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Accuracy of Volumetric Analysis Software Packages in Assessment of Tooth Volume Using CBCT

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Accuracy of Volumetric Analysis Software Packages in Assessment of Tooth Volume Using CBCT

by

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A Thesis submitted in partial satisfaction of
the requirements for the degree
Master of Science in Periodontics

June 2016

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 Master of Science.

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I would like to give a special thanks to my husband who has been providing moral support from the beginning. And finally, I would like to thank God for providing me the undeserved opportunity to study His creation and marvel in its complexity.

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ABBREVIATIONS

CBCT	Cone Beam Computed Tomography
ICC	Intraclass correlation coefficient.
DICOM	Digital Imaging and Communication in Medicine

ABSTRACT OF THE THESIS

Accuracy of Volumetric Analysis Software Packages in

Assessment of Tooth Volume Using CBCT

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Saylee Nimbalkar

Masters of Science, Advanced Specialty Education Program in Periodontics
Loma Linda University, June 2016
Dr. Erik Sahl, Chairperson
Dr. Kenneth Abramovitch, Committee member
Dr. Dwight Rice, Committee member

The purpose of this study was to evaluate the accuracy of volumetric analysis software packages in assessment of tooth volume using cone beam computed tomography and compare them to the volume obtained using an optical digital scanner.

Twenty-four single rooted teeth indicated for extraction were collected. Cone beam computed tomography scans of these teeth resting in a custom scan jig were taken. Three dimensional digital models were obtained from the DICOM image cone beam computed tomography files using segmentation software packages (Anatomage, Mimics, and Amira) and volumes were calculated for each of the segmented teeth. The teeth were then scanned using a 3-shape digital scanner. The stereolithographic files were used to calculate the volume. Volumetric analysis comparisons were made between the stereo-lithographic scanner measurements and the individual cone beam computed tomography software measurements of the segmented data. The intraclass correlation coefficient was used for the reliability tests. Friedman’s two-way analysis of variance was used to compare the volume obtained from the software programs.

Results: With the fixed threshold protocol, the volume difference was statistically significant for all software programs compared to the reference standard.

Conclusion: All three software programs were reliable in the volume determination of the teeth. Mean standard error with Anatomage fixed threshold was 7.1%, Amira fixed threshold was 13.2% and Mimics fixed threshold was 17%. Each software had a different technique for segmentation as well as there was difference in the values for fixed threshold in each software.

CHAPTER ONE

INTRODUCTION

Periodontal diagnostic and prognostic evaluation is based mostly upon the amount of bone supporting the tooth. Also, radiographs have been widely used to assess root length as a means of estimating the bone loss. Since root length is a one-dimensional linear measurement of bone height along the root surface, it results in statistically significant errors by overestimating or underestimating the remaining bone level. These errors include localization and size of the lesion in a bucco-lingual plane. These errors are compounded due to lack of information of the bone level on the buccal and lingual side of the tooth. The linear measurement of a vertical defect does not carry any information with regard to the width of the defect.

Considering that the tooth is a three dimensional structure, the volume of the tooth may be a better measure of the bone support as opposed to the surface area. The volume gives information of the bone displaced by the root in contrast to the surface area that measures only the attachment offered by the Sharpey's fibers. It also would account for the differences in root morphology in comparison to linear or area measurements.

In order to arrive at a realistic prognosis and treatment plan for a periodontally involved dentition, an accurate determination of the amount of remaining bone support is necessary. Most studies quantify root surface areas as a means to identify the remaining bone support using variations on one of three methods: (1) division planimetry, (2) weight conversion, or (3) the membrane technique. With division planimetry, the root is sectioned perpendicularly or longitudinally to the tooth vertical axis, and each section surface area is calculated by multiplying that section circumference by its thickness. With the weight conversion method, the tooth roots are coated with a uniform thickness of benzene, silver plate, or other coating agent; the weight change is then converted to a surface area. The membrane technique was the most commonly used technique. With this technique, the root surfaces are covered with thin material such as tin foil, polyvinyl chloride, or thin paper. Subsequently, the material is peeled off and the surface area of the material measured with devices such as a planimeter, grid paper, or grid slides. These techniques were cumbersome, inaccurate for multi-rooted teeth and required the tooth to be extracted. With the use of the volumetric 3 Dimensional software, the teeth can be analyzed using a routine cone beam computed tomography and does not necessitate the extraction of the tooth. To date the physical volume of a tooth has been measured using the water displacement method based on the Archimedes principle. The accuracy of in-vivo volumetric measurements using cone beam computed tomography images have been compared with the physical volume of the tooth. The measurements slightly deviate from the physical volumes within -4% to 7%. With the widespread use of cone beam computed tomography, the use of a three dimensional software that is primarily used in implant treatment planning may be convenient to volumetrically assess the tooth remaining in bone support. The software also allows for individualized determination of the actual bone support and not the extrapolated bone loss from linear measurements.

In today's era, intraoral mapping technology is one of the fastest growing new areas in dentistry since 3 dimensional scanning of the mouth is required in a large number of procedures such as restorative, orthodontics etc. Digitization in dentistry is known to create high quality of prosthetics and increases productivity ensuring consistent design and manufacturing results. It’s a convenient solution for scanning, models, impressions as well as patients with the CAD / CAM technology. Scanning accuracy is as close as < 15 microns and is fast with greater patient comfort.

With the advances in medical imaging technology, 3 dimensional imaging using computed tomography has been utilized for head and neck diagnosis and various oral surgical procedures. Cone beam computed tomography has been regarded to have the potential to be an accurate, noninvasive, practical method to reliably determine osseous lesion size and volume. Also, cone beam computed tomography images are not only comparable in measuring periodontal bone levels and defects as intraoral radiography but also demonstrate more potential in morphological description of periodontal bone defects.

A growing number of software programs to manage and analyze Digital Imaging Communications in Medicine (DICOM) files are available in the market every year. Many of these have incorporated tools for segmentation and volumetric analysis.

This study aimed to evaluate the accuracy of three different cone beam computed tomography software packages in determining the volume of the tooth and comparing it to the tooth volume obtained using an optical dental scanner. The null hypothesis was that there will be no difference in the tooth volume measured by an optical scanner compared to the tooth volume measured by volumetric analysis software packages using cone beam computed tomography data.

CHAPTER TWO

REVIEW OF LITERATURE

Periodontal diagnosis focuses on the loss of attachment or alveolar bone as an index of severity of periodontal disease making it necessary to detect small changes in alveolar bone support which occur over time. In order to obtain an index of the amount of bone remaining about a tooth root, the alveolar bone height is often expressed as a percentage/ratio of total root length. However, since no absolute measurement (in millimeters) of bone loss is obtained, a small amount of bone loss from a short rooted tooth may be expressed as the same percent bone loss as a large amount of bone loss from a long rooted tooth.

Linear methods do not take into account root shape in determining the percent of remaining alveolar bone. For instance, 50% bone loss around a thick, conical root has better prognosis than around a slender, tapered root. Also, the estimation error in predicting supported root surface area from either root length or projected area is greater at the cervical area where initial alveolar bone destruction took place.

A study investigated periodontal bone architecture using 2 dimensional and 3 dimensional full volume cone beam computed tomography based imaging modalities. Periodontal bone levels and defects were assessed and evaluated against two human skulls as reference standard. Visualization of lamina dura, crater defects, furcation involvements, contrast and bone quality were also evaluated. The conclusion was, cone beam computed tomography image measurements of periodontal bone levels and defects were comparable to intraoral radiography. It was found that cone beam computed tomography images demonstrated more potential in the morphologic description of periodontal bone defects and details. Using a dry skull with artificial defects and full volume cone beam computed tomography, a study found similar results. The investigation demonstrated that cone beam computed tomography was as accurate as direct measurements using a periodontal probe and as reliable as radiographs for interproximal areas. In measurements of the buccal and lingual defects, cone beam computed tomography proved superior to conventional radiography.

A study compared the precision and accuracy of six imaging software programs for measuring upper airway volumes using cone beam computed tomography data in thirty three patients. The oropharynx acrylic phantom was used as the reference standard. Results determined high reliability for all programs. Some showed less than 2% errors in volumes compared to the reference standard.

A study was set up in order to find a value for the measurement error of scanned dental surfaces and to try and find an artifact to serve as a dental standard for profilometers. [24] The recorded data was then entered into software and compared to the actual artifact of known dimension. Both machines showed "adequate" accuracy (7.7 ±0.8 μm and 13.9 ±1.0 μm).

Indeed the use of profilometry is not a particularly new concept. As far back as the early 1990's in a study they were able to use computer aided profilometry to assess the abrasive wear of human enamel and dentine. In one of the first attempts at volumetric measurement using profilometry a study used laser optical interferometry in order to assess wear in dental restorations. Using profilometry and computer software it is now possible to record a volumetric measurement.

CHAPTER THREE

MATERIALS AND METHODS

Twenty four extracted single rooted maxillary/mandibular permanent teeth were collected for the study. The teeth were selected based on following criteria:

1. Presence of single rooted maxillary/mandibular permanent tooth indicated for extraction.

2. The tooth must be free of caries, restorations, evidence of root resorption, endodontic treatment or periapical lesions.

The teeth were brushed against running water to remove adherent blood, and cleaned of residual tissue, bone and calculus. Cone beam computed tomography scans of these teeth were taken using the NewtomVGi (QR srl, Verona, Italy) with FOV 8x8 cm high resolution, 14 bit depth, scan time being 18-26s, 110 kV and effective dose 0.068mSv, minimum voxel size 0.075 cubic mm.

Teeth were then scanned using the optical 3 Shape D900L scanner (four 5MP cameras) with 7 microns accuracy, dimensions (37x29x33cm) and converted to stereolithographic files. These files were analyzed in the MeshMixer software (Autodesk Research, San Francisco, CA) where the total volume of the tooth was registered in cubic mm.

The cone beam computed tomography data of these teeth were reviewed and stored in a PC server station running under Microsoft Windows XP Professional (Microsoft Corp, Redmond, WA) and were also exported onto a portable external hard drive (Western Digital WD Elements 70 GB USB 2.0 Portable External Hard Drive, Irvine, CA). All data sets were exported using the Digital Imaging and Communication in Medicine (DICOM) files. Three dimensional digital models were obtained by segmentation in coronal and sagittal planes from the DICOM C cone beam computed tomography files using volumetric software; InVivoDental 5.4 (Anatomage, San Jose, CA), Mimics 18.0 (Materialise, Leuven, Belgium), Amira 4.0 (Visage Imaging Inc, Carlsbad, CA) and volume of the tooth was calculated in cubic mm for each software.

The segmentations were performed according to each software manufacturer's recommendations using the fixed threshold interval for semi-automatic segmentation and to test the variability among the software programs.

Comparisons were made between the optical digital scanner volume measurements and the individual volumetric software.

Volume rendering with Amira

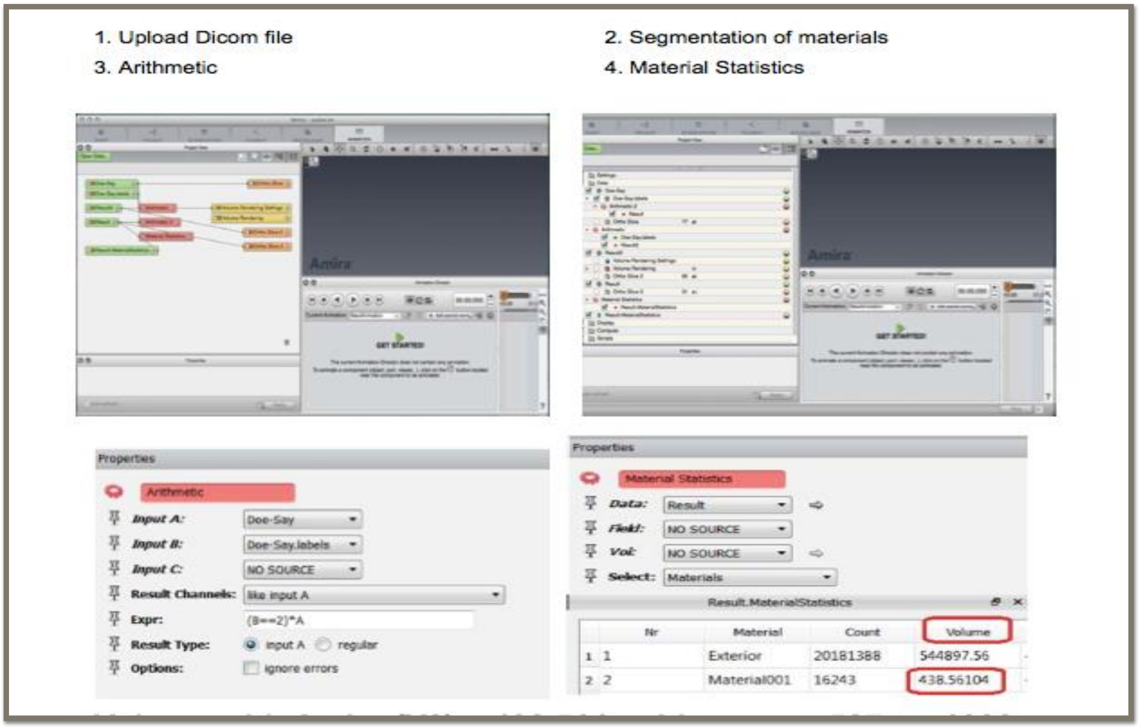


Figure 1. Software interface A

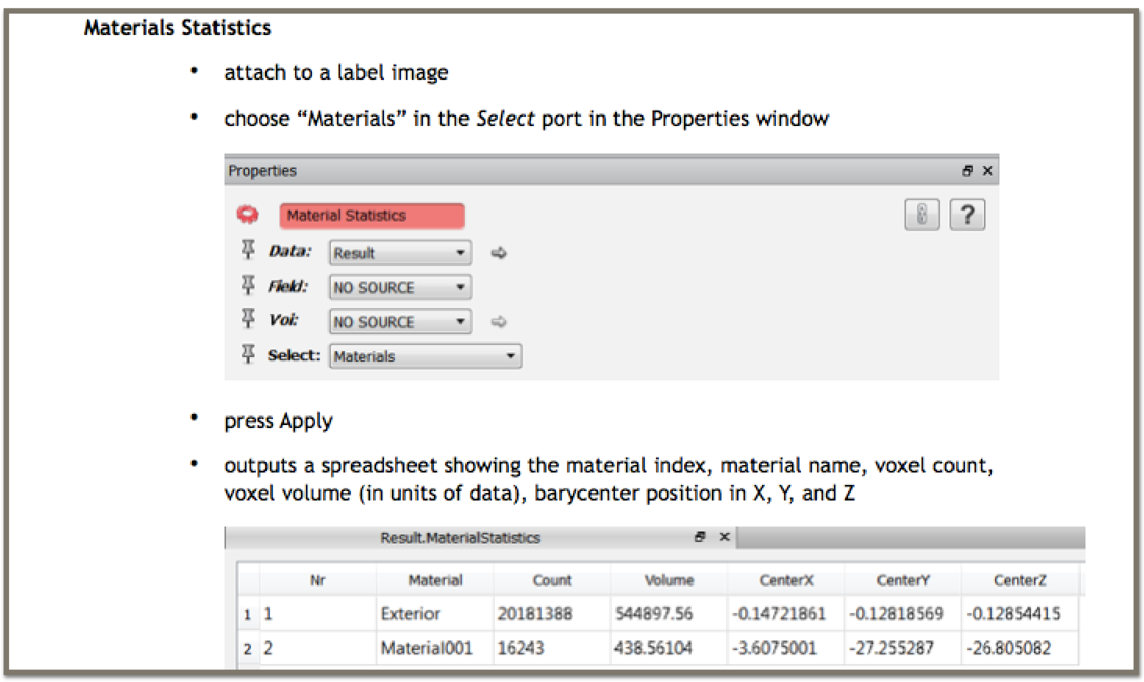


Figure 2. Software interface B

Volume rendering with Amira (cont.)

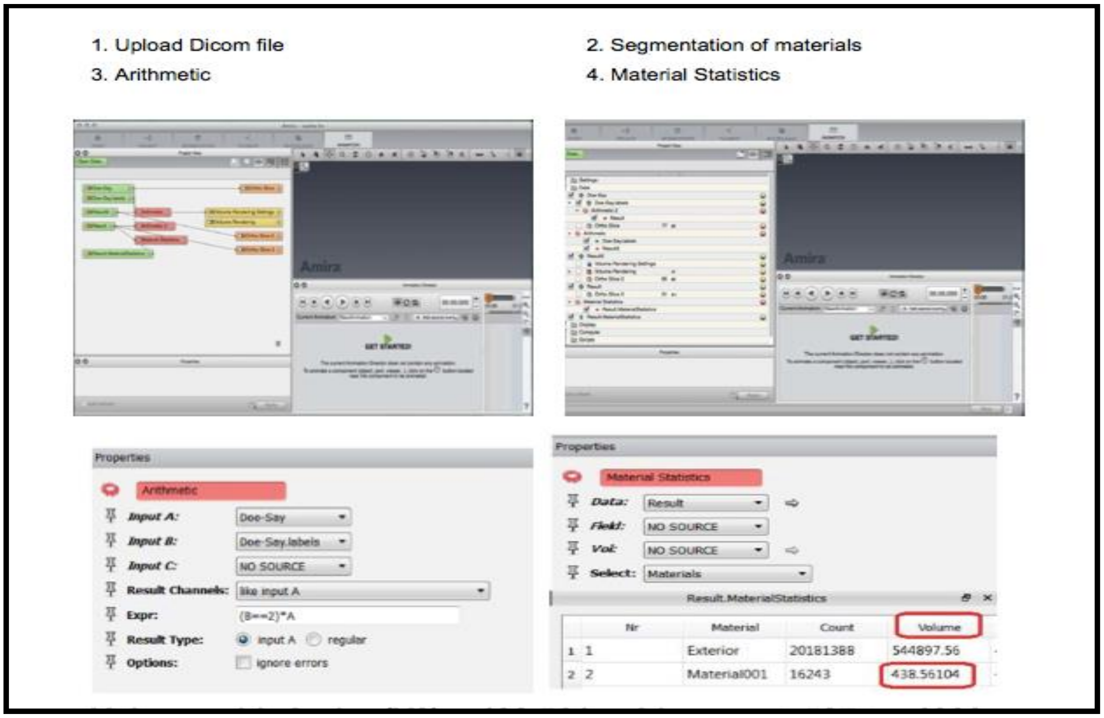


Figure 3. Software interface C

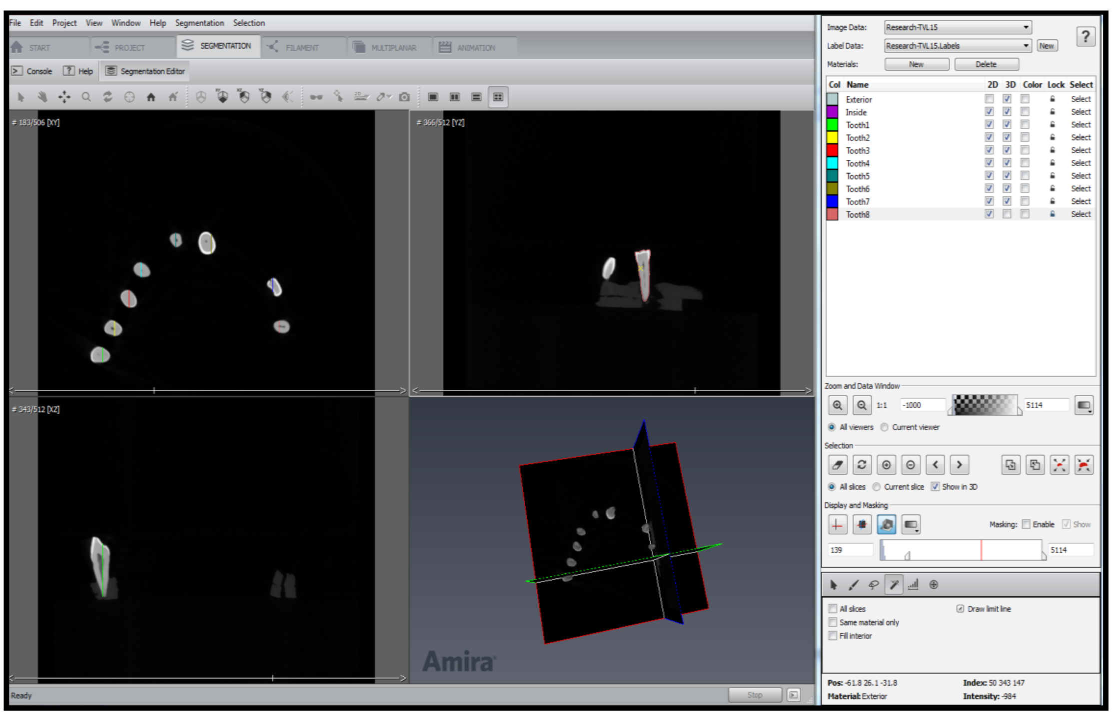


Figure 4. Software interface D

Volume rendering with Mimics

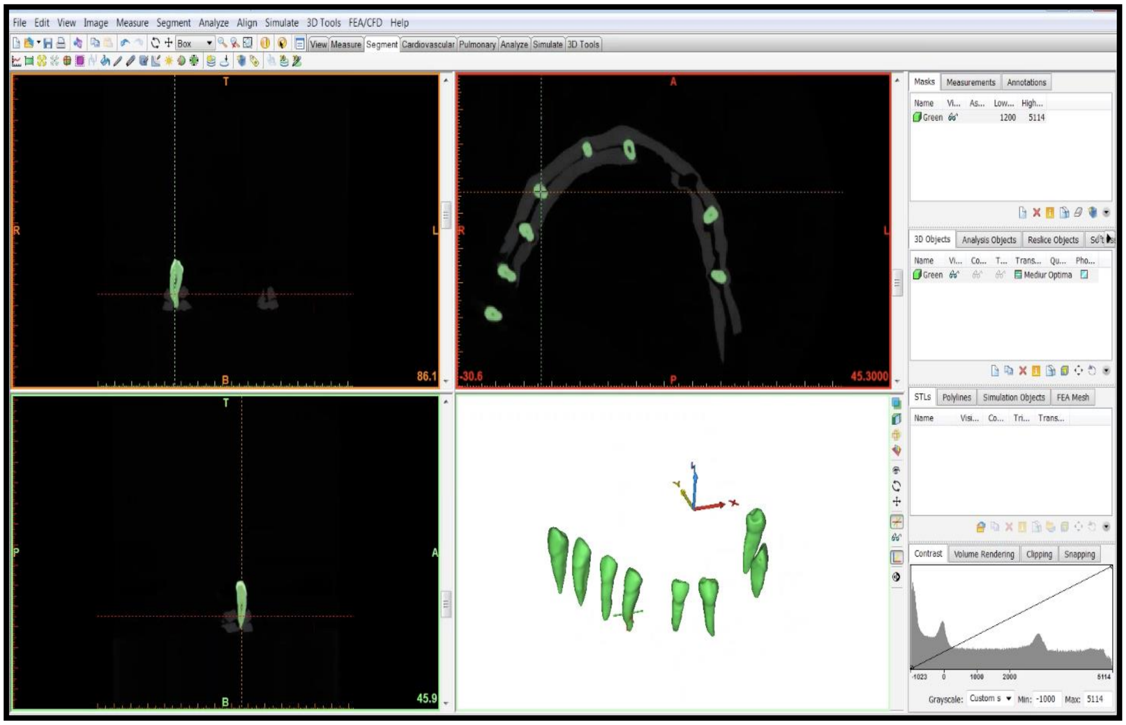


Figure 5. Software interface A

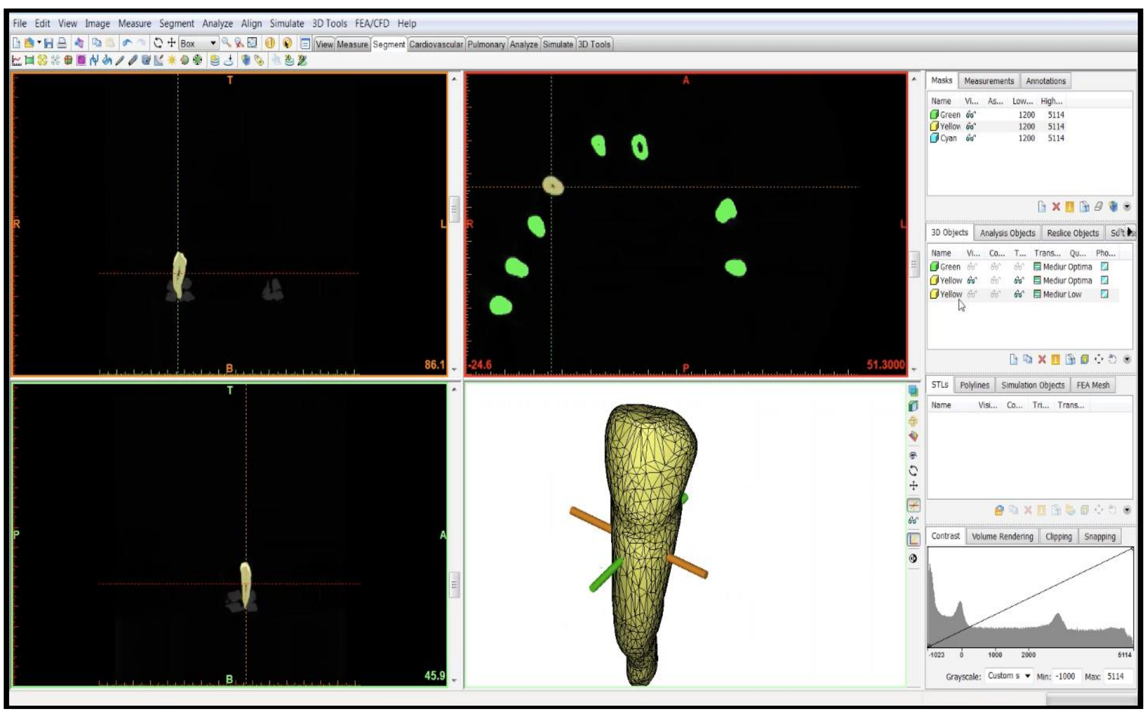


Figure 6. Software interface B

Volume rendering with Anatomage

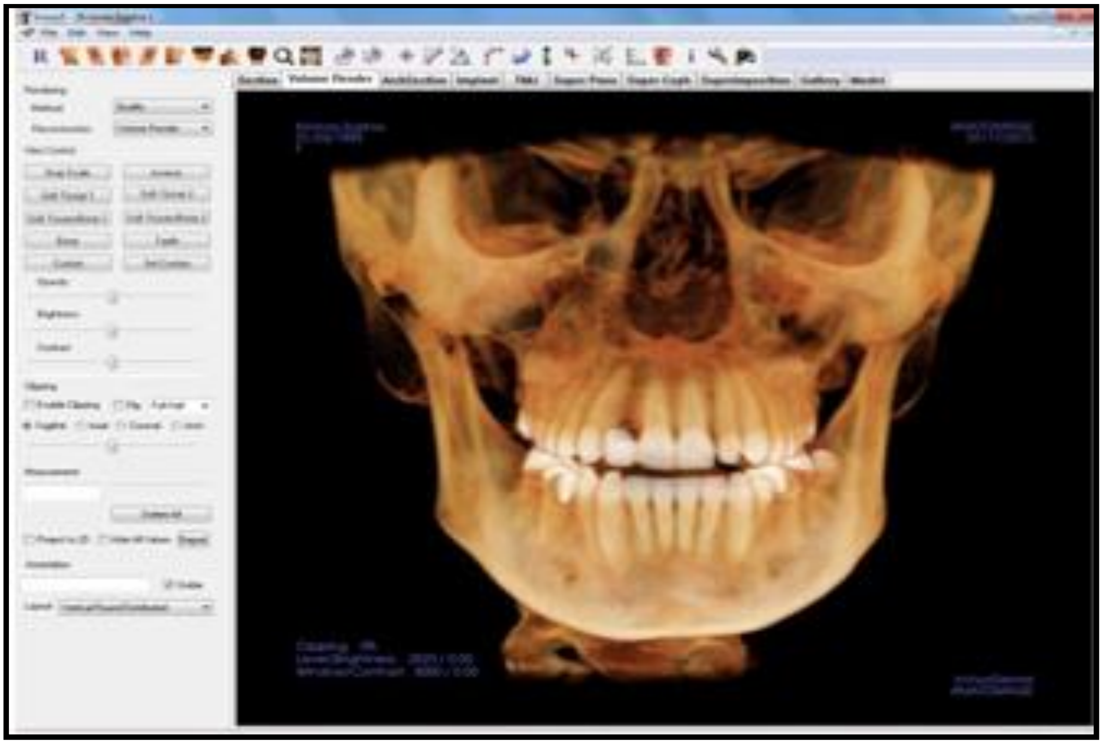


Figure 7. Software interface A

Figure 8. Software interface A

Statistical Analysis

All the data was measured by two examiners and was evaluated using the intra-class correlation coefficient to determine the reliability and agreement between the two examiners. All the values were imported into an Excel spreadsheet v 14.0 (Microsoft, Redmond, WA).

Freidman's two- way analysis of variance was used to compare the software packages for the fixed threshold protocols as well as to calculate the errors. Additionally, post-hoc tests - the Kolmogorov-Smirnov and the Shapiro -Wilk tests were used to compare the volumes between two imaging software programs.

The volumetric results of each software were compared with the reference standard as well as with each other.

CHAPTER FOUR

RESULTS

Table 1 reveals the intraclass correlation coefficient test for measuring the reference standard volume to the volume with Anatomage fixed threshold. Both the examiners had a high coefficient of reliability (ICC = 0.949). Figure 9 and 10, shows the box plot showing the high intraclass correlation coefficient.

Table 2 reveals the intraclass correlation coefficient test for measuring the reference standard volume to the volume with Amira fixed threshold. Both the examiners had a high coefficient of reliability (ICC = 0.892). Figure 11 and 12, shows the box plot showing the high intraclass correlation coefficient.

Table 3 reveals the intraclass correlation coefficient test for measuring the reference standard volume to the volume with Mimics fixed threshold. Both the examiners had a high coefficient of reliability (ICC for Examiner1= 0.831 and ICC for Examiner 2 = 0.839). Figure 13 and 14, shows the box plot showing the high intraclass correlation coefficient.

Table 4, figure 15 and 16 reveal the Friedman's two way analysis of variance comparing the volumes between reference standard and each software as well as the volumes calculated by the software with each other. With the fixed threshold protocol there were statistically significant differences ($P>0.05$) between the volume from Anatomage, Mimics and Amira with the reference standard as well as Anatomage with Amira, and Anatomage with Mimics. There was no significant difference in volumes between Amira and Mimics.

Table 5 reveals the standard error calculated for the volume determination for each software. Mean standard error with Anatomage fixed threshold was 7.1%, Amria fixed threshold was 13.2% and Mimics fixed threshold was 17%. Table 6 indicates histrogram showing the mean standard error with each of the software.

Figure 17 and Table 7 indicate the Friedman's two way analysis of variance comparing the mean standard error for each of the software. There was statically significant difference with the standard error of each software with each other (significance level is 0.05).

Table 8 describes the main advantages and disadvantages of each imaging software program.

Table 1. Intraclass correlation coefficient comparing Reference standard volume with Anatomage Fixed volume

Intraclass Correlation Coefficient

Examiner		Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
			Lower Bound	Upper Bound	Value	df1	df2	Sig
Examiner1	Single Measures	.949[a]	.465	.987	92.611	23	23	.000
	Average Measures	.974	.635	.993	92.611	23	23	.000
Examiner2	Single Measures	.949[a]	.465	.987	92.611	23	23	.000
	Average Measures	.974	.635	.993	92.611	23	23	.000

Two-way random effects model where both people effects and measures effects are random.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type A intraclass correlation coefficients using an absolute agreement definition.

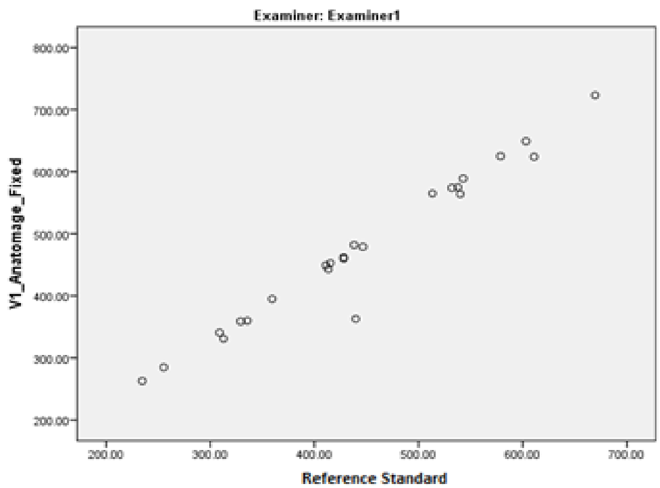


Figure 9. Box plot of Intraclass Correlation coefficient for comparison of Reference standard volume with Anatomage Fixed for Examiner -1

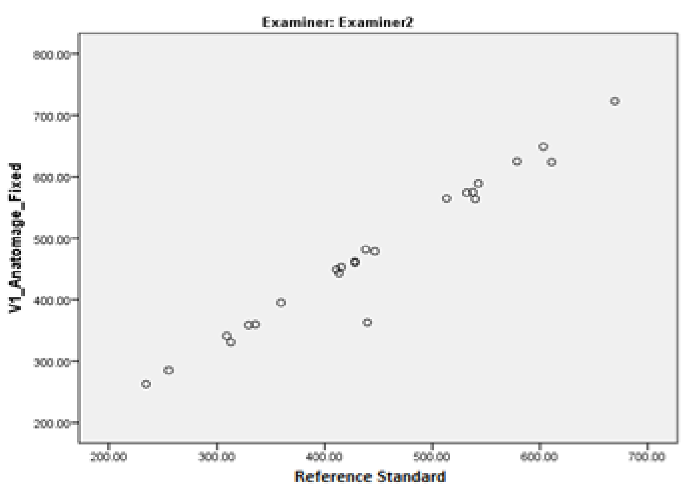


Figure 10. Box plot of Intraclass Correlation coefficient for comparison of Reference standard volume with Anatomage Fixed for Examiner -2

Table 2. Intraclass correlation coefficient comparing Reference standard volume with Amira Fixed volume

Intraclass Correlation Coefficient

Examiner		Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
			Lower Bound	Upper Bound	Value	df1	df2	Sig
Examiner1	Single Measures	.892[a]	-.020	.978	173.478	23	23	.000
	Average Measures	.943	-.041	.989	173.478	23	23	.000
Examiner2	Single Measures	.892[a]	-.020	.978	173.478	23	23	.000
	Average Measures	.943	-.041	.989	173.478	23	23	.000

Two-way random effects model where both people effects and measures effects are random.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type A intraclass correlation coefficients using an absolute agreement definition.

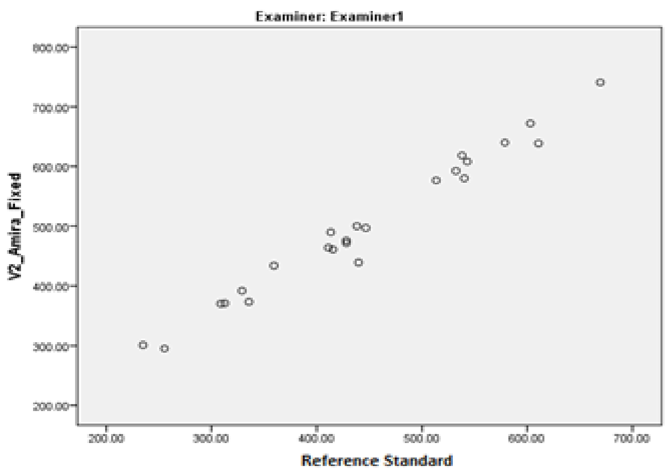


Figure 11. Box plot of Intraclass Correlation coefficient for comparison of Reference standard volume with Amira Fixed for Examiner -1

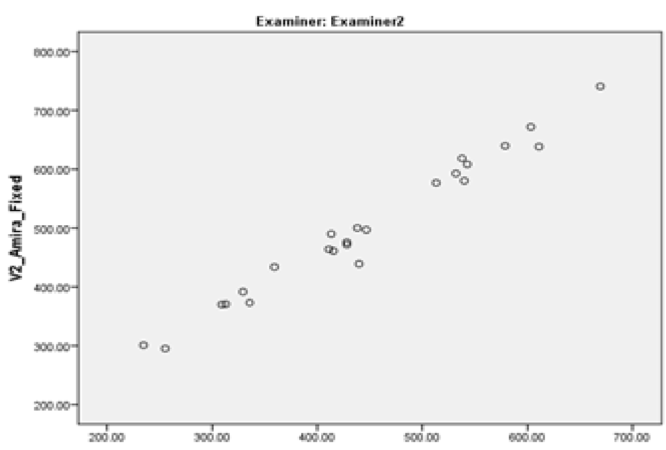


Figure 12. Box plot of Intraclass Correlation coefficient for comparison of Reference standard volume with Amira Fixed for Examiner -2

Table 3. Intraclass correlation coefficient comparing Reference standard volume with Mimics Fixed volume

Intraclass Correlation Coefficient

Examiner		Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
			Lower Bound	Upper Bound	Value	df1	df2	Sig
Examiner1	Single Measures	.831[a]	-.030	.963	106.859	23	23	.000
	Average Measures	.908	-.063	.981	106.859	23	23	.000
Examiner2	Single Measures	.839[a]	-.034	.965	97.447	23	23	.000
	Average Measures	.912	-.070	.982	97.447	23	23	.000

Two-way random effects model where both people effects and measures effects are random.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type A intraclass correlation coefficients using an absolute agreement definition.

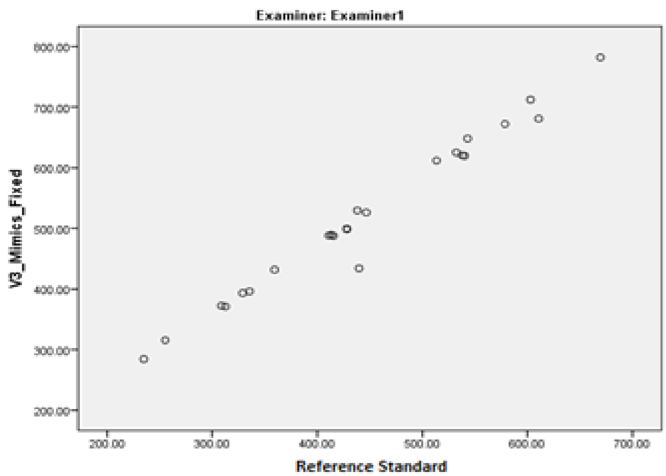


Figure 13. Box plot of Intraclass Correlation coefficient for comparison of Reference standard volume with Mimics Fixed for Examiner -1

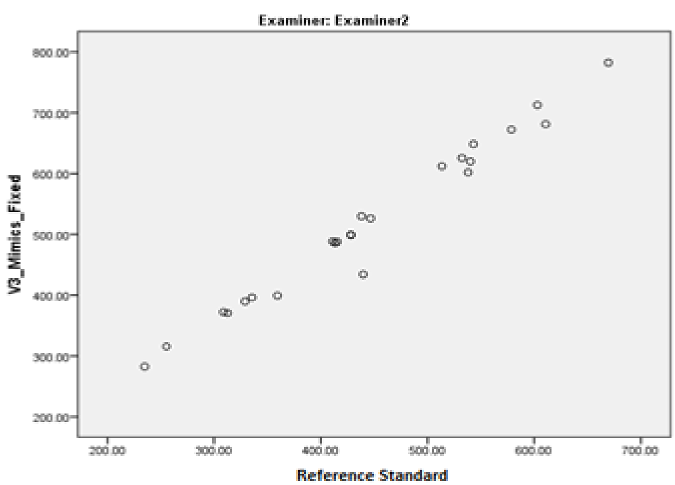
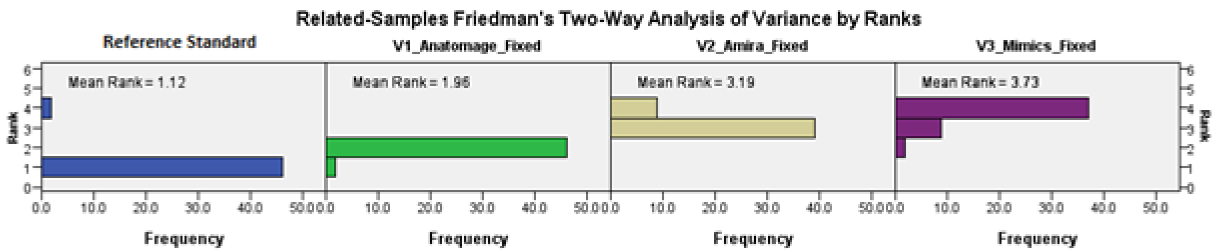


Figure 14. Box plot of Intraclass Correlation coefficient for comparison of Reference standard volume with Mimics Fixed for Examiner -2



Total N	48
Test Statistic	120.025
Degrees of Freedom	3
Asymptotic Sig. (2-sided test)	.000

Figure 15. Friedman's two way analysis of variance A

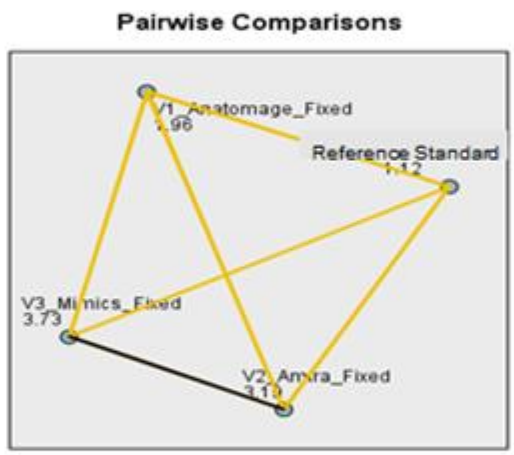


Figure 16. Friedman's two way analysis of variance B

Table 4. Friedman's two way analysis of variance comparing volumes

Each node shows the sample average rank.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
Reference Standard-V1_Anatomage_Fixed	-.833	.264	-3.162	.002	.009
Reference Standard-V2_Amira_Fixed	-2.062	.264	-7.827	.000	.000
Reference Standard-V3_Mimics_Fixed	-2.604	.264	-9.882	.000	.000
V1_Anatomage_Fixed-V2_Amira_Fixed	-1.229	.264	-4.664	.000	.000
V1_Anatomage_Fixed-V3_Mimics_Fixed	-1.771	.264	-6.720	.000	.000
V2_Amira_Fixed-V3_Mimics_Fixed	-.542	.264	-2.055	.040	.239

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

Table 5. Friedman's two way analysis of variance with Standard Error.

Software			Statistic	Std. Error
Anatomage Fixed	Mean		7.102020633957060	0.806773076247017
	95% Confidence Interval for Mean	Lower Bound	5.479002551084810	
		Upper Bound	8.725038716829310	
	5% Trimmed Mean		8.011669380656210	
	Median		7.963489910374570	
	Variance		31.242	
	Std. Deviation		5.589487832953890	
	Minimum		-17.434510554962900	
	Maximum		12.072271700686100	
	Range		29.506782255649000	
	Interquartile Range		2.542498096464660	
	Skewness		-3.702	0.343
	Kurtosis		14.855	0.674
Amira Fixed	Mean		13.249524279956400	0.820540250266559
	95% Confidence Interval for Mean	Lower Bound	11.598810215349500	
		Upper Bound	14.900238344563300	
	5% Trimmed Mean		13.186968697613700	
	Median		11.735830486551200	
	Variance		32.318	
	Std. Deviation		5.684869612467850	
	Minimum		-0.088251817919221	
	Maximum		28.182980355392700	
	Range		28.271232173311900	
	Interquartile Range		7.058763074722260	
	Skewness		0.293	0.343
	Kurtosis		1.259	0.674
Mimics_Fixed	Mean		17.000411997304000	0.678105959394960
	95% Confidence Interval for Mean	Lower Bound	15.636238766187800	
		Upper Bound	18.364585228420200	
	5% Trimmed Mean		17.555294891299500	
	Median		17.941344382292500	
	Variance		22.072	
	Std. Deviation		4.698055898349230	
	Minimum		-1.276239562744080	
	Maximum		23.631420815330400	
	Range		24.907660378074500	
	Interquartile Range		2.869167090445080	
	Skewness		-2.545	0.343
	Kurtosis		8.329	0.674

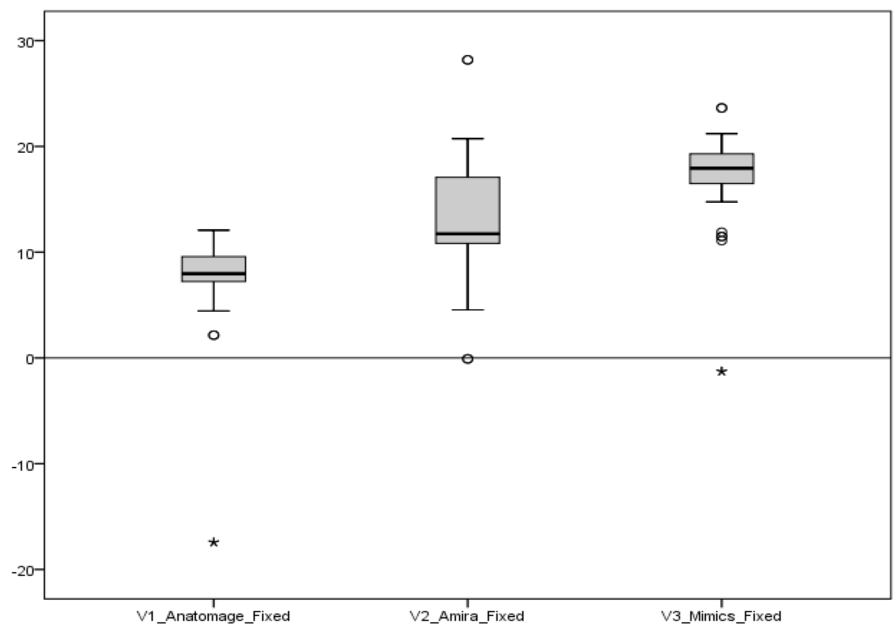


Figure 17. Histogram with standard error volume of each software

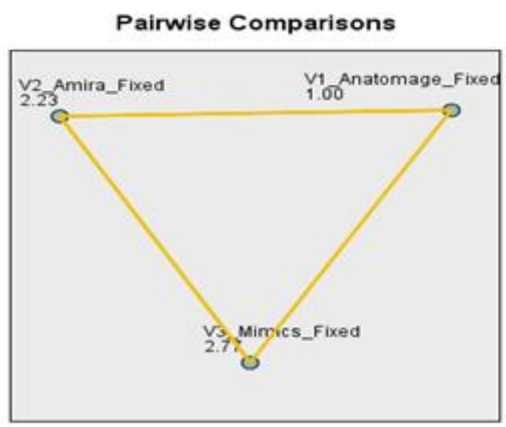


Figure 18. Friedman's two way analysis of variance comparing standard error

Table 6. Friedman's two way analysis of variance pairwise comparisons of standard of each software

Each node shows the sample average rank.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
V1_Anatomage_Fixed-V2_Amira_Fixed	-1.229	.204	-6.022	.000	.000
V1_Anatomage_Fixed-V3_Mimics_Fixed	-1.771	.204	-8.675	.000	.000
V2_Amira_Fixed-V3_Mimics_Fixed	-.542	.204	-2.654	.008	.024

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

Table 7. Advantages and Disadvantages of each software.

Software	Advantages	Disadvantages
Amira	Threshold interval units are compatible to other imaging software packages	Threshold control is very minimal.
	Segmentation can be done and checked in axial, coronal and sagital sections.	Big learning curve.
		Designed for use in Medicine.
		Not free
Mimics	User friendly	Not as user friendly as Anatomage
	Quick and easy segmentation	Designed for biomedical engineering
	Threshold interval units are compatible to other imaging software packages.	Not free
	Segmentation can be done and checked in axial, coronal and sagital sections	
	Great tool for segmentation control	
	Different tools available for segmentation	
Anatomage	User friendly	Not free
	Easy and quick segmentation	Threshold interval can be performed only in 3 Dimensional view.
	Easy thresholding adjustment	
	Threshold interval units are compatible to other imaging software packages.	

CHAPTER FIVE

DISCUSSION

This study was used to determine the accuracy of volumetric analysis of teeth using three different cone beam computed tomography imaging software programs and compared them to the volume obtained using a digital scanner.

The digital scanner was used as the reference standard to measure the volume of the teeth.

The method of repeatability in the measurements with the digital scanner were excellent and no differences were seen in the measurements made between the two observers. With the fixed threshold protocol, the volume difference was statistically significant for all software programs compared to the reference standard.

The method of repeatability for the volume measurements was high (ICC>0.98) for all software programs. There was a high correlation to the volume obtained by the software packages to that compared to the digital scanner.

Currently, several imaging software packages are available for volume rendering. This study compares Anatomage, Mimics and Amira which were compatible with the Windows operating system. They are also compatible with Macintosh operating system X (Apple, Cupertino, Calif) and Linux operating system. Optical 3 Shape D900L was used to scan the teeth and exported as stereolithographic files. These files were then imported in the mesh mixer software for the output of the volumes and was used as the reference standard. Anatomage and Amira software packages were used due to their popularity among implant surgeons, orthodontists, periodontists and maxillofacial surgeons. Mimics was chosen because of its widespread use in Biomedical engineering.

The results of this study can be used as the basis for future volumetric studies with cone beam computed tomography in both dentistry and medicine. The volume of the teeth depend upon segmentation accuracy, image quality and threshold selection.

The cone beam computed tomography image quality is impacted by several factors, such as the cone beam computed tomography device's settings, patient positioning and management, volume reconstruction, and DICOM export. When scanning is performed with high settings (small voxel size, longer scan time), the cone beam computed tomography images are obtained with better spatial resolution. In this study we scanned only extracted teeth using the Newtom VGi. With this study there was an elimination of the factors due to movement/motion-related artifacts. Segmentation accuracy and thresholding variation can be one of the factors which could affect the accuracy. Fixed thresholding eliminates operator subjectivity in boundary selection. When the fixed threshold protocol was used for the teeth similar results were obtained for both observers and were reproducible. Using the fixed threshold protocol each software had a different range and thus resulted in variable volumes.

CHAPTER SIX

CONCLUSIONS

1. Volume error with Anatomage was 7.1%; Amira was 13.2% and 17% with Mimics.

2. The volume of teeth depends upon the threshold interval, segmentation methods which are variable for each software as well as the operator. All the software packages used different segmentation engines and there is no established protocol or algorithm for processing DICOM images for assessment of volume of teeth, and there are variable methods for volume assessment that are commercially available.

3. Anatomage is more user friendly and the segmentation as well as volume assessment is quick and has no learning curve. Mimics software has more options for segmentation and has a slight learning curve. Amira is complex with more advanced options for segmentation and threshold variation and has the greatest learning curve.

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