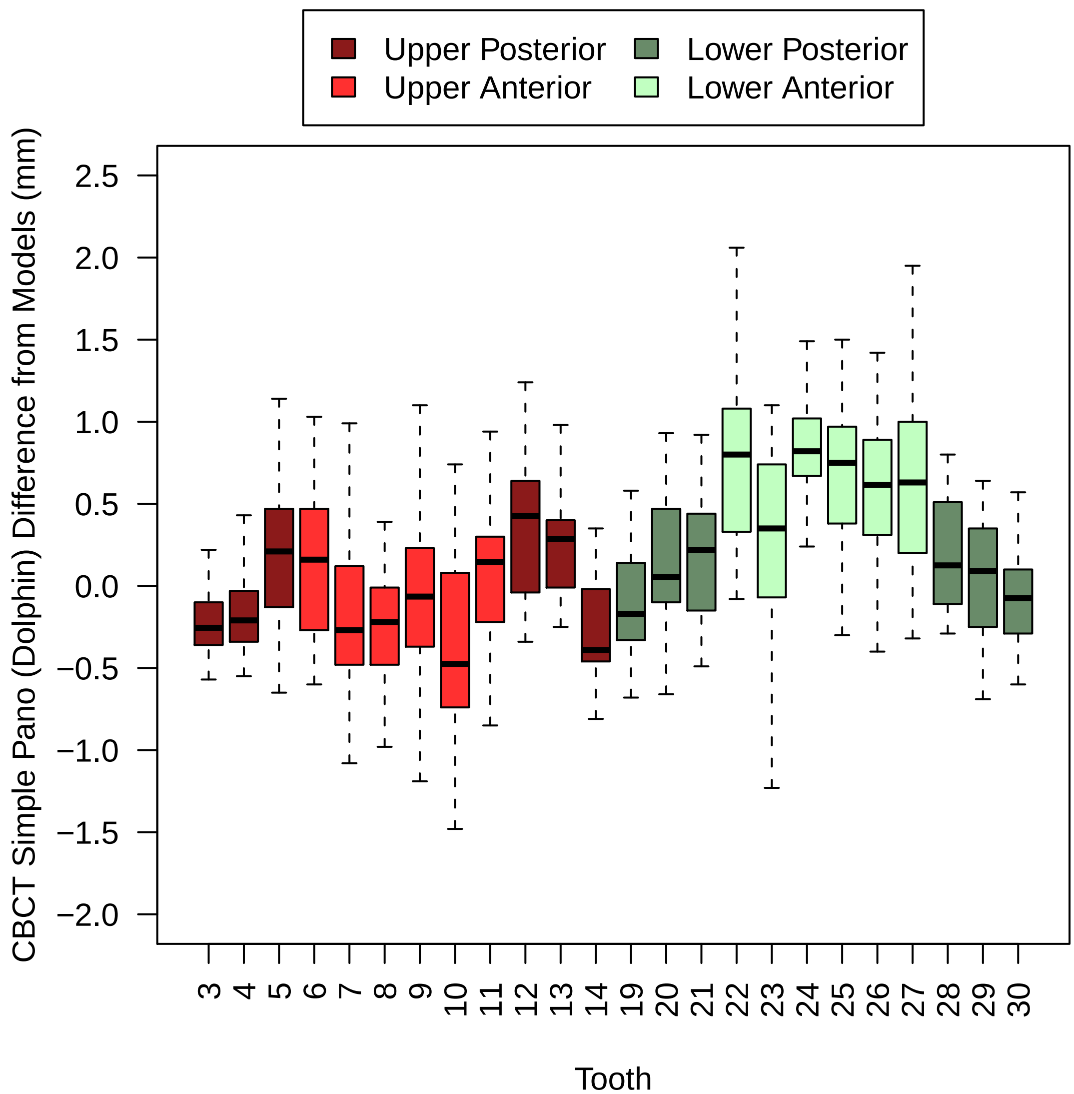

Fig 13. Result: CBCT Simple Pano - Dolphin

CHAPTER FIVE

DISCUSSION

Statistical Significance

The overall ICC results suggest that any one of the CBCT measurement methods correlates well and agrees with the reference model measurements at a high level. When anterior-posterior differences were compared, it is clear that anterior measurements are not as accurate and precise as reference model measurements. From the box-whisker plots, however, we see that the simple pano modalities produced more variation than the detailed pano or CBCT MPR measurements. The box-whisker plots for detailed panoramic and the CBCT MPR method also show a variation of ± 0.5 mm from the reference. This is quite good, as the voxel size used in this study was 0.4 mm.

Clinical Significance

From the box-whisker plots we can see that in the detailed pano methods as well as the CBCT MPR method, we can assume with fairly high confidence that measurements in these modalities should be within approximately ± 0.5 mm of the equivalent direct model measurement. Visual inspection of the simple pano box-whisker plots shows that the clinician cannot have high confidence in measurements made via simple panoramic cuts. By definition of the simple and detailed approaches, it is clear that the detailed approach should give a more accurate result. It is up to the clinician to determine if the variability found in the simple pano method is truly representative.

A practical application of using the alternative MD tooth width measurement modalities introduced is to perform the Bolton analysis. Tooth widths could be plugged into an algorithm to automatically determine tooth size discrepancies. In the case where contact point coordinates are picked, as in the CBCT MPR method, this information could help establish optimal arch form, evaluate arch length, and describe the curve of spee.

Differences Between Dolphin and OsiriX

In defining the cut line for the detailed panoramic slice through each contact point, the difference between OsiriX and Dolphin is minimal. Graphically we can see that this method in each software package produced very similar results (Figures 10 and 11). It is interesting to note, however, that in doing the generalized cut line through second molar central fossa, canines, and incisors, there is an observable difference in measurements taken off of the resulting MPR image. Figures 15 and 14 illustrate the difference in how each software package handles an open polygon. The OsiriX software uses a curve algorithm based on a 3D cubic bezier spline to connect the points chosen with its open polygon tool. Furthermore, the ends of the line drawn using the open polygon tool are weighted to reach back towards the midline. Dophin uses a straight line to connect the points.

Mathmatically and geometrically, a possible approximation for the difference is represented by the difference between the arc length and chord length of a circle. A graphical summary of this is found in Figure 16 taken from Weisstein[32]. Conceptually, the path through any given tooth created by the bezier curve in OsiriX could be approximated by an arc of a circle with radius R and ocupying θ radians. The arc length $s = R\theta$. The chord length $a = 2r\tan(\frac{1}{2}\theta)$.

Graphically, we see that there is a difference in in the box-whisker plots (Figures 12 and 13). A complete explanation, however, is not possible. One potential explanation has to do with the difference in where the panoramic trough points were selected between

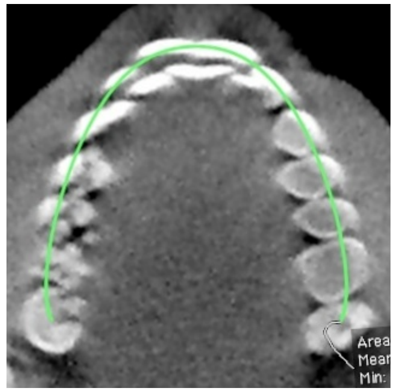

Fig 14. Cut Line: CBCT Simple Pano OsiriX

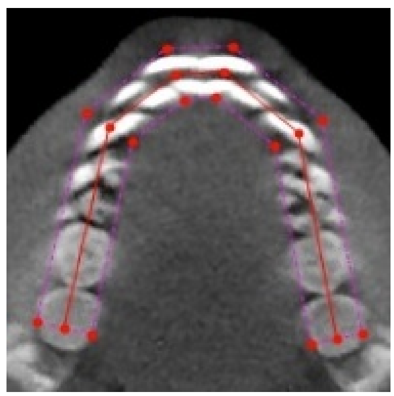

Fig 15. Cut Line: CBCT Simple Pano - Dolphin

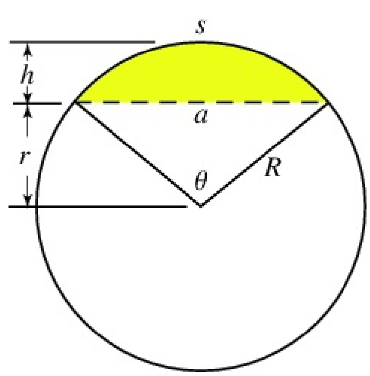

Fig 16. Difference in Length Between an Arc (*s*) and a Chord (*a*).

software packages. Although by design the points chosen are intended to be the same, choice of points cannot be expected to agree exactly. A second explanation can be made relating to orientation of the CBCT image set. Due to the fact that in dolphin the CBCT dataset can be easily re-oriented such that the occlusal plane is parallel to the horizon, some sort of standardized approach to picking points can be made. In contrast, the dataset was not able to be re-oriented in OsiriX. In cases where the occlusal plane was not parallel to the horizon, an estimation of the axial plane in which to make the cut was necessary. The resulting panoramic images appear slightly different and this may have introduced variability between the points picked in OsiriX and those picked in Dolphin.

CBCT MPR Measurements

To determine the true MD width of teeth, accurate selection of the contact points in three dimensions from CBCT data should yield more accurate measurements than those made by caliper on stone models. Calipers cannot reach the true contact point in most cases. Because this study did not measure the MD width of the actual teeth (a process that would have necessitated extraction of teeth) the true width of teeth is not known.

The process of selecting contact points of anterior teeth in upper and lower arches was subjectively difficult to do, especially in the canine areas. This could be due to the fact that the arch form does not fall parallel to any of the three planes of space in these areas. Additionally, because most imbrication of teeth occurs in the anterior areas, the contact points of teeth were often hidden, or overlapped.

CBCT Pano Measurements

When performing the detailed panoramic cut, the ideal scenario was to mark the MD contact points as the panoramic cut line was made. In areas where the teeth were severely rotated, or overlapping, this had to be approximated. Because these scenarios are most likely in the anterior region, we should expect that these areas would be less accurate. When looking at the ICC values in Table 4, we see that the anteriors in the detailed cut methods are, in fact, lower.

The error is magnified when only a simple cut is done. In this case, there is no average placement of the cut line, instead a pre-defined location is selected and the cut line falls based on a simple rule. The error is magnified in this case as no attempt at following the position of the teeth is made. Again, we see this in Table 4, with the ICC values even lower.

To rule out problems with selecting the panoramic cut line in the case of rotated or overlapped teeth, an even/odd approach could be used to trace the MD axis of the crowns more accurately, without bias from the adjacent teeth.

Accuracy

Extracted teeth or radio opaque plastic teeth could be used and measured directly without the pitfalls of measuring width on plaster models. The corresponding CBCT scan could be used via the modalities used in this study to determine if the 3D measurement MPR view was more accurate than the others.

Additionally, with the introduction of model scanners, MD widths can be measured off of the data produced by this equipment. These measurements could be compared to the various modalities in this study to see how well they correlate and agree.

Standardization

At the time of this study, the CBCT datasets were not reconstructed in the original aquisition software prior to exporting to Dolphin or OsiriX. In the case of measurements done in Dolphin, a tool was readily available to re-orient the data such that the occlusal plane was approximately level. The OsiriX software along with the CephalometriX plugin did not have a quick tool to do this and therefore the data was left in the same orientation it was obtained in. In order to rule out differences between the two modalities, a future study might first reconstruct each dataset with the occlusal plane parallel to the horizon prior to exporting to Dolphin or OsiriX in order to standardize it prior to taking measurements.

Conclusions

The null hypothesis was rejected and we have shown that there is significant correlation and agreement in measurements of MD tooth widths on unsegmented CBCT data in MPR views or reconstructed panoramic and reference model measurements. Based upon the results of this study, the following conclusions can be drawn:

1. Based upon ICC values, all measurement methods produced similar results to the reference model measurements. Anterior tooth measurements showed lower ICC values, especially in non-detailed panoramic cut lines.

2. The method of defining the cut line to produce a panoramic reconstruction is critical. The more accurate the cut line with respect to the MD contact points, the more accurate the resulting panoramic will be.

3. Accuracy in picking contact points in either the reconstructed panoramic, or directly by using the CephalometriX plugin is crucial to achieve accurate measurements.

4. If 2 and 3 above can be achieved, then the methods described in this paper can be considered a replacement for measurements of stone models.
5. If a CBCT scan is determined to be necessary for diagnosis, MD contact point information can be gathered from the data and used to establish MD tooth width.

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APPENDIX A

MAIN DATA

* all measurements in mm
** O = OsiriX, D = Dolphin Imaging

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
1	UR6	10.96	10.44	10.61	11.97	10.7	10.5
1	UR5	7.05	6.66	7.30	6.98	6.5	6.5
1	UR4	7.02	6.51	6.16	6.52	6.2	7.0
1	UR3	8.17	8.88	8.14	7.99	8.0	8.4
1	UR2	7.62	7.86	7.56	6.95	8.2	7.3
1	UR1	8.48	9.88	8.14	7.77	8.1	8.6
1	UL1	8.48	10.00	8.14	8.15	8.4	7.7
1	UL2	7.35	7.74	7.42	7.71	7.0	6.9
1	UL3	8.40	9.21	8.08	8.05	8.3	8.5
1	UL4	7.08	6.91	6.58	6.81	6.7	7.0
1	UL5	7.09	6.71	6.88	7.20	6.7	6.9
1	UL6	11.25	10.69	10.81	11.20	10.5	10.1
1	LL6	11.33	11.49	11.64	11.81	10.8	11.2
1	LL5	6.61	6.80	6.77	6.44	6.4	6.6
1	LL4	6.64	6.55	6.44	7.15	6.6	7.3
1	LL3	7.27	7.35	6.81	7.81	7.3	7.6
1	LL2	6.04	5.85	5.68	6.44	5.1	6.2
1	LL1	5.65	4.98	4.40	5.98	5.5	6.5
1	LR1	5.64	4.43	4.83	6.52	5.1	6.4
1	LR2	6.28	5.99	5.07	6.44	5.8	6.9
1	LR3	7.20	6.57	7.96	8.16	6.9	7.9
1	LR4	6.86	7.05	6.52	7.29	6.7	6.7
1	LR5	6.86	7.11	6.84	6.99	6.4	7.2
1	LR6	11.64	11.42	11.40	11.51	10.9	11.5
2	UR6	10.53	10.22	10.17	10.64	10.6	10.2
2	UR5	6.44	6.96	6.23	6.47	6.1	6.7
2	UR4	6.44	6.65	6.62	6.83	6.5	7.1
2	UR3	7.65	7.64	7.31	6.53	7.3	7.5
2	UR2	7.46	7.16	7.20	6.65	6.5	7.0
2	UR1	9.24	8.73	8.81	8.53	8.7	9.0
2	UL1	9.27	9.73	9.72	8.98	9.1	9.4
2	UL2	7.30	7.32	6.92	6.71	7.4	6.4
2	UL3	8.17	8.13	8.49	7.10	7.9	7.6

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
2	UL4	6.80	6.65	6.93	7.02	6.2	6.7
2	UL5	6.80	6.75	6.33	6.40	6.8	7.1
2	UL6	10.60	9.99	11.00	9.97	10.5	10.2
2	LL6	10.59	11.02	11.10	11.54	10.5	11.0
2	LL5	6.46	6.16	6.70	7.06	6.7	6.8
2	LL4	6.18	7.07	6.07	7.23	6.8	7.1
2	LL3	6.79	7.64	6.47	8.02	6.9	7.0
2	LL2	5.77	5.88	6.11	5.77	5.4	6.2
2	LL1	5.14	5.45	4.69	6.17	5.2	6.1
2	LR1	4.80	4.86	4.87	5.94	4.9	6.3
2	LR2	5.77	5.78	5.67	7.35	5.8	6.6
2	LR3	6.79	6.79	6.15	6.68	6.9	7.3
2	LR4	6.22	6.78	6.11	6.71	6.5	6.6
2	LR5	6.35	6.73	7.03	6.68	6.3	6.7
2	LR6	10.48	11.24	11.43	11.50	10.7	10.8
3	UR6	10.26	10.78	10.72	9.80	10.2	10.1
3	UR5	6.51	6.78	7.09	6.26	6.2	6.3
3	UR4	6.55	6.88	8.09	6.32	7.1	6.6
3	UR3	7.83	8.43	8.06	8.15	7.7	8.4
3	UR2	7.15	8.13	6.62	7.67	7.3	6.9
3	UR1	8.70	9.19	8.05	9.05	7.5	8.5
3	UL1	8.70	9.02	8.45	9.24	8.1	8.5
3	UL2	6.79	6.66	6.82	7.43	5.9	6.1
3	UL3	7.73	8.49	8.12	8.38	7.8	9.0
3	UL4	7.43	6.55	7.36	6.44	6.9	7.3
3	UL5	6.83	6.90	6.67	8.37	7.4	7.3
3	UL6	10.41	10.20	10.92	10.13	10.8	10.5
3	LL6	11.11	11.24	11.08	11.11	10.9	10.6
3	LL5	8.17	7.32	8.56	7.31	7.5	7.7
3	LL4	8.18	7.50	6.91	6.35	7.0	7.8
3	LL3	7.07	7.56	7.58	5.27	7.7	7.9
3	LL2	6.03	5.68	5.28	5.41	6.2	4.8
3	LL1	5.48	5.81	5.27	5.71	6.1	5.1
3	LR1	5.30	4.82	4.76	5.23	5.7	5.0
3	LR2	5.97	5.17	5.35	5.87	6.0	6.2
3	LR3	7.20	7.51	7.12	7.04	7.5	7.0
3	LR4	8.03	7.65	7.40	7.07	7.5	7.8
3	LR5	7.23	7.14	7.75	7.04	7.4	7.5
3	LR6	11.23	11.38	10.96	11.09	11.0	11.0
4	UR6	10.54	9.97	10.28	10.75	10.6	10.3

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
4	UR5	6.43	6.30	6.58	5.74	6.1	6.1
4	UR4	6.91	6.93	6.57	7.05	7.1	7.4
4	UR3	7.97	8.16	7.76	7.38	7.9	7.6
4	UR2	6.52	6.31	6.23	5.45	6.6	6.1
4	UR1	8.81	8.34	8.23	7.16	8.7	7.5
4	UL1	8.79	9.42	8.47	7.12	9.0	7.6
4	UL2	6.78	6.39	6.73	5.66	6.9	5.3
4	UL3	8.35	8.55	8.48	6.84	8.3	7.5
4	UL4	6.85	6.79	7.22	6.61	7.2	8.0
4	UL5	6.32	6.90	6.95	6.32	6.5	7.3
4	UL6	10.79	10.72	10.23	10.35	10.4	10.1
4	LL6	10.74	10.61	10.89	11.93	10.7	11.2
4	LL5	6.43	6.36	6.57	6.98	6.7	7.1
4	LL4	7.11	6.64	6.91	7.57	6.5	6.9
4	LL3	6.74	6.40	6.55	6.88	6.5	7.6
4	LL2	5.80	5.78	4.59	5.30	5.4	5.4
4	LL1	5.27	5.16	5.31	5.30	4.8	6.4
4	LR1	5.27	5.15	4.35	5.16	5.1	5.0
4	LR2	5.84	5.85	4.80	5.24	4.8	5.7
4	LR3	7.05	6.28	6.39	7.42	7.2	7.4
4	LR4	7.05	6.85	7.23	6.61	6.8	7.0
4	LR5	6.76	6.68	5.44	6.90	6.5	6.9
4	LR6	10.49	11.04	10.54	11.25	10.7	10.5
5	UR6	10.13	10.03	9.53	9.87	9.9	9.6
5	UR5	6.94	6.57	7.25	6.31	6.7	6.6
5	UR4	7.06	6.53	6.52	7.35	6.9	7.4
5	UR3	7.63	7.55	6.85	6.90	7.1	7.2
5	UR2	7.27	7.07	6.88	7.06	6.7	6.7
5	UR1	8.76	7.93	8.26	8.13	8.4	8.5
5	UL1	9.23	8.56	8.11	8.13	8.3	8.7
5	UL2	7.12	6.37	7.10	5.64	6.9	7.2
5	UL3	7.41	8.20	6.26	7.38	6.8	7.7
5	UL4	6.99	6.24	6.51	6.63	7.0	7.4
5	UL5	6.92	6.82	6.47	6.97	6.8	7.0
5	UL6	10.20	10.24	9.89	10.05	10.0	9.5
5	LL6	10.99	11.90	11.51	11.62	10.9	10.5
5	LL5	7.16	7.47	7.64	6.99	7.0	6.5
5	LL4	7.48	7.51	7.64	7.37	7.6	7.2
5	LL3	6.52	6.86	8.16	6.70	7.0	7.3
5	LL2	6.30	5.30	5.91	5.21	4.9	4.8

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
5	LL1	5.26	4.94	5.21	5.24	5.3	6.0
5	LR1	5.26	5.74	5.76	4.95	5.4	5.3
5	LR2	6.21	4.90	5.89	5.90	6.2	6.6
5	LR3	6.52	7.67	7.83	6.52	7.1	6.2
5	LR4	7.62	7.39	7.35	7.47	7.6	7.6
5	LR5	7.62	7.41	7.24	7.60	7.5	7.3
5	LR6	11.05	10.70	11.06	10.74	10.4	10.7
6	UR6	11.16	11.18	11.33	11.61	10.8	10.8
6	UR5	7.89	7.42	8.67	7.71	7.5	7.6
6	UR4	8.58	8.11	8.41	8.70	8.0	8.8
6	UR3	8.18	9.03	8.41	8.46	8.3	8.9
6	UR2	7.51	7.99	7.58	7.74	7.0	7.5
6	UR1	10.05	10.46	10.52	10.35	9.1	9.9
6	UL1	10.21	10.96	10.26	10.01	9.3	10.1
6	UL2	7.38	7.72	8.35	7.51	7.3	7.5
6	UL3	7.89	9.20	8.65	8.60	8.1	8.4
6	UL4	8.00	7.95	7.99	8.68	8.4	8.6
6	UL5	7.12	8.08	7.34	7.26	7.6	7.9
6	UL6	11.16	10.36	11.29	12.09	10.9	10.8
6	LL6	11.70	12.11	11.95	12.82	12.0	11.6
6	LL5	8.46	7.70	8.77	8.20	8.1	8.6
6	LL4	8.13	8.24	8.12	8.64	8.2	8.4
6	LL3	7.97	7.05	7.23	8.63	7.7	8.8
6	LL2	6.69	6.90	6.62	7.18	6.8	6.7
6	LL1	5.89	5.93	5.46	6.65	6.1	6.6
6	LR1	5.89	5.69	5.31	6.48	6.4	6.7
6	LR2	6.63	6.32	7.08	7.15	6.6	7.1
6	LR3	7.74	7.51	7.59	7.76	7.8	8.3
6	LR4	7.68	7.76	7.96	7.48	7.9	8.2
6	LR5	8.29	8.67	8.03	8.53	8.2	8.3
6	LR6	11.50	11.69	12.39	12.05	12.0	11.6
7	UR6	10.57	10.12	10.81	10.94	10.5	10.3
7	UR5	7.01	6.53	6.73	6.55	6.8	6.8
7	UR4	7.49	7.09	7.39	7.67	7.4	7.9
7	UR3	8.46	8.80	8.06	8.36	8.1	8.6
7	UR2	7.38	8.89	7.47	7.81	7.7	7.5
7	UR1	9.33	10.19	9.53	9.12	9.0	9.5
7	UL1	9.25	10.17	9.12	10.86	9.5	9.8
7	UL2	7.38	8.54	7.46	7.10	7.3	7.2
7	UL3	8.46	8.80	8.13	8.22	7.8	8.5

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
7	UL4	7.49	7.47	7.96	7.39	7.4	8.0
7	UL5	7.05	7.30	7.13	6.72	7.0	7.1
7	UL6	10.57	9.81	10.31	11.29	10.5	10.1
7	LL6	10.72	11.25	11.86	12.38	11.3	11.3
7	LL5 *	7.12	7.04	7.65	8.04	7.3	7.8
7	LL4	7.39	7.06	7.18	6.80	7.1	7.6
7	LL3	7.23	7.35	7.86	7.97	7.5	9.2
7	LL2	6.22	6.01	5.63	6.39	6.3	6.2
7	LL1	5.42	5.05	5.49	6.34	5.6	5.5
7	LR1	5.42	5.00	5.10	5.82	6.3	5.4
7	LR2	6.07	6.45	6.17	7.25	6.1	7.1
7	LR3	7.43	7.63	7.55	7.97	8.1	8.8
7	LR4	7.48	7.11	7.51	7.33	7.2	7.5
7	LR5	7.12	6.95	7.33	7.38	6.7	7.1
7	LR6	11.08	11.36	11.81	12.14	11.7	11.9
8	UR6	11.24	10.45	10.69	11.36	11.5	10.8
8	UR5	7.29	7.52	7.26	7.40	7.2	7.1
8	UR4	7.71	7.62	7.99	8.11	7.4	8.0
8	UR3	8.37	8.46	8.39	7.62	8.2	8.4
8	UR2	6.92	7.21	6.38	6.65	7.0	6.3
8	UR1	8.70	8.32	8.30	7.74	8.0	7.5
8	UL1	8.70	8.16	8.39	7.67	8.5	8.1
8	UL2	6.97	6.41	6.56	6.43	6.7	6.0
8	UL3	8.41	8.07	8.44	7.93	8.3	8.7
8	UL4	7.30	7.18	7.32	7.87	7.3	8.0
8	UL5	7.38	7.70	7.11	7.16	7.2	7.7
8	UL6	11.21	10.52	10.94	11.42	11.4	10.8
8	LL6	11.74	11.73	12.09	12.20	11.7	12.0
8	LL5	6.93	8.67	8.26	8.34	7.6	7.4
8	LL4	7.85	6.98	7.71	8.45	7.6	7.9
8	LL3	7.52	7.19	7.81	7.81	7.2	8.6
8	LL2	6.07	5.22	5.37	6.50	6.0	6.0
8	LL1	5.89	5.54	4.92	5.63	5.3	5.4
8	LR1	5.89	4.79	4.85	5.33	5.5	5.9
8	LR2	6.17	5.89	5.53	6.19	5.8	6.2
8	LR3	7.31	6.87	7.03	7.82	7.1	7.9
8	LR4	8.09	7.83	7.88	8.71	8.6	8.6
8	LR5	7.86	8.31	8.14	8.37	7.8	8.2
8	LR6	11.33	11.24	11.58	12.23	11.6	11.9
9	UR6	10.43	10.30	10.00	9.68	10.2	9.9

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
9	UR5	7.01	6.91	7.17	7.64	7.0	7.0
9	UR4	7.09	7.13	6.69	7.40	6.8	7.5
9	UR3	8.70	7.82	6.72	7.00	7.8	8.1
9	UR2	6.88	7.12	5.58	5.79	6.1	6.5
9	UR1	8.51	9.21	7.80	7.64	8.2	8.9
9	UL1	8.31	8.28	7.74	7.85	8.0	9.0
9	UL2	6.81	6.26	6.29	5.68	5.9	6.2
9	UL3	7.56	7.62	6.95	6.85	7.1	7.7
9	UL4	6.88	6.65	6.78	7.37	7.1	7.2
9	UL5	6.90	6.41	6.68	6.45	7.0	7.3
9	UL6	9.95	9.78	10.80	11.89	10.5	10.3
9	LL6	10.75	10.62	11.24	11.81	10.8	11.1
9	LL5	7.50	7.32	7.59	8.14	7.7	7.7
9	LL4	6.90	6.36	6.97	7.20	6.6	7.1
9	LL3	7.02	6.94	6.71	6.39	7.0	7.3
9	LL2	5.93	5.93	4.70	6.47	6.1	6.3
9	LL1	5.81	5.08	4.62	5.98	5.7	6.6
9	LR1	5.35	5.08	5.23	5.99	6.0	6.2
9	LR2	6.00	5.46	5.16	5.93	6.4	6.8
9	LR3	7.01	6.45	6.46	6.39	6.2	6.8
9	LR4	7.15	7.31	6.66	6.88	6.6	7.1
9	LR5	6.90	6.94	7.11	7.36	7.3	7.4
9	LR6	10.62	10.86	11.66	10.72	10.5	10.6
10	UR6	10.97	10.63	10.54	10.58	10.6	10.7
10	UR5	7.48	7.32	7.34	7.24	7.4	7.2
10	UR4	7.20	7.15	7.05	7.44	7.2	7.9
10	UR3	8.57	8.51	8.54	7.42	7.9	8.2
10	UR2	7.30	7.30	7.02	5.39	7.3	6.6
10	UR1	9.05	9.98	8.21	6.63	8.7	8.5
10	UL1	9.06	8.76	8.18	7.54	8.5	8.8
10	UL2	7.25	6.97	7.19	6.19	7.7	7.3
10	UL3	8.65	8.14	8.31	7.96	8.2	8.6
10	UL4	7.26	6.99	7.30	7.33	7.3	7.9
10	UL5 *	7.40	7.61	7.28	7.57	7.5	8.0
10	UL6	10.64	10.59	10.54	12.23	11.6	10.7
10	LL6	11.60	11.16	11.44	12.19	10.9	11.3
10	LL5	7.35	7.23	7.37	8.25	7.1	8.0
10	LL4	7.68	6.75	7.24	7.80	7.3	7.7
10	LL3	7.58	8.52	7.57	7.57	7.1	7.5
10	LL2	6.06	5.93	5.90	6.44	6.1	6.8

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
10	LL1	5.74	4.89	4.97	6.56	6.3	6.7
10	LR1	5.74	4.66	5.81	6.11	5.8	6.7
10	LR2	6.00	5.68	5.20	6.67	6.5	6.2
10	LR3	7.25	8.02	8.09	7.08	8.0	8.0
10	LR4	7.91	7.36	7.95	8.12	7.5	7.8
10	LR5	7.24	7.75	7.47	7.99	7.6	7.5
10	LR6	11.66	11.31	11.29	11.67	11.5	11.7
11	UR6	10.88	10.57	11.04	12.07	11.2	11.1
11	UR5	7.11	6.75	6.62	7.21	6.8	6.9
11	UR4	7.33	6.81	7.23	7.39	7.4	7.5
11	UR3	8.38	8.23	8.45	8.13	8.1	8.2
11	UR2	7.37	8.01	7.00	6.83	7.1	7.1
11	UR1	9.27	8.89	8.60	8.86	8.7	8.7
11	UL1	9.10	9.12	8.89	8.71	8.8	8.8
11	UL2	7.09	6.76	6.92	7.15	7.0	7.0
11	UL3	8.63	8.29	8.40	7.75	8.2	8.6
11	UL4	7.34	7.16	7.28	7.58	7.2	7.9
11	UL5	7.34	7.20	7.13	7.54	7.4	7.6
11	UL6	11.15	11.19	11.11	12.12	11.1	11.1
11	LL6	11.26	11.34	11.90	11.67	11.4	11.4
11	LL5	7.55	7.30	7.68	7.83	7.4	7.7
11	LL4	7.55	7.06	7.37	8.37	7.3	7.8
11	LL3	7.13	7.35	6.94	7.21	7.1	8.2
11	LL2	6.61	6.52	5.76	6.37	5.6	5.9
11	LL1	5.32	5.87	5.94	5.71	5.1	6.5
11	LR1	5.32	5.62	4.91	5.78	5.0	5.7
11	LR2	6.52	6.51	6.02	7.06	5.9	7.0
11	LR3	7.30	7.49	7.56	7.74	7.2	8.4
11	LR4	7.23	7.14	6.99	7.35	7.3	7.5
11	LR5	7.62	7.80	7.57	7.12	7.0	7.5
11	LR6	11.27	11.71	11.71	12.17	11.4	11.2
12	UR6	10.11	10.03	10.32	9.77	10.2	10.1
12	UR5	6.97	6.47	6.70	6.86	6.8	7.4
12	UR4	7.30	6.55	7.73	7.48	7.1	7.5
12	UR3	7.82	8.09	7.65	7.34	7.2	7.3
12	UR2	7.20	6.84	6.70	6.11	7.4	6.4
12	UR1	8.38	8.27	8.14	7.44	8.1	7.4
12	UL1	8.38	7.92	7.86	7.32	8.3	7.7
12	UL2	7.20	7.31	6.70	6.42	6.6	6.1
12	UL3	7.73	7.52	7.66	6.93	7.2	7.3

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
12	UL4	6.91	6.39	7.03	7.24	7.0	7.5
12	UL5	6.81	6.78	7.14	7.32	6.8	7.0
12	UL6	9.98	10.41	10.03	9.84	9.8	10.1
12	LL6	11.38	11.19	11.02	11.95	11.2	11.1
12	LL5	6.99	7.24	7.66	7.81	7.4	7.5
12	LL4	7.16	7.44	6.97	8.03	7.2	7.6
12	LL3	7.01	6.92	7.13	6.66	7.5	7.3
12	LL2	5.98	5.35	5.91	6.05	6.2	5.7
12	LL1	5.62	5.21	5.39	4.86	5.4	6.3
12	LR1	5.62	5.05	5.25	5.38	5.6	5.8
12	LR2	6.05	5.28	5.95	6.17	6.1	6.2
12	LR3	7.28	7.28	6.77	6.72	6.4	7.1
12	LR4	7.22	6.97	7.32	8.47	7.6	7.6
12	LR5	6.84	7.15	6.72	7.46	7.0	7.1
12	LR6	11.43	11.37	11.54	11.49	11.5	11.4
13	UR6	10.78	10.16	10.26	11.94	10.7	10.5
13	UR5	7.12	6.80	6.89	7.63	6.6	7.5
13	UR4	6.94	6.75	6.90	7.76	6.8	7.6
13	UR3	7.58	7.66	7.18	6.91	7.1	8.1
13	UR2	6.28	6.38	6.45	4.99	6.2	5.2
13	UR1	7.78	7.73	7.86	7.25	7.4	7.3
13	UL1	7.78	8.08	8.38	7.63	8.0	7.7
13	UL2	6.28	6.73	6.17	5.72	5.1	5.3
13	UL3	7.53	7.37	7.38	7.38	7.1	7.8
13	UL4	7.31	6.62	6.82	7.07	6.6	8.2
13	UL5	7.31	6.71	6.40	7.56	6.7	7.7
13	UL6	10.35	10.34	10.38	12.80	10.6	9.9
13	LL6	10.46	10.67	10.81	12.73	10.8	10.6
13	LL5	6.97	6.90	7.10	8.39	7.1	7.9
13	LL4	6.97	7.14	6.98	9.18	6.7	7.6
13	LL3	6.39	6.37	6.41	8.00	6.3	8.0
13	LL2	5.36	5.17	5.03	5.62	5.7	6.3
13	LL1	5.08	4.24	4.67	5.33	5.2	6.1
13	LR1	4.96	4.16	4.95	5.43	5.0	5.7
13	LR2	5.36	5.15	5.26	5.40	5.8	6.1
13	LR3	6.36	6.10	6.39	7.84	5.9	8.2
13	LR4	7.00	6.77	6.59	8.23	6.6	7.8
13	LR5	7.46	7.50	7.61	8.61	7.2	8.1
13	LR6	10.67	10.66	10.72	12.06	10.5	10.7
14	UR6	10.97	10.05	10.59	10.72	10.7	10.4

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
14	UR5	7.59	7.18	7.01	6.78	6.9	7.2
14	UR4	8.18	7.39	7.81	7.17	7.6	7.7
14	UR3	8.60	8.92	8.93	8.06	8.4	8.6
14	UR2	7.15	7.30	7.24	6.89	7.2	7.3
14	UR1	9.02	8.62	9.38	7.69	8.8	9.3
14	UL1	9.02	8.49	9.52	7.95	8.8	9.0
14	UL2	7.23	6.95	7.88	6.66	7.0	7.3
14	UL3	8.89	8.53	8.91	8.29	8.2	8.5
14	UL4	7.93	7.13	7.95	7.45	7.3	7.8
14	UL5	7.53	7.24	7.24	7.66	7.3	7.3
14	UL6	10.66	10.31	10.16	10.72	10.4	10.2
14	LL6	11.23	11.80	11.57	11.64	11.3	10.9
14	LL5	8.11	8.44	8.06	8.34	7.9	7.7
14	LL4	7.50	7.25	7.62	7.58	7.1	7.1
14	LL3	7.49	8.06	7.49	6.82	7.0	8.0
14	LL2	6.64	6.33	6.22	5.98	6.5	6.7
14	LL1	6.19	5.95	5.72	5.63	6.3	7.2
14	LR1	5.91	6.14	5.95	5.27	5.6	7.1
14	LR2	6.75	6.39	6.12	6.14	6.5	6.8
14	LR3	7.90	7.80	7.67	7.15	7.6	8.1
14	LR4	7.95	7.50	7.80	7.51	7.6	7.8
14	LR5	8.06	8.73	7.78	8.06	8.3	8.1
14	LR6	11.40	11.42	11.65	11.37	11.3	11.1
15	UR6	10.55	9.97	9.67	10.74	11.0	10.4
15	UR5	6.57	6.42	6.34	6.55	6.5	6.2
15	UR4	7.35	6.64	7.20	6.39	6.7	6.7
15	UR3	7.85	8.48	7.73	7.43	7.8	7.3
15	UR2	7.23	6.99	6.86	6.01	6.9	6.2
15	UR1	8.78	9.43	8.24	8.13	8.1	8.2
15	UL1	8.78	9.17	7.95	8.01	8.5	8.0
15	UL2	7.04	7.09	6.69	6.77	7.5	6.3
15	UL3	7.82	7.81	7.15	7.41	7.5	7.3
15	UL4	7.34	6.88	7.28	6.93	7.1	7.0
15	UL5	6.44	6.77	6.48	6.43	6.8	6.2
15	UL6	10.38	9.93	9.60	11.19	11.7	10.0
15	LL6	10.97	11.30	10.75	11.64	11.1	11.0
15	LL5	7.70	7.42	7.79	7.55	7.1	7.2
15	LL4	7.73	7.10	6.99	7.16	7.3	7.4
15	LL3	6.38	6.13	6.75	6.16	6.4	7.0
15	LL2	5.72	5.59	5.12	6.23	5.9	6.3

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
15	LL1	5.12	4.58	4.66	5.60	5.4	5.9
15	LR1	5.12	4.99	5.01	5.65	4.7	5.7
15	LR2	5.73	5.29	5.01	6.26	5.5	6.1
15	LR3	6.53	6.49	7.67	6.33	6.8	7.2
15	LR4	7.59	7.46	7.21	7.79	7.0	7.3
15	LR5	7.44	7.38	7.34	7.10	7.4	6.9
15	LR6	11.05	11.13	10.59	11.72	10.9	10.7
16	UR6	11.04	11.03	11.09	11.93	11.2	10.7
16	UR5	7.73	8.15	7.19	7.54	7.8	7.5
16	UR4	7.99	7.57	7.59	7.79	7.6	7.5
16	UR3	7.68	8.55	7.92	7.31	8.1	8.1
16	UR2	7.46	7.24	7.35	6.84	7.8	7.0
16	UR1	8.67	8.88	8.57	8.38	9.3	9.0
16	UL1	8.67	8.95	8.49	9.03	9.2	8.9
16	UL2	7.40	7.06	7.72	7.09	7.9	6.7
16	UL3	7.75	8.07	7.60	7.70	7.7	7.9
16	UL4	8.05	7.94	7.58	8.09	7.8	7.9
16	UL5	8.05	8.00	8.00	8.25	8.2	7.8
16	UL6	11.05	10.68	11.09	12.10	10.9	10.6
16	LL6	12.47	11.93	11.96	12.48	12.0	12.2
16	LL5	8.07	8.30	8.38	8.26	8.1	8.0
16	LL4	8.07	7.96	7.97	8.43	7.9	8.4
16	LL3	7.36	7.82	7.11	7.64	7.8	7.6
16	LL2	6.22	5.86	6.22	6.91	6.1	6.6
16	LL1	5.59	4.88	4.75	6.30	5.7	6.5
16	LR1	5.43	5.30	5.11	5.50	5.8	6.4
16	LR2	6.28	6.19	5.48	6.72	6.2	7.1
16	LR3	7.35	7.69	7.15	7.58	7.0	7.6
16	LR4	8.54	7.81	7.95	8.84	8.2	8.6
16	LR5	8.06	7.81	7.97	8.12	7.9	7.8
16	LR6	12.24	11.89	11.95	12.95	12.1	11.7
17	UR6	11.64	11.64	11.85	13.13	11.5	11.5
17	UR5	7.77	7.50	7.30	7.88	7.7	7.7
17	UR4	9.15	8.56	8.73	8.23	8.5	8.5
17	UR3	9.62	10.30	9.22	9.40	9.4	9.9
17	UR2	7.84	7.94	7.99	8.16	7.9	8.5
17	UR1	10.27	10.96	9.71	9.31	9.8	10.0
17	UL1	10.34	10.59	9.95	9.20	9.6	10.1
17	UL2	8.76	9.19	7.92	8.41	8.6	8.4
17	UL3	9.31	10.29	9.08	9.06	8.9	9.4

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
17	UL4	8.94	8.14	8.56	8.50	8.5	8.9
17	UL5	8.17	8.33	8.02	8.63	8.4	8.3
17	UL6	11.22	11.61	11.81	12.97	11.6	11.2
17	LL6	12.74	13.50	13.42	15.02	13.1	13.0
17	LL5	8.67	8.88	9.58	9.81	8.8	8.7
17	LL4	8.67	8.50	8.66	9.28	9.7	8.9
17	LL3	8.98	9.86	9.57	9.82	8.9	9.8
17	LL2	6.91	6.76	6.71	7.30	6.2	7.8
17	LL1	6.22	6.35	5.83	6.64	6.1	7.5
17	LR1	6.22	6.63	5.63	6.48	6.0	7.0
17	LR2	6.91	6.56	6.84	6.83	6.8	7.6
17	LR3	9.05	9.45	9.10	9.09	9.4	9.5
17	LR4	9.02	8.38	8.56	8.78	9.2	8.9
17	LR5	9.02	9.11	9.30	9.28	9.1	8.6
17	LR6	12.80	13.66	13.53	13.86	13.0	12.7
18	UR6	10.69	10.12	11.20	11.19	10.9	10.7
18	UR5	7.10	6.69	6.82	6.98	7.3	6.6
18	UR4	7.10	7.25	6.75	7.07	7.2	7.2
18	UR3	7.93	8.01	8.08	7.86	7.8	7.9
18	UR2	7.55	7.14	6.88	6.56	7.3	6.7
18	UR1	9.87	9.11	9.53	8.73	9.5	9.6
18	UL1	9.87	9.22	9.74	9.17	9.7	9.5
18	UL2	7.34	6.83	6.95	6.46	7.3	6.6
18	UL3	7.80	7.52	8.05	7.77	7.8	8.1
18	UL4	7.00	6.72	6.94	6.77	6.6	6.9
18	UL5	7.00	6.96	7.24	6.02	7.3	6.9
18	UL6	10.75	10.62	10.58	10.44	10.6	10.4
18	LL6	11.54	11.74	11.67	12.00	11.1	11.4
18	LL5	7.52	7.53	7.29	7.79	7.3	7.2
18	LL4	7.52	7.08	7.19	7.50	7.1	7.5
18	LL3	7.07	7.27	7.56	6.95	7.3	7.9
18	LL2	6.90	6.61	6.34	6.62	5.8	6.2
18	LL1	6.32	5.47	5.83	6.90	6.1	7.0
18	LR1	6.54	5.61	5.76	6.91	6.1	7.2
18	LR2	6.49	7.08	6.15	6.82	6.4	7.1
18	LR3	7.03	6.97	7.54	7.69	7.7	7.2
18	LR4	7.51	7.41	7.10	7.88	7.4	7.4
18	LR5	7.12	7.19	7.22	7.50	7.3	6.7
18	LR6	11.43	11.78	11.37	11.10	11.3	11.0
19	UR6	10.08	10.36	10.47	11.65	10.4	10.4

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
19	UR5	7.22	7.07	6.95	7.39	7.4	7.0
19	UR4	7.31	6.84	7.12	7.27	7.2	7.5
19	UR3	8.56	9.08	8.91	9.01	8.9	9.1
19	UR2	6.51	6.92	7.52	6.29	7.3	6.7
19	UR1	8.13	8.85	8.91	8.60	10.0	9.0
19	UL1	8.30	9.57	10.08	8.10	9.7	9.4
19	UL2	6.64	7.36	7.16	6.75	8.0	7.3
19	UL3	8.52	9.11	9.04	8.49	9.0	9.6
19	UL4	6.89	6.92	7.06	7.77	7.3	7.7
19	UL5	7.40	7.38	7.05	7.93	7.3	7.4
19	UL6	10.72	10.81	10.97	12.14	10.7	10.2
19	LL6	11.44	11.75	11.33	12.57	11.7	11.0
19	LL5	7.62	7.66	7.90	8.39	7.9	7.6
19	LL4	7.61	7.13	7.63	8.08	8.2	8.5
19	LL3	7.33	7.67	7.88	7.64	7.9	9.2
19	LL2	5.99	6.41	6.29	5.91	6.6	6.7
19	LL1	5.35	5.43	4.88	6.00	5.9	6.3
19	LR1	5.14	5.92	5.17	5.69	6.1	6.2
19	LR2	5.78	6.15	5.59	6.76	7.0	7.2
19	LR3	7.75	7.99	8.00	9.39	8.3	9.2
19	LR4	7.61	7.37	7.57	8.35	7.5	7.8
19	LR5	7.56	7.70	7.85	8.01	7.8	7.8
19	LR6	11.24	11.08	10.67	12.11	10.9	11.1
20	UR6	12.15	11.79	11.73	12.97	11.8	11.9
20	UR5	8.49	8.42	8.64	8.14	8.5	8.4
20	UR4	8.69	8.70	8.50	8.62	8.8	9.3
20	UR3	8.51	9.13	9.12	8.97	9.2	9.5
20	UR2	7.88	8.93	6.75	7.56	7.9	8.5
20	UR1	10.80	11.49	9.97	9.44	10.8	10.4
20	UL1	11.22	11.41	11.21	8.66	11.4	11.9
20	UL2	7.83	7.56	7.00	7.91	7.9	8.0
20	UL3	8.31	9.84	9.04	8.56	9.0	10.1
20	UL4	9.17	8.15	8.99	8.84	8.9	9.5
20	UL5	8.38	8.93	8.55	8.35	9.1	8.9
20	UL6	12.16	11.61	12.51	13.34	11.9	11.7
20	LL6	12.89	12.75	12.80	13.52	12.7	12.6
20	LL5	9.36	8.57	9.25	9.97	9.9	9.4
20	LL4	8.93	9.20	9.06	9.10	9.2	9.3
20	LL3	8.10	8.10	8.38	8.78	8.6	9.1
20	LL2	7.11	6.93	6.71	7.52	7.2	7.9

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
20	LL1	6.46	5.28	5.29	6.75	5.7	7.7
20	LR1	6.56	6.03	6.07	6.08	6.8	7.2
20	LR2	6.56	7.24	6.85	7.65	7.3	7.6
20	LR3	8.40	8.32	9.21	8.33	8.4	9.4
20	LR4	8.62	8.57	8.71	8.98	8.8	9.1
20	LR5	8.68	8.81	8.83	9.17	9.2	9.1
20	LR6	12.32	13.13	12.63	13.93	12.9	12.8
21	UR6	10.63	10.23	10.11	10.75	10.3	10.2
21	UR5	6.60	10.40	6.71	6.77	6.6	7.4
21	UR4	7.56	6.97	8.07	8.12	7.2	8.3
21	UR3	8.36	8.41	8.13	8.06	7.9	8.8
21	UR2	7.11	7.50	7.85	7.55	7.8	7.7
21	UR1	8.73	10.28	8.38	7.78	9.0	8.7
21	UL1	8.84	8.94	8.61	7.78	8.5	8.4
21	UL2	7.29	7.38	7.54	7.19	8.0	6.7
21	UL3	8.49	9.30	7.81	7.52	8.5	8.7
21	UL4	7.36	7.40	7.08	7.77	7.4	8.6
21	UL5	7.06	6.62	7.23	7.57	7.1	8.1
21	UL6	10.54	10.35	10.50	12.23	10.5	10.4
21	LL6	11.46	11.17	10.37	12.76	11.4	11.0
21	LL5	7.51	8.20	7.52	8.79	7.6	8.4
21	LL4	8.02	8.28	7.91	9.67	8.8	8.8
21	LL3	7.31	8.16	8.22	6.99	8.6	9.2
21	LL2	6.53	6.42	6.19	6.48	6.1	6.1
21	LL1	5.96	5.33	6.46	6.04	6.1	6.2
21	LR1	5.74	6.47	5.37	5.31	5.4	6.6
21	LR2	6.31	6.67	6.84	6.66	6.9	6.7
21	LR3	7.35	7.57	7.65	8.55	8.0	9.0
21	LR4	7.86	7.88	7.42	8.90	7.9	8.6
21	LR5	7.49	7.34	7.27	8.05	7.7	7.9
21	LR6	11.04	11.03	11.26	12.71	11.0	11.4
22	UR6	10.75	10.51	11.54	12.43	11.4	10.6
22	UR5	7.08	7.64	7.37	7.29	7.0	7.0
22	UR4	7.63	7.50	6.98	8.52	7.4	7.2
22	UR3	8.16	7.95	7.15	7.49	8.6	8.4
22	UR2	6.79	7.25	6.63	5.82	7.2	7.1
22	UR1	8.33	8.09	7.90	7.82	8.2	8.3
22	UL1	8.40	9.20	8.39	7.79	8.5	9.0
22	UL2	6.86	6.53	7.89	7.08	7.6	7.6
22	UL3	7.79	8.89	8.47	6.89	8.4	8.7

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
22	UL4	7.36	6.84	7.49	7.60	7.7	7.8
22	UL5	6.75	7.51	6.90	7.19	7.1	7.1
22	UL6	10.81	11.07	11.58	11.98	11.2	10.6
22	LL6	11.36	11.63	11.70	12.23	11.4	11.4
22	LL5	7.66	7.58	7.58	8.19	7.6	7.6
22	LL4	8.09	7.92	7.45	8.27	8.0	7.6
22	LL3	6.84	8.38	6.65	7.66	7.4	7.2
22	LL2	6.36	6.18	5.85	7.00	6.6	7.2
22	LL1	5.14	4.88	5.45	6.03	5.6	6.7
22	LR1	5.81	4.98	5.01	6.35	5.8	6.3
22	LR2	5.98	6.11	5.34	6.51	7.3	6.9
22	LR3	6.58	7.63	7.04	7.71	7.0	7.5
22	LR4	7.42	7.70	7.41	8.09	7.7	8.0
22	LR5	7.41	8.11	7.39	8.32	7.5	7.8
22	LR6	11.51	11.68	11.75	12.54	11.7	11.5
23	UR6	10.84	11.13	11.16	11.69	11.2	10.6
23	UR5	7.35	8.06	7.46	7.50	7.8	7.2
23	UR4	7.83	7.95	7.53	7.89	7.9	7.7
23	UR3	8.01	8.92	8.24	7.99	8.2	8.5
23	UR2	6.90	6.47	7.07	6.79	7.4	6.7
23	UR1	9.21	8.98	9.79	8.55	10.0	9.2
23	UL1	9.14	8.73	8.75	8.26	10.2	8.9
23	UL2	6.78	6.60	7.14	6.38	8.0	7.2
23	UL3	8.16	8.71	8.53	8.33	8.7	9.1
23	UL4	8.01	7.82	8.30	7.94	7.8	8.4
23	UL5	7.23	7.93	7.57	7.25	7.6	7.5
23	UL6	10.64	10.95	10.95	12.64	11.5	10.0
23	LL6	11.43	11.45	11.39	13.04	11.9	11.1
23	LL5	7.91	7.15	8.55	8.35	8.3	7.9
23	LL4	7.77	8.92	8.30	8.50	8.2	8.1
23	LL3	7.10	7.50	7.99	8.33	7.8	8.9
23	LL2	6.23	5.96	5.83	6.07	6.4	6.4
23	LL1	5.68	4.53	5.13	6.59	6.2	6.3
23	LR1	5.51	5.88	5.39	6.24	6.1	6.3
23	LR2	6.03	5.67	5.89	7.21	6.5	7.0
23	LR3	6.90	7.70	6.50	7.91	7.1	8.6
23	LR4	7.24	7.61	7.33	8.34	7.5	8.0
23	LR5	7.61	8.58	7.85	8.72	8.2	8.1
23	LR6	11.29	11.13	11.26	12.11	11.3	11.0
24	UR6	10.36	10.07	10.22	11.32	10.6	10.1

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
24	UR5	7.22	7.49	6.82	6.97	7.2	7.1
24	UR4	7.73	7.43	7.49	7.24	7.2	7.5
24	UR3	8.52	8.89	8.38	7.96	8.3	8.7
24	UR2	7.27	7.36	7.42	7.07	7.3	7.0
24	UR1	9.25	9.16	8.73	8.19	8.7	8.7
24	UL1	9.05	8.68	9.32	8.84	9.4	9.0
24	UL2	7.62	7.84	7.15	6.86	7.1	6.7
24	UL3	8.69	8.99	8.27	7.79	8.1	8.2
24	UL4	7.70	6.94	7.45	7.44	7.7	7.7
24	UL5	7.18	6.77	7.11	7.22	7.0	7.1
24	UL6	10.45	10.81	10.87	11.97	10.5	10.5
24	LL6	12.01	11.22	11.91	12.91	11.7	11.5
24	LL5	7.66	7.58	7.73	7.99	7.8	7.5
24	LL4	7.68	7.91	7.56	7.99	7.7	8.0
24	LL3	7.38	7.91	7.04	7.66	7.4	7.6
24	LL2	6.47	6.13	6.08	5.98	6.6	6.8
24	LL1	5.82	5.68	5.48	5.70	6.2	6.5
24	LR1	5.94	5.55	5.21	6.05	6.2	6.6
24	LR2	6.90	6.99	6.09	6.45	6.9	6.5
24	LR3	7.31	7.50	7.27	7.55	7.7	7.9
24	LR4	7.95	7.50	7.25	7.82	7.8	8.1
24	LR5	7.99	7.72	7.21	7.51	7.4	7.6
24	LR6	12.00	11.92	11.56	11.83	11.5	11.4
25	UR6	11.98	11.20	11.74	12.08	11.7	10.9
25	UR5	7.79	7.61	7.10	6.92	7.2	7.4
25	UR4	7.79	7.68	7.53	7.68	7.2	7.9
25	UR3	8.87	9.32	8.84	8.38	9.1	9.9
25	UR2	7.47	7.07	8.47	6.62	7.7	7.2
25	UR1	9.58	9.91	9.65	9.19	10.0	9.4
25	UL1	9.40	9.46	9.91	9.45	9.7	9.5
25	UL2	7.20	6.59	8.09	6.88	7.8	6.7
25	UL3	9.02	9.10	9.21	8.74	8.9	8.8
25	UL4	7.55	7.19	7.09	7.79	7.3	8.3
25	UL5	7.52	7.15	7.19	7.70	7.2	7.4
25	UL6	11.53	11.07	11.56	12.62	11.4	11.1
25	LL6	12.38	11.60	12.14	13.58	11.7	11.7
25	LL5	7.80	7.60	8.02	8.12	7.5	7.7
25	LL4	7.58	7.15	7.23	7.80	7.1	7.7
25	LL3	7.64	8.44	7.97	9.34	8.2	9.7
25	LL2	6.27	6.23	6.41	7.87	6.5	7.1

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
25	LL1	5.41	5.77	5.35	6.16	5.5	6.9
25	LR1	5.41	5.54	5.35	6.07	5.7	6.8
25	LR2	6.42	6.60	6.50	7.71	6.5	7.8
25	LR3	7.75	7.79	7.46	8.65	8.3	9.7
25	LR4	7.47	8.09	7.65	8.02	7.7	8.2
25	LR5	7.78	7.89	7.31	8.71	7.7	7.6
25	LR6	11.90	12.29	12.44	12.66	11.9	12.1
26	UR6	9.76	9.63	11.18	11.49	10.4	10.3
26	UR5	6.80	6.55	6.23	6.60	6.8	6.4
26	UR4	6.55	6.37	6.65	6.41	6.7	6.4
26	UR3	7.93	8.19	7.35	7.65	7.6	7.8
26	UR2	6.73	6.91	6.82	6.87	6.7	6.6
26	UR1	7.79	8.96	7.13	7.32	7.9	7.8
26	UL1	7.44	8.99	7.07	7.12	7.8	7.4
26	UL2	7.22	6.66	6.55	6.54	7.1	6.4
26	UL3	7.37	7.91	7.97	7.66	7.6	7.7
26	UL4	6.79	6.50	6.20	7.39	6.5	7.0
26	UL5	6.71	6.86	7.10	7.01	6.8	6.7
26	UL6	9.57	9.64	10.47	11.64	10.5	10.5
26	LL6	10.70	10.71	10.17	11.60	10.6	10.4
26	LL5	7.21	7.40	7.56	7.85	7.1	7.6
26	LL4	6.97	6.99	6.88	7.04	6.8	6.9
26	LL3	6.60	6.92	6.00	7.33	6.3	7.0
26	LL2	5.60	5.58	5.19	6.84	5.4	6.4
26	LL1	5.28	5.77	4.81	6.37	5.1	6.2
26	LR1	5.09	4.70	5.26	6.19	5.2	7.1
26	LR2	5.38	5.63	5.13	6.07	5.3	6.5
26	LR3	7.05	7.65	6.62	6.96	6.9	6.9
26	LR4	7.25	7.03	6.79	7.46	7.2	7.0
26	LR5	7.35	7.77	6.83	7.99	7.2	7.1
26	LR6	10.54	10.50	10.77	11.83	10.8	10.3
27	UR6	10.20	10.11	10.73	11.31	11.0	10.1
27	UR5	6.33	6.77	6.26	6.32	6.6	6.3
27	UR4	6.33	6.92	7.10	6.87	6.6	6.8
27	UR3	8.03	8.39	8.23	7.98	8.4	8.4
27	UR2	4.21	4.20	5.40	5.52	6.6	5.2
27	UR1	7.79	8.22	7.30	7.84	8.4	7.5
27	UL1	7.83	8.05	8.01	8.26	8.4	8.3
27	UL2	4.39	2.97	4.80	4.46	5.2	4.8
27	UL3	8.03	8.54	8.04	8.27	9.0	8.3

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
27	UL4	7.00	6.64	6.72	7.09	7.2	7.1
27	UL5	6.48	7.13	6.41	6.65	6.9	6.8
27	UL6	10.41	10.41	9.95	10.12	10.5	9.6
27	LL6	11.39	11.78	10.89	13.08	11.6	11.4
27	LL5	6.93	6.87	7.49	7.45	7.1	7.0
27	LL4	6.85	6.90	7.50	7.96	7.2	7.3
27	LL3	7.00	7.37	6.72	7.52	7.4	7.5
27	LL2	5.20	4.39	5.86	6.24	5.8	6.3
27	LL1	4.93	4.67	5.22	5.44	5.4	5.6
27	LR1	4.92	4.33	5.19	5.68	5.1	5.6
27	LR2	5.57	4.95	5.41	6.07	5.9	6.0
27	LR3	7.20	7.33	6.93	7.60	7.1	8.1
27	LR4	7.10	6.73	7.10	7.96	7.3	7.5
27	LR5	6.86	7.20	6.75	7.85	7.2	6.8
27	LR6	11.02	11.11	11.32	12.33	11.1	11.5
28	UR6	9.78	10.73	10.35	10.99	10.8	10.0
28	UR5	6.30	7.29	6.82	6.94	7.2	7.0
28	UR4	6.76	6.93	6.58	6.92	7.2	7.0
28	UR3	7.79	8.27	7.44	6.80	7.2	7.3
28	UR2	7.07	6.81	6.66	6.27	6.9	6.9
28	UR1	8.59	9.47	8.56	8.25	9.0	8.5
28	UL1	8.57	8.99	9.03	8.20	9.3	9.3
28	UL2	6.92	7.12	7.68	6.58	8.1	7.0
28	UL3	7.86	7.69	7.57	7.29	7.8	7.9
28	UL4	6.96	6.96	7.46	7.10	7.3	7.5
28	UL5	6.47	7.44	7.05	7.67	7.5	7.1
28	UL6	9.92	11.20	10.90	11.64	10.3	10.1
28	LL6	10.92	11.26	11.47	11.79	11.3	10.7
28	LL5	6.93	7.19	7.79	7.22	7.4	7.4
28	LL4	6.73	8.18	7.59	7.36	7.4	7.5
28	LL3	6.51	7.50	7.50	8.08	7.8	7.6
28	LL2	5.92	5.26	5.85	6.71	6.2	6.0
28	LL1	5.44	5.16	5.03	6.48	6.4	6.1
28	LR1	5.44	6.14	5.34	5.62	5.2	5.8
28	LR2	6.04	5.40	5.26	6.41	5.9	6.7
28	LR3	6.44	6.67	7.16	7.16	7.7	7.3
28	LR4	6.98	6.92	7.01	7.37	7.2	7.5
28	LR5	6.98	7.37	8.21	7.59	8.0	7.4
28	LR6	10.66	10.92	10.98	11.44	11.2	10.5
29	UR6	9.78	9.37	9.60	10.17	9.3	9.5

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
29	UR5	6.69	6.58	6.06	7.16	6.3	6.7
29	UR4	6.47	6.38	6.43	6.19	6.5	6.7
29	UR3	7.07	7.65	6.70	6.76	6.9	6.8
29	UR2	5.78	6.00	5.59	5.14	5.9	5.3
29	UR1	7.22	7.33	7.26	6.52	7.6	6.9
29	UL1	7.22	7.49	7.64	6.98	7.7	7.2
29	UL2	5.78	5.42	6.38	5.59	6.0	5.5
29	UL3	7.12	7.34	6.96	6.81	7.0	6.7
29	UL4	6.46	6.22	6.50	7.01	6.3	6.9
29	UL5	6.30	6.41	6.50	7.13	6.2	6.6
29	UL6	9.85	9.39	9.58	10.74	9.7	9.4
29	LL6	9.19	9.75	9.31	10.92	9.3	9.5
29	LL5	6.91	6.99	6.90	7.29	6.6	6.5
29	LL4	6.25	6.32	6.52	6.51	6.3	6.1
29	LL3	6.11	6.43	5.90	7.31	6.0	6.5
29	LL2	4.81	4.78	4.80	5.28	4.9	5.4
29	LL1	4.57	4.11	4.45	4.80	4.5	5.2
29	LR1	4.60	4.50	4.89	5.60	4.8	5.6
29	LR2	4.81	4.66	4.51	5.54	4.9	5.7
29	LR3	6.26	6.31	5.64	6.18	5.9	6.2
29	LR4	6.10	6.37	6.17	6.97	6.1	6.2
29	LR5	6.85	6.79	6.71	7.15	6.8	6.6
29	LR6	9.38	9.74	9.58	10.70	9.3	9.3
30	UR6	10.38	10.20	10.92	11.95	11.1	10.7
30	UR5	7.07	7.07	6.95	6.61	6.9	6.7
30	UR4	7.46	7.14	7.91	8.54	8.0	8.6
30	UR3	7.73	8.23	7.39	7.95	7.9	8.2
30	UR2	6.53	6.55	6.67	6.45	6.8	6.1
30	UR1	8.13	8.90	8.51	7.59	8.8	8.0
30	UL1	7.68	8.52	8.90	8.08	8.4	7.8
30	UL2	6.32	6.61	6.53	6.04	6.3	5.7
30	UL3	7.68	8.16	8.03	7.58	8.1	7.9
30	UL4	7.38	7.02	7.86	8.00	7.8	8.2
30	UL5	7.23	7.34	7.20	7.37	7.6	7.6
30	UL6	10.43	10.47	10.52	11.26	10.9	10.4
30	LL6	11.30	11.46	10.88	12.25	11.0	11.1
30	LL5	7.70	7.70	8.29	8.25	8.1	7.8
30	LL4	7.33	7.12	7.49	7.37	7.1	7.1
30	LL3	6.89	7.11	7.74	7.02	6.6	7.2
30	LL2	5.72	5.93	5.85	6.36	5.4	6.2

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
30	LL1	4.88	5.44	4.89	5.79	5.1	6.7
30	LR1	5.10	5.28	5.03	5.80	5.3	6.3
30	LR2	5.49	6.34	4.71	5.83	5.7	5.8
30	LR3	6.71	6.74	7.27	7.75	7.5	7.7
30	LR4	7.27	7.08	7.56	7.71	7.4	7.3
30	LR5	7.59	7.25	7.14	7.30	7.2	6.9
30	LR6	11.55	11.25	11.41	12.40	11.3	11.1

APPENDIX B

RELIABILITY DATA

* all measurements in mm
** O = OsiriX, D = Dolphin Imaging

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
1	UR6	11.06	10.26	10.68	11.80	11.1	10.8
1	UR5	7.10	6.70	6.26	6.80	6.7	6.8
1	UR4	7.05	6.54	6.12	6.54	6.5	7.0
1	UR3	8.18	8.88	7.70	7.76	8.1	8.8
1	UR2	7.48	8.11	7.61	7.45	8.3	7.6
1	UR1	8.44	9.75	9.12	7.95	9.4	8.6
1	UL1	8.71	8.51	9.05	8.16	8.7	8.5
1	UL2	7.30	8.00	8.27	7.76	8.5	7.0
1	UL3	8.41	8.19	8.50	8.05	8.9	8.4
1	UL4	7.09	6.16	6.09	6.57	6.9	7.2
1	UL5	6.89	6.65	6.46	6.83	7.0	7.0
1	UL6	11	10.39	10.23	11.78	10.7	10.3
1	LL6	11.65	11.55	11.73	12.01	11.1	11.5
1	LL5	6.77	6.67	6.83	7.07	6.7	7.0
1	LL4	6.76	7.04	6.54	6.41	6.8	7.3
1	LL3	7.22	7.20	6.86	7.89	7.1	8.0
1	LL2	6.03	6.10	5.91	6.80	6.1	6.3
1	LL1	5.38	5.00	4.97	6.38	5.2	6.2
1	LR1	5.46	5.51	5.92	6.47	5.5	6.1
1	LR2	6.30	6.42	5.91	6.79	6.4	6.9
1	LR3	7.18	7.09	6.95	7.68	7.2	8.3
1	LR4	6.91	7.15	6.77	7.13	6.6	7.1
1	LR5	6.89	6.82	6.64	6.93	6.9	7.4
1	LR6	11.53	11.74	11.67	12.84	11.3	11.8
2	UR6	10.41	9.94	10.47	11.10	10.2	10.3
2	UR5	6.66	6.73	6.59	6.61	6.8	6.6
2	UR4	6.43	6.87	6.41	6.79	6.6	6.8
2	UR3	7.52	8.24	7.62	6.88	7.3	7.4
2	UR2	7.37	8.35	7.53	5.95	6.8	6.5
2	UR1	9.22	8.96	9.39	7.56	8.7	8.7
2	UL1	9.22	9.56	9.05	8.35	8.9	9.3
2	UL2	7.04	7.12	7.83	7.27	8.0	6.9
2	UL3	8.08	8.10	8.33	7.04	7.3	7.8

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
2	UL4	6.87	6.86	6.49	7.17	6.7	7.0
2	UL5	6.32	6.97	6.68	6.39	6.7	7.0
2	UL6	10.61	10.05	10.83	10.96	10.9	10.2
2	LL6	10.72	11.90	10.35	11.80	10.4	10.3
2	LL5	6.37	6.45	6.78	6.94	6.7	6.8
2	LL4	6.37	6.96	5.82	6.72	6.6	7.0
2	LL3	6.86	7.25	7.34	7.65	7.6	7.7
2	LL2	5.75	5.75	5.22	5.67	5.9	5.7
2	LL1	5.17	5.47	4.71	5.28	5.4	6.1
2	LR1	4.80	5.05	4.77	5.29	5.7	6.0
2	LR2	6.13	5.34	5.99	7.36	6.5	6.6
2	LR3	6.78	7.51	6.08	7.49	6.9	7.6
2	LR4	6.33	6.39	6.51	6.59	6.2	6.8
2	LR5	6.33	7.25	6.65	7.08	6.5	6.7
2	LR6	10.48	11.12	10.51	11.32	10.6	10.9
3	UR6	10.28	9.92	10.48	11.49	10.1	10.1
3	UR5	6.76	7.03	7.19	6.15	6.4	6.4
3	UR4	6.94	6.78	6.45	6.41	7.0	6.8
3	UR3	8.38	8.24	8.30	7.97	8.3	8.2
3	UR2	7.13	7.13	7.12	7.40	7.5	8.1
3	UR1	8.70	8.95	9.21	9.18	8.5	8.0
3	UL1	8.54	8.51	8.72	9.21	8.6	8.4
3	UL2	6.67	6.73	7.22	7.67	6.5	5.9
3	UL3	8.04	9.17	9.08	8.77	9.3	8.9
3	UL4	7.04	6.18	7.40	7.30	7.1	7.1
3	UL5	6.70	6.60	7.20	7.60	7.5	7.3
3	UL6	10.21	10.44	11.05	12.08	10.7	10.4
3	LL6	11.01	10.73	11.22	11.07	11.1	10.6
3	LL5	7.80	8.12	7.72	7.45	8.2	7.1
3	LL4	7.80	7.87	7.75	6.62	7.9	7.9
3	LL3	7.35	7.95	7.17	6.88	7.3	7.1
3	LL2	5.98	6.01	5.10	5.60	6.0	5.0
3	LL1	5.48	4.04	5.32	6.09	5.8	4.8
3	LR1	5.09	4.73	4.96	5.96	5.9	5.0
3	LR2	5.55	5.24	6.01	5.98	5.7	5.6
3	LR3	7.34	8.02	7.40	7.01	7.6	6.8
3	LR4	7.84	6.94	7.53	7.04	7.9	7.7
3	LR5	7.49	7.80	7.61	7.08	7.4	7.2
3	LR6	11.01	10.91	11.03	11.13	11.2	10.7
4	UR6	10.57	10.14	11.13	10.90	10.5	10.3

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
4	UR5	6.51	6.59	6.40	5.65	6.2	6.1
4	UR4	6.98	6.62	6.57	6.49	6.6	7.2
4	UR3	7.91	8.25	7.61	7.23	7.8	7.0
4	UR2	6.51	6.79	6.40	5.34	6.3	5.7
4	UR1	8.82	9.03	9.27	7.26	8.4	7.6
4	UL1	9.13	9.34	9.12	7.33	8.8	7.8
4	UL2	6.62	6.18	7.28	5.96	6.7	5.8
4	UL3	8.38	8.64	8.78	6.58	8.2	7.6
4	UL4	7.08	7.04	7.25	7.55	7.5	7.5
4	UL5	6.41	6.60	6.58	6.06	6.4	6.6
4	UL6	10.49	10.58	10.26	11.21	11.4	10.1
4	LL6	10.58	10.87	10.44	11.71	10.7	10.5
4	LL5	6.19	6.85	7.05	6.96	6.6	6.7
4	LL4	6.99	7.27	7.18	7.10	6.8	7.2
4	LL3	6.81	7.21	7.09	7.36	6.4	7.2
4	LL2	5.86	5.58	5.81	6.12	5.4	5.9
4	LL1	5.50	5.13	4.86	5.57	5.0	5.5
4	LR1	5.15	5.29	5.00	5.95	5.0	5.2
4	LR2	5.58	5.71	5.62	5.71	5.4	5.9
4	LR3	6.92	7.36	6.64	7.66	6.7	7.0
4	LR4	7.13	6.81	7.00	6.56	7.1	6.8
4	LR5	7.15	6.97	6.44	7.12	6.5	6.8
4	LR6	10.84	10.40	10.63	11.32	10.4	10.4
5	UR6	10.13	9.96	10.24	10.35	9.6	9.9
5	UR5	6.89	6.40	6.38	6.45	6.8	6.9
5	UR4	7.08	7.28	6.76	7.27	6.7	7.1
5	UR3	7.57	7.42	7.55	7.01	7.2	7.5
5	UR2	7.23	6.91	7.37	7.03	7.4	6.8
5	UR1	8.97	9.68	8.46	7.95	8.9	8.6
5	UL1	8.97	9.69	8.54	7.87	8.9	8.4
5	UL2	7.38	7.78	6.94	6.03	7.2	7.1
5	UL3	7.29	8.52	7.74	7.14	7.8	7.9
5	UL4	7.04	6.90	7.57	7.13	7.2	7.5
5	UL5	6.76	7.43	7.07	6.40	7.2	6.8
5	UL6	10.27	10.14	10.89	10.69	10.0	9.9
5	LL6	11.08	11.25	11.28	11.62	11.2	11.0
5	LL5	6.94	7.22	6.73	7.03	7.3	7.1
5	LL4	7.60	7.47	7.48	7.51	7.4	7.7
5	LL3	6.47	7.59	7.45	5.78	7.2	7.2
5	LL2	6.24	5.73	5.91	5.33	5.8	6.0

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
5	LL1	5.10	5.97	5.50	5.48	5.7	5.3
5	LR1	5.10	5.22	5.22	5.19	5.5	5.4
5	LR2	6.22	6.16	6.28	5.50	5.5	6.2
5	LR3	6.62	7.05	7.55	6.30	7.2	6.9
5	LR4	7.44	7.37	6.80	7.38	7.8	8.0
5	LR5	7.44	7.44	7.81	7.88	7.4	7.6
5	LR6	10.74	10.80	10.94	11.32	10.7	10.9
6	UR6	11.24	11.19	10.60	11.81	10.9	10.8
6	UR5	7.74	8.10	9.03	7.80	7.6	7.6
6	UR4	8.37	8.12	8.12	8.70	8.2	8.7
6	UR3	7.98	8.63	8.86	8.32	7.7	8.6
6	UR2	7.50	8.27	7.23	7.58	7.3	7.6
6	UR1	9.94	10.52	11.33	10.07	10.1	9.9
6	UL1	9.94	9.55	10.57	10.02	10.7	10.1
6	UL2	7.41	7.08	8.41	7.32	7.2	7.3
6	UL3	7.93	8.38	8.48	8.47	8.2	8.6
6	UL4	8.14	8.35	8.85	8.36	7.9	8.5
6	UL5	7.51	7.57	7.82	7.24	7.5	8.3
6	UL6	11.39	11.02	10.74	12.51	11.4	10.5
6	LL6	11.73	11.88	12.66	11.95	11.9	11.9
6	LL5	8.44	9.74	8.45	8.06	8.6	8.2
6	LL4	7.94	7.28	7.86	7.46	8.4	8.9
6	LL3	7.48	8.18	8.41	8.49	7.9	8.7
6	LL2	6.30	5.98	6.31	7.03	6.7	6.9
6	LL1	5.87	5.01	5.67	7.15	6.0	6.7
6	LR1	5.68	5.62	5.66	6.37	6.0	6.8
6	LR2	6.19	6.32	6.68	6.47	6.9	7.3
6	LR3	7.40	7.85	8.17	7.94	7.8	7.5
6	LR4	7.66	7.75	7.86	7.64	7.7	8.0
6	LR5	7.68	8.37	7.80	8.72	8.2	8.2
6	LR6	11.52	11.87	12.66	11.88	11.8	11.7
7	UR6	10.66	10.47	10.56	10.91	10.6	10.3
7	UR5	6.97	7.23	6.92	6.55	6.8	6.9
7	UR4	7.67	7.39	7.12	6.83	7.3	7.7
7	UR3	8.51	8.38	8.74	8.33	8.5	8.6
7	UR2	7.48	8.53	8.21	7.37	8.5	7.9
7	UR1	9.44	9.54	8.98	9.75	10.0	9.5
7	UL1	9.10	9.60	9.74	9.66	9.7	9.9
7	UL2	7.47	7.74	7.67	7.65	7.7	7.6
7	UL3	8.54	8.13	8.48	8.51	8.3	9.1

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
7	UL4	7.60	7.62	7.54	7.45	7.2	8.0
7	UL5	7.31	7.04	7.23	6.72	7.3	7.3
7	UL6	10.47	10.61	10.56	10.99	10.3	10.1
7	LL6	11.00	11.91	11.64	12.54	11.2	11.5
7	LL5 *	7.12	7.86	7.18	7.57	7.5	7.5
7	LL4	7.54	7.31	7.04	6.88	7.4	7.8
7	LL3	7.54	7.22	8.10	8.41	7.9	8.8
7	LL2	6.34	5.18	5.78	7.13	6.3	6.7
7	LL1	5.44	4.83	5.16	6.70	5.8	6.4
7	LR1	5.44	5.40	5.68	6.68	6.1	5.9
7	LR2	6.07	6.62	5.67	7.08	6.6	7.3
7	LR3	7.35	7.69	7.80	7.78	8.3	8.7
7	LR4	7.35	7.26	6.92	7.43	7.3	7.5
7	LR5	7.12	7.14	6.78	7.03	7.0	7.0
7	LR6	11.40	11.81	11.50	12.04	11.4	11.3
8	UR6	11.21	10.96	11.00	11.48	11.2	10.7
8	UR5	7.55	7.62	6.99	7.54	7.4	7.5
8	UR4	7.86	7.47	7.86	8.10	7.8	8.0
8	UR3	8.40	8.70	8.11	7.37	9.0	8.3
8	UR2	7.07	6.40	6.64	6.56	7.6	6.7
8	UR1	8.46	7.84	7.97	8.06	8.6	7.4
8	UL1	8.46	8.34	8.65	7.90	8.7	7.8
8	UL2	6.88	7.14	6.80	6.46	7.2	6.0
8	UL3	8.47	8.47	8.15	7.89	8.9	8.5
8	UL4	7.56	7.48	7.84	7.23	7.7	8.2
8	UL5	7.56	7.67	7.85	7.30	7.2	7.8
8	UL6	11.21	11.09	10.35	9.60	11.4	10.9
8	LL6	11.71	12.01	11.86	12.58	11.5	11.9
8	LL5 *	7.93	8.22	8.04	6.97	7.8	8.4
8	LL4	7.78	8.24	7.57	8.32	8.1	8.1
8	LL3	7.45	7.82	7.60	8.59	7.2	8.4
8	LL2	6.29	5.59	5.90	5.78	6.5	5.8
8	LL1	5.33	4.92	5.49	5.71	5.8	5.7
8	LR1	5.37	5.12	5.39	5.40	5.7	5.8
8	LR2	6.05	6.03	5.94	6.01	6.3	6.7
8	LR3	7.29	7.71	6.79	7.68	7.2	8.2
8	LR4	7.87	8.08	7.82	8.33	8.1	8.1
8	LR5	7.93	8.07	7.70	8.76	8.0	8.3
8	LR6	11.19	12.18	11.52	12.32	11.9	12.0
9	UR6	9.96	10.44	10.32	9.75	10.1	10.1

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
9	UR5	7.09	7.24	7.09	7.21	7.1	7.2
9	UR4	6.81	7.37	6.74	6.90	7.0	7.6
9	UR3	7.71	8.08	6.93	7.03	7.7	8.1
9	UR2	6.71	6.42	5.93	5.60	6.5	6.6
9	UR1	8.52	7.86	8.06	7.33	9.2	9.0
9	UL1	8.31	7.26	7.77	7.74	8.7	9.2
9	UL2	6.85	6.00	6.41	5.80	6.8	6.5
9	UL3	7.39	7.49	7.06	6.81	7.1	7.6
9	UL4	7.02	6.71	6.53	7.33	7.0	7.8
9	UL5	6.55	6.83	7.06	6.74	6.9	7.4
9	UL6	10.11	9.95	10.19	11.55	10.5	10.3
9	LL6	10.74	11.03	10.66	11.46	10.8	11.1
9	LL5	7.38	7.29	7.91	7.83	7.8	7.7
9	LL4	6.96	7.33	6.52	6.92	6.5	7.0
9	LL3	7.02	6.74	6.87	6.75	6.5	7.1
9	LL2	6.18	5.55	5.71	6.78	5.9	6.4
9	LL1	5.64	5.20	5.18	5.74	5.3	6.1
9	LR1	5.26	5.18	5.19	6.04	6.2	6.6
9	LR2	6.00	5.62	5.96	6.10	5.4	6.6
9	LR3	7.00	6.85	6.35	6.53	5.7	6.5
9	LR4	7.22	6.77	6.77	6.67	6.7	6.9
9	LR5	7.10	7.66	7.10	7.20	7.2	7.4
9	LR6	10.79	10.37	11.35	10.93	11.0	10.9
10	UR6	10.80	10.64	11.34	11.07	10.6	10.5
10	UR5	7.65	7.33	7.10	7.44	7.4	7.0
10	UR4	7.22	7.52	7.55	7.31	7.5	7.8
10	UR3	8.33	8.62	8.62	7.61	8.2	7.9
10	UR2	7.37	7.16	6.96	5.59	7.5	6.7
10	UR1	9.02	9.01	8.20	7.40	9.4	8.6
10	UL1	8.92	8.84	8.23	7.41	8.5	9.5
10	UL2	7.15	7.08	7.05	6.07	7.9	7.2
10	UL3	8.44	8.56	7.74	7.54	8.3	8.5
10	UL4	7.08	7.25	7.55	7.10	7.6	7.4
10	UL5	7.38	7.78	7.33	7.71	7.4	8.0
10	UL6	10.60	10.47	10.56	10.58	11.6	10.7
10	LL6	11.78	11.56	11.60	11.26	11.1	10.9
10	LL5	7.18	8.17	7.57	7.75	7.0	7.9
10	LL4	7.74	7.24	7.15	7.22	7.5	7.5
10	LL3	7.44	8.32	7.93	6.75	7.2	8.5
10	LL2	6.10	5.85	5.85	6.53	6.3	6.9

Subject	Tooth	Model	3D	Detailed O	Simple O	Detailed D	Simple D
10	LL1	6.03	5.27	5.00	6.37	6.2	6.1
10	LR1	5.87	5.45	5.64	6.40	5.8	6.1
10	LR2	6.32	5.68	5.55	6.74	6.2	5.9
10	LR3	7.30	8.05	7.79	7.11	8.0	7.8
10	LR4	7.90	7.69	7.70	7.92	8.0	7.4
10	LR5	7.23	7.62	7.31	7.75	7.6	7.2
10	LR6	11.56	11.87	11.18	11.83	11.4	11.2

APPENDIX C

PYTHON SCRIPT TO EXTRACT XYZ POINTS

```
from xml.etree import ElementTree as ET
from math import *
import re
import os
from os.path import join

rootDir = './'
toothWidths = {}

widthsFile = open('./MDWidths.txt', 'w')
widthsFile.write('Legend:\nFileName \nUR6 \nUR5 \nUR4 \
   nUR3 \nUR2 \nUR1 \nUL1 \nUL2 \nUL3 \nUL4 \nUL5 \nUL6\n')
widthsFile.write('LL6 \nLL5 \nLL4 \nLL3 \nLL2 \nLL1 \nLR1 \
   nLR2 \nLR3 \nLR4 \nLR5 \nLR6\n\n')

def getDistance(x1,y1,z1,x2,y2,z2):
    distance = sqrt((x1-x2)**2+(y1-y2)**2+(z1-z2)**2)
    return distance

def getToothWidths(cephFile):
    f = open(cephFile, 'r')
    cephText = f.read()
    cephData = ET.fromstring(cephText)

    landmarks = cephData.findall("LandmarkDICOMCoordinates/
       landmark")

    i = 0
    lastTooth = None
    mesialFound = False
    distalFound = False
    for item in landmarks:
        item.get(landmarks[i])
        name = str(item.find("name").text)

        #Which tooth are we at?
```

```
        if (lastTooth == None):
            lastTooth = name[0:3]

        thisTooth = name[0:3]

        #Is it mesial or distal?
        matchDistal = re.search(r'...D',name)
        if matchDistal:
            distalx = float(item.find("x").text)
            distaly = float(item.find("y").text)
            distalz = float(item.find("z").text)
            distalFound = True

        matchMesial = re.search(r'...M',name)
        if matchMesial:
            mesialx = float(item.find("x").text)
            mesialy = float(item.find("y").text)
            mesialz = float(item.find("z").text)
            mesialFound = True

        if (thisTooth == lastTooth):
            if (distalFound == True):
                if (mesialFound == True):
                    #print thisTooth, distalx, distaly,
                       distalz, mesialx, mesialy, mesialz
                    distance = getDistance(distalx, distaly,
                        distalz, mesialx, mesialy, mesialz)
                    #print thisTooth, distance
                    distalFound = False
                    mesialFound = False
                    toothWidths[thisTooth] = distance

        lastTooth = thisTooth
        i = i+1

count = 0
for dirPath,dirNames,fileNames in os.walk(rootDir):
    for file in fileNames:
        fileExt=os.path.splitext(file)[-1]
        #print fileExt
        if (fileExt == '.xml'):
            count = count +1
```

```
            #print "This is a good one"
            cephFile = join(dirPath, file)
            getToothWidths(cephFile)
            if (count%2 == 0):
                #print toothWidths
                #print toothWidths['UR6']
                widthsFile.write('%s \n%.2f \n%.2f \n%.2f \n
                   %.2f \n%.2f \n%.2f \n%.2f \n%.2f \n%.2f \
                   n%.2f \n%.2f \n%.2f\n' %
                        (file, toothWidths['UR6'],
                           toothWidths['UR5'],toothWidths['
                           UR4'],toothWidths['UR3'],
                           toothWidths['UR2'],toothWidths['
                           UR1'],toothWidths
                ['UL1'],toothWidths['UL2'],toothWidths['UL3
                   '],toothWidths['UL4'],toothWidths['UL5'],
                   toothWidths['UL6']))
                widthsFile.write('%.2f \n%.2f \n%.2f \n%.2f
                   \n%.2f \n%.2f \n%.2f \n%.2f \n%.2f \n%.2f
                    \n%.2f \n%.2f\n' %
                   (toothWidths['LL6'],toothWidths['LL5'],
                      toothWidths['LL4'],toothWidths['LL3'],
                      toothWidths['LL2'],toothWidths['LL1'],
                      toothWidths['LR1'],
                   toothWidths['LR2'],toothWidths['LR3'],
                      toothWidths['LR4'],toothWidths['LR5'],
                      toothWidths['LR6']))

widthsFile.close()
print "Congrats! The widths are measured..."
```