Mir Khan
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Education

University of Maryland Dental School Endodontic Residency
Summer 2015- Summer 2018
Certificate of Endodontics Completion June 2018
Master of Science Completion June 2018

American Academy of Oral Medicine AAOM
Fall 2013-Spring 2018
Fellow of AAOM April 2018

University of Medicine and Dentistry New jersey
Advanced Education in Implant Dentistry 2011- 2014
Eligible Associate Fellow AAID 2018

VA Medical Center Wilkes Barre PA
General Practice Residency 2007

VA New York Harbor Healthcare System, Brooklyn NY
VA New York St Albans
The Brooklyn Hospital Trauma Center
Fellowship in Oral and Maxillofacial Surgery 2006

NYU College of Dentistry
D.D.S. Doctor of Dental Surgery 2005

Government Dental College and Hospital (Osmania), Hyderabad, AP, India
Postgraduate Certificate in Prosthodontics 1998

H.K.E.'s Dental College and Hospital
University of Karnataka, India
General Dentistry Internship 1996

H.K.E.'s Dental College and Hospital
University of Karnataka, India
B.D.S. (Bachelor of Dental Surgery) 1991-1996
Academic Honors (Double Gold Medalist)

Professional Experience

Teaching Resident–University of Maryland Fall 2015 - Current

- Teach 2nd year dental students the basics of endodontics in a pre-clinical course
- Supervise 3rd and 4th year dental students in their treatment of patients

Dental GPR Residency Program Director
VA Medical Center, Wilkes Barre PA – Spring 2007- 2015

Senior GPR Resident
VA Medical Center, Wilkes Barre, PA -2007.

Fellowship in Oral and Maxillofacial Surgery
VA New York Harbor Healthcare System, Brooklyn NY -2006

Intern Doctor in Oral and Maxillofacial Surgery and Oncology Unit
Paradise Dental Hospital & Maxillofacial Center, Hyderabad, AP, India -1998-1999

Postgraduate Resident (Senior Internship) in Prosthodontics
Government Dental College and Hospital (Osmania), Hyderabad, AP, India -1997-1998

General Practice Residency
University of Karnataka, H.K.E.'s Dental College and Hospital, India -1995-1996

Research Experience

Resident, University of Maryland Dental Summer 2015 – Current

Estimating the accuracy of the CBVT InVesalius imaging software to measure the volume of the simulated periapical defects in a human cadaver mandible. Summer 2016

Mentor: Dr. Patricia Tordik
• Poster presentation at 2017 AAE national conference
• Analyzed the accuracy of Carestream InVesalius imaging software to estimate the volume of simulated periapical defects in cadaver mandible as compared to true volume.

Professional Achievements

2015- Successful Accreditation of General Practice Residency Program at VAMC Wilkes Barre from the Commission of Dental Accreditation (CODA)

2008- Successful Accreditation of General Practice Residency Program at VAMC Wilkes Barre from the Commission of Dental Accreditation (CODA)

Academic Honors

- Fellow American Academy of Oral Medicine (AAOM) 2018
- Board Eligibility American Board of General Dentistry (ABGD) – 2016
- Associate fellow Eligibility Implant Dentistry – (AAID) - 2018
- Masters American Academy of General Dentistry – (MAGD) - 2013
- Fellow American Academy of General Dentistry – (FAGD) - 2011

Academic Awards

- Service Award for the Dedicated Service to Veterans VA Medical Center Wilkes Barre, PA USA 2014

- America's Top Dentist Award Consumers Research Council of America 2014

- International College of Dentist Leadership Award for highest professional achievement NYU College of Dentistry U.S.A 2005

- Gold Medal and Certificate of Recognition (***Dr. Kalolgi Award***) for scholastic achievement in all four years of B.D.S program from Karnataka University India 1996

- Gold medal and Certificate of Recognition (***Dr. M.A. Raoff Award***) for scholastic achievement in all four years of B.D.S program Karnataka University India 1996

- Certificate of Merit & Merit Shield – Excellence in Periodontics. Annual Conference of Indian Society of Periodontology 1995

- Certificate of Excellence – H.K. E's Dental College & Hospital, Securing distinction in orthodontics periodontics, oral surgery and operative dentistry/Endodontics, final year – B.D.S. 1995

- Certificate of Excellence – H.K. E's Dental College & Hospital, Securing distinction in General Medicine, 3rd year – B.D.S. 1994

- Certificate of Excellence – H.K. E's Dental College & Hospital, Securing distinction in General Surgery, 3rd year – B.D.S. 1994

- Certificate of Excellence – H.K. E's Dental College & Hospital, Securing distinction in oral medicine, oral radiology, community dentistry and pedodontics, 3rd year – B.D.S. 1994

- Certificate of Excellence -H.K. E's Dental College & Hospital, Securing distinction in Pharmacology, 2nd year – B.D.S. 1993

- Certificate of Excellence – H.K.E's Dental College & Hospital, Securing distinction in Pathology, Microbiology, Dental Anatomy, Oral Embryology & Histology, 2nd year – B.D.S. 1993

Licensures/Certifications

- Basic Cardiac Life Support 2018
- State of New York Dental License Fall 2007- Current

Board Certifications

- Board eligible American Board of General dentistry 2018
- North East Regional Boards Clinical Licensure Examination 2005 - Present
- National Dental Board Examinations 2005

Professional Membership Organization & Activities

- Member of American association of Endodontics AAE 2014 - Present
- Member Association of Dental Traumatology AADT 2016 - Present
- Member American Academy of Oral Medicine AAOM 2014 - Present
- Member-American Dental Education Association ADEA 2014 - Present
- Member American Academy of Implant Dentistry AAID 2012 - Present
- Member-American Academy of General Dentistry AGD 2007 - Present
- Member-American Dental Association ADA 2002 -Present
- Member-American Academy of Cosmetic Dentistry AACD 2013 - Present
- Member American Dental Society of Anesthesiology 2013 - Present
- Graduate Member of the Pankey Institute of Advanced Continuing Dental Education FL 2007 - Present

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Community Service 2007 – 2015

Homeless Veteran Program: Provided dedicated individualized comprehensive oral screenings and multidisciplinary oral health care to the homeless veteran population.

Teaching Experience

Dental GPR Director   2007 - 2015

Teaching Resident–University of Maryland Spring 2016. Current

ABSTRACT

TITLE: Estimating accuracy of the CBVT InVesalius Imaging Software to measure the volume of simulated periapical defects in a human cadaver mandible.

Mir Khan, Master of Science 2018

Thesis Directed By: Patricia A. Tordik, DMD, FICD

AIM: This *invitro* study tested the accuracy of the CBVT InVesalius software to determine volumetric data as compared to true volume.

METHODOLOGY: Ten artificial periapical osseous defects of similar size were created bilaterally in the posterior region of a human cadaver mandible. Vinyl polysiloxane impression material was injected to create a replica of each defect. The true volume of each replica was obtained using Archimedes' method and compared to volumetric measurements done by InVesalius. Statistical analysis was performed with one-way ANOVA and the significance level was set to $p \leq .05$.

RESULTS: The mean difference in volume measurement for InVesalius (.0454 cc) and Archimedes' method (.0436 cc) was very small ($p = .48$).

CONCLUSION: CBVT InVesalius imaging software appeared to be a true representation of the true volume.

Estimating accuracy of the CBVT InVesalius Imaging Software to measure the volume of simulated periapical defects in a human cadaver mandible

by
Mir Khan

Thesis submitted to the Faculty of the Graduate School of the
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INTRODUCTION

Successful management of endodontic problems depends on accurate clinical and radiographic evaluation to provide vital information about the teeth under examination and their surrounding anatomy. Conventional two-dimensional (2D) intraoral radiography has remained the foundation of imaging in endodontics. The Endodontics specialty lays a heavy emphasis on accurate radiographic interpretation. Therefore, radiographic examination serves as a critical component throughout the scope of endodontics from diagnosis to progress of cases, landmarks, surgical guide, outcomes etc. They are a blueprint for all technical aspects to endodontics.

REVIEW OF LITERATURE

The primary outcome in determining successful endodontic treatment is the assessment of the healing of periapical bone during the post-treatment endodontic therapy period. Previous studies have shown conflicting results when comparing radiological findings with histologic sections. Most of the root filled teeth that showed radiographic evidence of success had some degrees of histologic inflammation (Brynolf, 1967). Histopathological exam has been considered the gold standard for diagnosis of periapical pathosis for years (Thoma, 1917; Langeland, 1959; Seltzer, 1963; Bhasker, 1966; Lin, Shovlin, Skribner, & Langeland, 1984). This method has proved to be of utmost importance in establishing the basis for diagnostic classification by correlating the clinical and histological state of pulp and development of clinical strategies for endodontic treatment (Ricucci D, 2004; Ricucci et al, 2006; Paula-Silva et al, 2009).

Conventional 2D radiography has remained the foundation of imaging in endodontics. (Forsberg, 1987). It has been used increasingly in all aspects of endodontic treatment from diagnosis and treatment planning to outcome assessment although conventional radiographs may provide limited information because of geometric distortion and anatomical noise, especially when the lesions are restricted to cancellous bone (Bender & Selt`zer, 1961; Schwartz, 1971; Scarfe WC, 1999). A study evaluating healing of periapical lesions in the maxillary molar region using 2D periapical radiographs showed that there was only 47 % agreement between 6 examiners (Goldman et al,1972) because of the complexity of anatomy. When the same examiners evaluated the radiographs at two various points in time, a 19%-80 % agreement between the two evaluations was found (Goldman et al, 1974).

The images produced by conventional 2D intraoral imaging are representations of 3-dimensional (3D) objects, patients' teeth. The correct interpretation of the 2D radiographs can be influenced by several factors including projection geometry, complex regional anatomy, superimposition of teeth and surrounding dentoalveolar structures. These confounding projection geometry factors may lead to misdiagnosis and less than ideal treatment outcomes. In recent times, CBVT imaging has also been successfully utilized in various fields of dentistry. With the advent of CBVT, the limitations of medical CT, including excessive radiation exposure, have been overcome for use in dentistry. The introduction of CBVT in endodontics with limited field of view (FOV) for diagnosis and treatment planning has revolutionized the field of endodontics (Brown et al, 2009).

British engineer Sir Godfrey Hounsfield of EMI Laboratories, England, and physicist Allan Cormack developed first computer tomography (CT) scan technology in 1970's. A major credit also goes to The Beatles — John, Paul, George, and Ringo — for facilitating revenue from record sales for the development of early models of Computed Axial Tomography (CAT) scanners. Funding generated from the success of The Beatles for their recording company, EMI, (Electrical and Musical Industries) which was once an industrial research company, supported Sir Godfrey Hounsfield while he and Cormack developed the world's first commercially successful CAT scan machine (Mazlin, 2012).

Robert Steven Ledley was a pioneer dentist and physicist turned biomedical researcher who invented the first whole body Automatic Computerized Transverse Axial (ACTA) scanner in 1973 at Georgetown, DC that could scan the entire body. Earlier in his career, he was credited for the groundbreaking publication "Reasoning Foundations of Medical Diagnosis" that was widely accepted by the medical community. The original prototype of the scanner is at Smithsonian institution.

Early CAT machines were radiation intensive supine gantry units that occupied huge space in the hospitals as compared to machines today. CAT scans have made significant advances since their introduction in 1970's. Early CT scans took 30 minutes to acquire information as compared to scans today that take may take only a few seconds, depending on the field of view.

With the evolving technology, adaptive statistical image reconstruction techniques and efficient CT detector materials have significantly reduced the radiation dose by 70 to 80% for patients as compared to the original technique. The engineering and technological improvements in the new CT machines has increased the speed of acquisition of 3D volumes, better routine spatial resolution in the slice direction and reliable image quality. This has led to important clinical applications and a large impact in patient care. In CT, the voxel is the smallest volume element in 3D imaging as compared to the pixel in 2D imaging. A quantitative measuring unit, the Hounsfield unit (HU) was developed to measure and differentiate the relative densities of the various biological structures. The value of HU ranges from air at -1000 HF, through water at 0 HF, +400 for cancellous bone, up to +1000 HF for cortical bone, and 2000-3000 for metallic structures. Care should be exercised when interpreting density measurements using HU for CBVT imaging as noise and artifacts can significantly affect the accurate conversion of grey scale density measurements to HU (Molteni, 2013).

CBVT was introduced in the late 1990s specifically to generate a reconstructed 3D image of the maxillofacial skeleton. Since the first efforts by the pioneers (Arai, Tammisalo, Hashimoto, & Shinoda, 1999; Mozzo, 1998) trying to apply conventional computed tomography (CT) and micro-CT in endodontics, the introduction of maxillofacial CBVT provided the first clinically and practical technology demonstrated the application of 3D imaging for endodontic considerations. Since approval by the Food and Drug Administration (FDA), dentists have considered the advantages of CBVT 3D imaging technology over conventional radiography (Arai, Hashimoto, Iwai, & Shinoda, 2000).

The ability of CBVT technology to demonstrate geometrically accurate images in three dimensions facilitates the assessment of endodontic diagnosis, treatment outcomes and long-term prognosis. The optimal resolution for CBVT images in endodontics is invariably task specific—however; most aspects of endodontics involves imaging of small structures. A minimal voxel resolution of 0.3 mm was recommended for the detection of external root resorption (Cotton et al, 2007).

The outcome assessment of endodontic treatment that involves the complete healing of the periapical lesion may not be determined for at least one year and may take up to 4 years in some cases following completion of endodontic treatment (Orstavik, 1996). Two important studies reported similar results in which 85% of the roots under investigation completely healed in a 2-year period (Bystrom, 1981). A study that evaluated the short term periapical healing after surgical endodontic treatment reported 97% of the teeth healed completely within 1 year (Rubinstein, 2002). The above investigations used 2D radiographs for radiographic assessment. Cone beam computed tomography (CBCT) imaging as compared to conventional radiographs can be more reliable and accurate in monitoring the progression of the healing process of chronic apical periodontitis (Patel, 2009).

Accurate measurement of the size of periapical lesions after endodontic treatment enables clinicians to radiographically assess healing outcomes. Conventional radiography used for routine endodontic procedures offers a 2D view of a 3D structure, thereby limiting accurate interpretation. Several studies in the past have attempted to quantify changes in the size of periapical lesions using 2D radiographs. The periapical index scoring system was developed by Ostravik for radiographic assessment of apical periodontitis using 2D radiographs. The Periapical index scoring system compared the periapical radiographs to set of five radiographic images obtained from Brynolf's histologic radiographic correlation study (Brynolf, 1967). A score of 1 represents healthy periapical tissues, a score of 2 represents small changes in bone structure and widening of the periodontal ligament, a score of 3 represents development of the periapical lesion with changes in the mineral content of the periapical bone, a score of 4 represents apical periodontitis and a score of 5 represents severe periodontitis with exacerbating features. The periapical index scoring was qualitative and subjective. Also, the periapical index scoring system was developed for assessment of the periapical region of single-rooted teeth; the overlapping anatomy of multi-rooted teeth may render a single radiograph non-diagnostic for periapical index scoring. Furthermore, the radiograph taken at the recall appointment must be able to reproduce the exact viewing angle as the immediate post-treatment radiograph to allow an accurate comparison of the 2D image (Orstavik et al, 1986). With the advent of cone beam volumetric tomography for 3D imaging, the size, extent and position of the periapical lesions can be assessed accurately on three orthogonal planes eliminating false negatives (Hedesiu et al, 2012).

In recent years there has been a considerable interest in the capabilities of CBVT in generating reproducible volumetric measurements of periapical pathosis. This has challenged researchers to develop software programs to accurately measure volumes of periapical defects in bone. Volumetric and linear measurements of periapical lesions on initial and post-treatment CBVT images have been evaluated by different studies (Whyms et al, 2013). Several studies have been performed to determine three-dimensional volumetric changes to assess healing of lesions diagnosed with apical periodontitis after root canal treatment (Patel et al, 2007).

Volumetric assessments of periapical lesions may play a very important role in preoperative endodontic treatment planning and monitoring healing after non-surgical and surgical endodontic therapy. As periapical lesion area and volume are important predictors of early stages of apical periodontitis, this knowledge can help endodontists in early recognition and intervention to prevent unfavorable outcomes. Presently, there is no commercially CBVT viewing software that can perform volumetric quantification of automated thresholded and segmented defects and accurate prediction of periapical lesion size.

Several authors suggested that small FOV CBVT scans should be done to assess the healing of lesions associated with apical periodontitis. Since CBVT's can detect periapical lesions at smaller sizes than periapical radiographs (Al-Nuaimi et al, 2016; Ahlowalia et al, 2013). CBVTs may be capable of detecting dimensional changes in lesions at an earlier stage in time than periapical radiographs (Esposito et al, 2011).

Numerous studies investigated the accuracy of the ability of CBVT software to estimate the volume from manual linear measurements of simulated lesions or defects, using calibration cubes and spherical phantoms of known size. However, most of the results from these CBVT software products were not shown to be statistically accurate. (Adisen et al, 2015).

Recently, a pilot study, demonstrated that DiThreshGui software (DTG) (Fike, 2017) is accurate in reproducing the volume of periapical lesions. Additionally, this software was able to make an estimation of volumetric decrease in lesion size in as early as 91 days following the initiation of treatment (Arasu, 2017).

Previous investigators used a 6-point scoring system, which included the variables of cortical bone expansion and destruction, to determine the linear size of periapical lesions (Estrela et al, 2008). It is possible to make assessments of lesions in three dimensions using CBVT images and CBVT viewing software (Lofthag-Hansen et al, 2007). Therefore, recommendations have been made to do volumetric measurements of lesions to assess dimensional change. Different authors (Ahlowalia et al, 2013; Esposito et al, 2011) have found a correlation between volumetric measurements of artificially created bone defects and actual true volumes.

Linear measurements of the periapical lesions from the reconstructed CBVT scans combined with a fast algorithm for calculating the volume of lesions has been tried with some success (Ahlowalia et al, 2013; Brown et al, 2009). There are a limited number of studies evaluating the accuracy of CBVT software to precisely measure the lesion in the bone volumetrically (Damstra et al, 2010; Al-Nuaimi et al, 2016).

The remaining gap in knowledge is how accurate, fast, reliable and user-friendly is the 3D CBVT viewing software specially designed for clinicians in determining volumetric measurements in diagnosis of periapical endodontic lesions without submitting the data volumes to an oral radiologist. Volumetric measurements of periapical pathosis can assist endodontists in making clinical evaluations and monitor the progression of healing after nonsurgical and surgical endodontic treatment.

There are several CBVT software programs available that can measure volumes of periapical lesions. However, the accuracy of the software programs has not been tested and therefore the clinicians do not rely on them. Endodontists could benefit from this technology in making clinical decisions. The CBVT software would have to be time efficient in generating volumetric data and prove appropriate accuracy in order to be deemed reliable for clinician use.

InVesalius software was developed in Brazil in 2001 by Centro de Tecnologia da Informação Renato Archer (CTI). The software is an open source medical software that generates 3D models corresponding to anatomical parts of the human body by automated thresholding, image segmentation, mesh generation, volume rendering and allows 3D printing of anatomic models. The software is free and has the ability to run on low-cost computers and different operating systems. InVesalius image viewing software program has the capability of doing automatic computer thresholding, segmentation and volume calculation as compared to other software in the market that may take a long time to generate volumetric data. There are no available studies to confirm the reliability of InVesalius software in doing volumetric measurements of periapical lesions using CBVT DICOM data.

PURPOSE

The purpose of this study is to evaluate the accuracy of InVesalius imaging software to determine the volume of the simulated periapical defects in a human cadaver mandible as compared to the true volume measured through the water displacement method.

NULL HYPOTHESIS

There is no significant difference between the volumetric measurements done by the InVesalius imaging software as compared to the true volume of the simulated defects made in a human cadaver mandible.

METHODS AND MATERIALS

Bone preparation

One partially edentulous human cadaver mandible was obtained from the Gross Anatomy laboratory of the University of Maryland Medical Center. All soft tissue was carefully dissected and removed from the skull and mandible. The processing and cleaning of the mandible was done by medical school lab personnel. The specimen was ready, after 6 weeks, for conducting the experiment.

CBVT pre-scan

CBVT pre-scans were taken using a Carestream Dental CS 9300 with a mandibular arch scan FOV. The protocols were the ones used in ordinary clinical settings. All protocols had the following exposure factors: 84 kVP, 5 mA, rotation 360°, exposure time 12 s and 359 mGy/cm^2. Isotropic voxels with a size of 0.200 mm for a 10 x 5 cm FOV were used. Image reconstruction was performed in axial, coronal and sagittal planes and imported into InVesalius at a slice thickness of 0.200mm. The CBVT scans revealed uniform bone density and normal trabecular architecture of bone in the anterior and posterior regions of mandible.

Creation of simulated periapical defects

The study design involved creating artificial periapical defects into the buccal cortical and cancellous bone bilaterally in a human cadaver mandible. An endodontic resident (MK) conducted the experiment and completed the measurements to determine the true volume of the samples, the gold standard.

A bench top drill press machine (Sears Craftsman 15 ½ inch drill press) and a drill bit (Diameter: 9/64-inch HSS 3.5 mm) were used to perform the experiment. The drill bit was measured to a length of 5mm with a Vernier calipers (Mitutoyo Zoro: #G1983457 Lock Screw, 0-6 in) and masking tape was wrapped around the drill bit to mark the set depth of exactly 5mm. In use, the drill unit was placed in a desired position upon the mandible to be drilled. The location of each osseous defect was marked on a horizontal line on the mandible with a ruler at 10 mm intervals. An initial osteotomy of 1.5-2mm depth was created with a high-speed No. 6 carbide bur (HSI Model: 7724402 Friction grip Diameter: 1.8 mm) with water to reduce the impact of the initial force from the drill bit, thereby minimizing the risk of fracturing the mandible.

Each specimen was positioned at a predetermined distance to the drill bit so that the long axis of the mandible and the teeth were perpendicular to the drill bit. The mandible was secured in position with wooden blocks and stabilized by a stabilization platform. The mounting blocks consisted of five blocks of wood that measured 10 x 10 inches and they were arranged in a manner that allowed pivoting and positioning on the alignment base. The entire assembly was locked into a fixed position by the Vise-grip. The drill press motor was then activated, and the advancing lever was pulled to advance the drill unit at a predetermined distance relative to the longitudinal axis of the main unit, maintaining the trajectory with each pull of the advancing lever.

The procedure ended when the masking tape was level with the cortical surface of the cadaver mandible indicating that the desired depth of penetration of 5mm was reached. Ten artificial buccal osseous defects were created bilaterally around the base of the sockets of the teeth (#s 17, 18,19, 20, L ant 21, R ant 28, 29, 30, 31 and 32) in one human cadaver mandible to simulate periapical lesions. One drill bit was used to create ten simulated periapical defects. Any residual bone dust was carefully purged from the defects by using a small air brush and the defects were inspected. A digital caliper was used to check the width of each defect, which was 3.5 mm.

CBVT post scan

CBVT post—defect scans was taken of the cadaver mandible using a Carestream Dental CS 9300 with a mandibular arch FOV and voxel size of 0.200 mm with the same parameters described earlier.

InVesalius software

The InVesalius software was used to determine the volumetric size of the defects. InVesalius is a free software for reconstruction of computed tomography. InVesalius was developed in Brazil in 2001 by Centro de Tecnologia da Informação Renato Archer (CTI). The software is an open source medical software that generates 3D models corresponding to anatomical parts of the human body by automated thresholding, image segmentation, mesh generation, volume rendering and allows 3D printing of anatomic models.

After the DICOM files were imported into the software program, defects were displayed using InVesalius software in axial, coronal and sagittal planes in a four-panel window. A threshold value for grayscale density was assigned that represents the sample defect and the initial automated thresholding of bone density within the CBVT data as determined by the software program. The next step involved the identification of the densities representing non-impression material. These were removed with a thresholding brush in the areas surrounding the impression to define its margins. The purpose of this was to remove any fins of impression material that could have entered the bone marrow spaces. After this manual refinement, the software performs an automated segmentation of each defect that was thresholded. In the final step, the InVesalius software completes volume rendering for the segmented data and generates a virtual 3D model of each sample.

InVesalius measurements (Segmentation and thresholding of each sample)

Volumetric analysis of pre- and post-op CBVT scans were completed by one examiner - a board-certified oral and maxillofacial radiologist (JP) under ideal viewing conditions using InVesalius imaging software. The CBVT slices in three orthogonal planes that demonstrate the defects clearly were included for final assessment by the radiologist. The scans were transferred to the image processing software InVesalius to measure the volume of the simulated periapical defects. A brush tool in the InVesalius software helped to delineate the boundaries of the defect. Defects with well demarcated bony borders were finally processed by the InVesalius software for thresholding and segmentation in all three orthogonal planes to determine the final three-dimensional volume of each defect (Table

1). The image of each defect was volume rendered by the InVesalius software to produce the three-dimensional reconstructed image of the specimen (Fig. 1,2,3).

Table 1.

Invesalius Volumetric Measurements of the Defects

SAMPLES	INVESALIUS MEASUREMENT (cm^3)
17	.0549
18	.0431
19	.0551
20	.0411
L ANT 21	.0421
R ANT 28	.0354
29	.0472
30	.0423
31	.0471
32	.0459

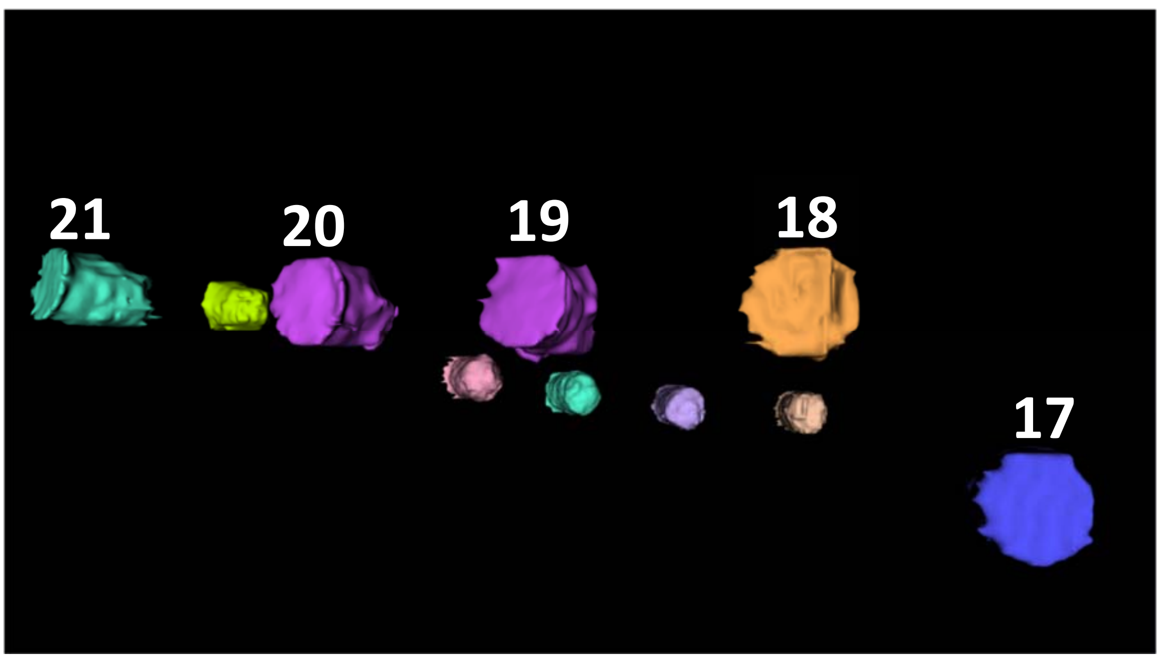

Figure 1. **CBVT/InVesalius Acquisitions Image Left Mandible**

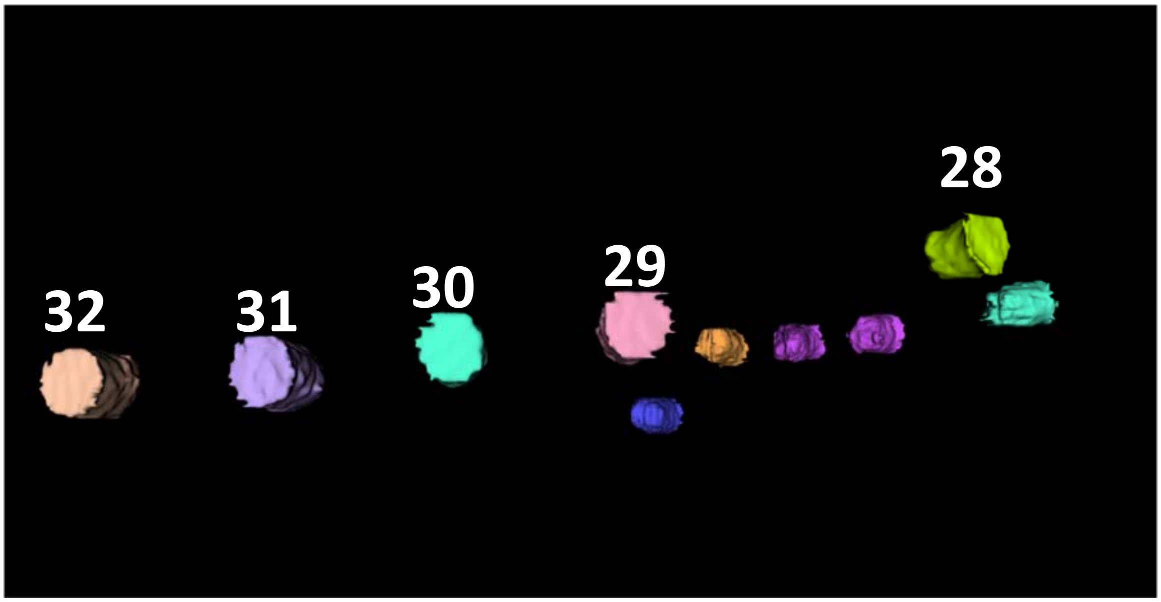

Figure 2. **CBVT/InVesalius Image Right Mandible**

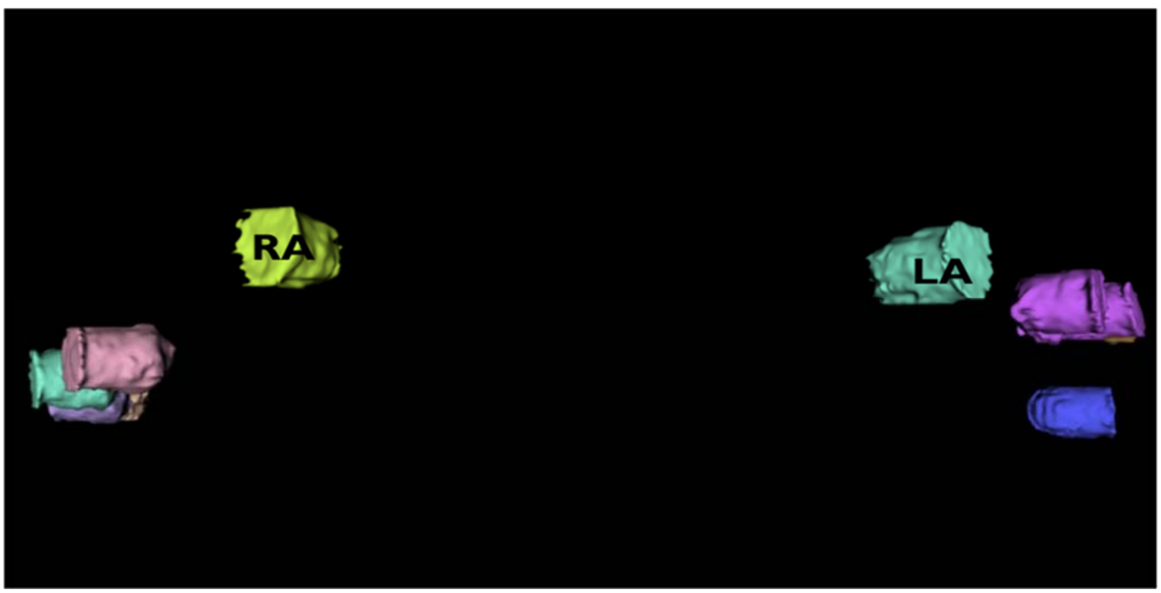

Figure 3. **CBVT/InVesalius Acquisitions Image Anterior Mandible**

True Volume measurements

The true volume of each simulated periapical defect was calculated by creating a replica of the defect using VPS impression material. The volume of the VPS replicas was quantified by using the water displacement method. According to the Archimedes principle, when a body is immersed in water the weight of the water displaced is equal to the buoyancy force experienced by the body (Hughes, 2005).

The defects were cleaned of any debris after the osteotomy and a separating medium containing petroleum jelly was thinly and evenly applied over the inner surface of the defects. This was allowed to dry for 10 min before injecting the impression material. Using Extrude® VPS Putty, impressions were made over the defects to prepare a customized matrix to minimize impression flash on the surface of the mandible. Light body syringeable VPS impression material (Acquasil LV, regular set) was carefully injected into the artificially created simulated bony defect and left to set for six minutes as per manufacturer's recommendation. The putty matrix was secured in place over all the defects to reduce the marginal flash. Excess flash material was removed after the final set. A CBVT post scan was taken of the cadaver mandible using a Carestream Dental CS 9300 with a mandibular arch FOV and voxel size of 0.200 mm with the same parameters described earlier.

Acquisition of the samples

Under magnification 2.25X (KFM Magnifier, 45" Arm, 3-Diopter, Clamp Brand Luxo Model # KFK025818 Pemro # LUX-1006) the sample defects in the cadaver mandible were carefully troughed and enlarged, using a Diamond Needle bur (Kerr # F859, 1.4 mm Diameter, 10.0 mm Length) and the samples was carefully retrieved. The surface debris was cleaned with an air syringe and inspected. The samples were finally ready for measurement after 30 minutes. As per the manufacturer's instruction, the VPS impression material (Acquasil LV) is dimensionally stable for 14 days after the initial setting time of 6 minutes.

True measurement of the volume using the Archimedes' principle

A precision weighing balance (Mettler Toledo Model: AB104-S) with a readability of 0.001 g was used to measure the volume of each of the 10 impression samples through Archimedes' principle (the weight of a solid immersed in a liquid decreases by an amount equal to the volume of the liquid that it displaces). The Eppendorf tube (1.7 ml) was used to measure the volume of the samples. One ml of distilled water was collected with a pipette and transferred to the Eppendorf tube. The dry samples were then immersed into the Eppendorf tube containing 1ml of distilled water. The volume of each sample was determined by calculating the amount equal to the volume of the liquid displaced of the sample immersed in water. An average of three readings was recorded as the mean volume (cm^3) for each given sample and corresponding defect (Table 2).

Table 2.

Volume Measurements of 10 Samples

SAMPLES	TRUE VOLUME MEASUREMENTS 1 (cm^3)	TRUE VOLUME MEASUREMENTS 2 (cm^3)	TRUE VOLUME MEASUREMENTS 3 (cm^3)	MEAN (cm^3)
17	.050	.060	.050	.0533
18	.040	.045	.040	.0416
19	.050	.055	.050	.0516
20	.040	.040	.040	.0400
L ANT 21	.040	.040	.045	.0416
R ANT 28	.040	.035	.040	.0383
29	.050	.045	.040	.0450
30	.040	.040	.045	.0416
31	.040	.040	.040	.0400
32	.050	.040	.040	.0433

STATISTICAL METHODOLOGY

An initial power analysis determined 10 simulated periapical defects were needed for this study. Statistical analysis was done using SPSS version 22 software. A one-way ANOVA was used to analyze the differences between the volumes recorded using the InVesalius software and the physical volumetric measurements. The significance level was set to $p \leq .05$.

Table 3.

Comparison of Volumetric Measurements Invesalius/True Volume

SAMPLES	INVESALIUS MEASUREMENT (cm^3)	TRUE VOLUME MEASUREMENTS MEAN (cm^3)
17	.0549	.0533
18	.0431	.0416
19	.0551	.0516
20	.0411	.0400
L ANT 21	.0421	.0416
R ANT 28	.0354	.0383
29	.0472	.0450
30	.0423	.0416
31	.0471	.0400
32	.0459	.0433

RESULTS

The mean impression volume mean CBVT volume measurements F and P values are shown in Table 4 and Fig. 4. There was no significant difference ($F=.514$, $p=.483$) in the volumetric measurement of the simulated periapical defects done with the InVesalius software as compared to that of the true volume. The sum of the area measurements determined with the InVesalius imaging software tool appeared to be close to the true volume (Fig 5).

Table 4.

Volumetric InVesalius Measurement of the defects Compared to the True Volume

SAMPLES	N	MEAN	SD	F	p-value
InVesalius	10	.04542	.006	.514	.483
True Volume	10	.04363	.005		

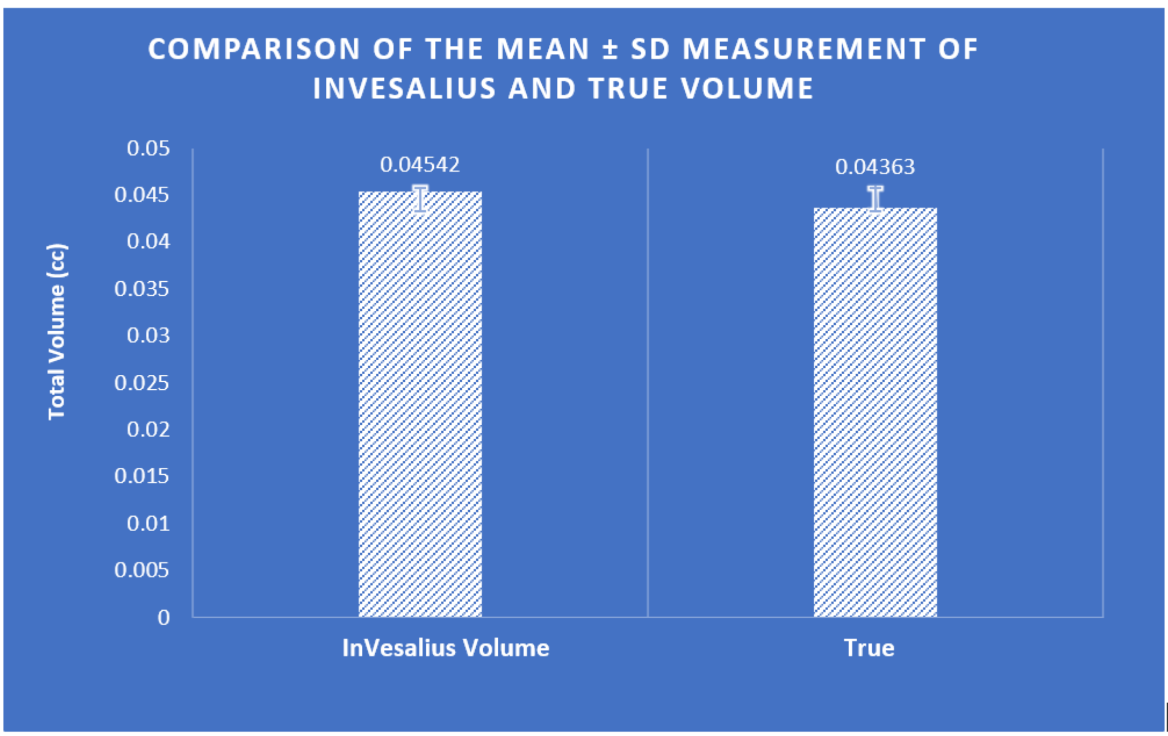

Figure 4. **Comparison of Final Volume Measurements InVesalius and True Volume**

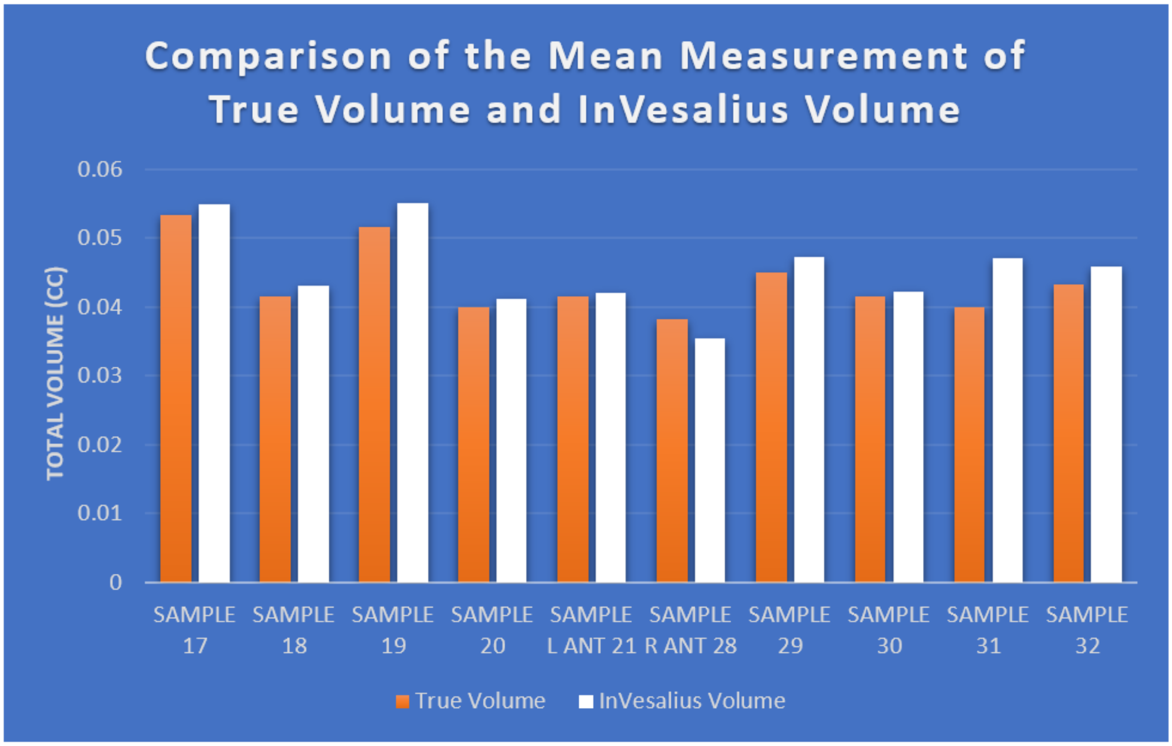

Figure 5. **Comparison of the Mean Measurement of True Volume and Invesalius Volume**

DISCUSSION

The purpose of this study was to evaluate the accuracy of InVesalius imaging software in determining the volume of the simulated periapical defects in a human cadaver mandible *in vitro* as compared to the true volume measured by the water displacement method (Hughes, 2005). Overall, data obtained in the present study revealed that the InVesalius imaging software was accurate in determining the volume of the simulated periapical defects in the human cadaver mandible as compared to the true volume. Previous research (Ahlowalia et al, 2013) analyzed bovine mandible as a substitute for human bone to assess the accuracy of CBVT in determining the volumetric measurement of artificial periapical defects. As there is a significant difference in the trabecular texture (dense or medium) between bovine bone and human bone (Poumarat et al, 1993) extrapolating the results from earlier studies done on bovine bone may not be accurate in making clinical decisions. A distinctive aspect of this study was that a human cadaver mandible was used to create defects simulating periapical pathosis to mimic a clinical situation.

Previous researchers attempted to use two-dimensional measurements to measure the volume of the periapical lesions with some level of success. In this study, the accuracy of the software was directly compared to true volume, by the water displacement method which is the gold standard. Based on the results, this study suggests that the volumetric data obtained from the InVesalius imaging software is much more efficient in measuring the true volume.

A previous study investigating the outcomes of root canal retreatments with a sample size of 54 teeth revealed that preoperative measurement of periapical lesion size varied between 2-13 mm with a mean value of 4.2 mm. (Sundqvist et al, 1998). A number of animal and human models have been used in the past to create periapical defects that simulate periapical pathosis. In order to mimic various endodontic situations, many defect sizes of varying depth and diameters ranging from 1- 8 mm were created. (Kullendorff et al, 1988). The problem in finding a correct reference method for creating simulated periapical defects was the lack of diagnostic accuracy of radiographic methods in previous studies. In order to overcome the limitations associated with previous in-vitro studies it was essential to adopt a suitable in-vivo bone defect in the human cadaver model that is similar in size for testing the accuracy of the InVesalius software. Ten artificial periapical osseous defects simulating periapical pathosis of size 3.5 x 5mm was used for this study.

Future research should focus on assessing the accuracy of CBVT software to obtain periapical volume of defects of different shapes, diameter and depth.

The periapical index scoring system described by Ostravik has been used for evaluating radiographic healing. One of the challenges of the periapical index was assessing the bone healing in cases that are questionable in terms of healing time after non-surgical or surgical endodontic treatments and present a challenge in making clinical decisions. (Orstavik, 1996; Wu et al, 2005; Wu et al, 2009). The periapical index scoring system was developed for assessment of the periapical region of single-rooted teeth; the overlapping anatomy of multi-rooted teeth may render a single radiograph undiagnostic for periapical index scoring. Calibration in using periapical index had the limitation of spending good deal of time and efforts of researchers and examiners in reviewing 100 radiographs and analyzing results of intra-rater and inter-rater reliability. Furthermore, the radiographs taken at the recall appointment must be able to reproduce the exact viewing angle as the immediate post-treatment radiograph in order to allow accurate comparison of the 2D images. CBVT technology can overcome the limitations of 2D radiography for assessing healing outcomes using the periapical apical index. With the advent of cone beam volumetric tomography for 3D imaging, the size, extent and position of the periapical lesions can be assessed accurately on three orthogonal planes for anterior and posterior teeth eliminating false negatives. This technology can be utilized in diagnosis, clinical evaluation and making treatment planning decisions in endodontics.

In the past, researchers have utilized linear measurements of the CBVT scans for determining the volumes of periapical defects using calibration cubes, spherical phantoms and algorithms that compute the volume and surface area of the sphere**.** (Adisen et al, 2015; Fike, 2016). Linear measurements provide limited information and values in one plane in comparison to volumetric measurements. As the periapical lesions may have irregular or 3D shapes, the algorithm for calculating volume of the sphere cannot be applied. Linear accuracy of the measurements done by this method is inadequate to translate into a clinical setting. CBVT imaging with InVesalius software may provide clinically useful information in making diagnoses and in outcomes assessment. The volumetric data from the software may generate qualitative and quantitative measurements of bone that is accurate and reliable in assessing progression of healing after non-surgical endodontic and surgical endodontic treatment in a clinical setting. In the present study, the InVesalius software was able to do fast thresholding and segmentation of the high contrast CBVT scans to generate volumetric data of apical defects.

Different CBVT software programs have been utilized in the past to measure volumetric size of periapical defects (Ahlowalia et al, 2013; Adisen et al, 2015). Most of the software packages require manual tracing of the periapical defects on the CBVT slices in three orthogonal planes (axial, coronal and sagittal) to define the boundaries of the lesion to generate volumetric data. Based on the results, this has not been shown to be statistically accurate. Extrapolating the results to a clinical situation is not feasible. The advantage InVesalius software has in comparison to other software programs is the minimal manual thresholding with automated segmenting and volume rendering capability which makes it an efficient tool for making clinical decisions.

The value of knowing the volumes of periapical lesions in the initial stages after non-surgical and surgical endodontic therapy can help endodontists reduce unnecessary treatments and unfavorable outcomes in teeth with persistence of apical radiolucency that have undergone adequate endodontic treatments. InVesalius software can import the DICOM files and perform manual or semiautomatic image segmentation and volumetric rendering of the thresholded periapical lesions for accurate prediction of periapical lesion size. As periapical lesion area and volume are important predictors of early stages of apical periodontitis, this knowledge can help the endodontists in early recognition and intervention as needed.

Success and failure are two broad terms in endodontics and must be defined in a clinical situation. A radiographically detectable periapical lesion with no clinical signs and symptoms may represent failure biologically; however, from a clinical stand point it may be considered successful treatment. Shared decision making in this situation helps to make decisions based on the best available clinical evidence that balances risks, benefits and outcomes. Adequate knowledge is required to help the clinician in making the best clinical decision. Information derived from the InVesalius technology can help determine the progression of healing by accurately determining the volume of the periapical defects and help the clinician make important clinical decisions (Reit et al, 1998).

In the present study, a dry human cadaver mandible was used. All the scans obtained from CBVT were high contrast for volumetric analysis by the software. Further research should take into consideration soft tissue components as the attenuation coefficients can significantly affect the contrast and quality of the final CBVT image before volume rendering.

The results of the study met the success criteria proving that the automated thresholding, segmentation and volume rendering as compared to the manual process is accurate and could save time for the endodontist in a clinical setting. Future directions should apply this process and compare the computer segmented volumes to oral radiologist hand segmented volumes. One of the limitations of the study was the intra-rater reliability analysis that was not performed because of lack of resources. In future studies, intra-rater reliability needs to be established to ensure any differences in volumetric measurements generated by InVesalius software. Despite this limitation, the volumetric data generated by the InVesalius software was an accurate representation of the true volume because of the automated volume rendering capability.

InVesalius software, proved to be a reliable method in determining the volumes of simulated periapical osseous defects in the human cadaver mandible as compared to the true volume measured through the water displacement method. This study confirmed that InVesalius software is a useful imaging technique which can provide significant information in monitoring progression of healing outcomes of endodontic treatment. Further clinical studies are required to test the accuracy of the CBVT InVesalius software to measure the volumes of periapical lesions *in vivo*.

The present study validated that InVesalius software is an accurate tool for volumetric rendering and measurement of endodontic defects. The world of CBVT 3D imaging and third-party software programs are constantly evolving. InVesalius is a reliable tool for volumetric rendering and measurement of endodontic defects. CBVT manufacturers like Carestream and others can adopt the concept and license the InVesalius software or incorporate the software as add-ons to improve the efficiency and quality of custom applications to determine volumetric data. The proprietary CBVT viewing software companies could integrate the features of the software into one of their own modules to make it easier for clinicians to monitor the progression of healing of periapical defects. Proper education and training will significantly enhance the ability of all clinicians to comfortably interpret the scans and determine volumes of periapical lesions without submitting the data volume for an expert second opinion.

CONCLUSIONS

In this study, CBVT imaging with InVesalius software was accurate in determining the volume of simulated periapical defects in a human cadaver mandible as compared to true volume.

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