THE EVALUATION OF DEHISCENCES USING

CONE BEAM COMPUTED TOMOGRAPHY

Nicholas S. Ising, D.M.D.

An Abstract Presented to the Faculty of the Graduate School
of Saint Louis University in Partial Fulfillment
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ABSTRACT

Introduction: Cone beam computed tomography (CBCT) has allowed for the visualization of the entire maxillo-mandibular complex in three dimensions without overlap of structures at a significantly reduced radiation dose and cost to the patient. **Purpose:** The purpose of this study was to validate the use of 3-D surface volume rendering (SVR) images to quantify the height of alveolar dehiscences. **Materials and Methods:** Twenty-four dehiscences were created on 9 incisors, 9 canines, and 6 premolars on 4 cadaver skulls. i-CAT CBCT’s were taken of each skull at 2mm voxel size. Each dehiscence was quantified by 21 orthodontic residents using the 3-D SVR starting at a density value (DV) of 1365. The principal investigator (PI) also quantified each dehiscence using the 2-D multiplanar (MP) image and 3-D SVR image starting at 1200 DV. **Results:** The results of this study showed an average method error of the residents as a group to be .57mm with an intraclass correlation (ICC) of .77%. The resident’s method error ranged from .45mm-1.32mm, and the ICC was from .201-.857%. Only 4 of the residents showed significant systematic differences compared to the direct measurement. As a group, the paired t-test was non-significant. Systematic error was low at -.01mm for the direct measurement compared to the resident’s average 3-D SVR at 1365 DV measurement. The 3-D SVR at 1365 DV images were compared to the MP and 3-D SVR images at 1200 DV with no significant differences in the measurements and low systematic error. The method error of the PI was .45mm, .45mm, and .41mm for the 3-D SVR at 1365 DV, 3-D SVR at 1200 DV, and 2-D MP respectively. **Conclusions:** Using the 3-D SVR image, dehiscences of the periodontium can be quantified to a significant level.
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A Thesis Presented to the Faculty of the Graduate School of Saint Louis University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Dentistry

2010
COMMITTEE IN CHARGE OF CANDIDACY:

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Adjunct Professor Peter H. Buschang
DEDICATION

I dedicate this thesis to my loving wife for her patience throughout my residency, and her ability to withstand all of the trials of pregnancy. I also dedicate this to my parents and brothers. I would not be the man that I am today without their help and guidance.
I would like to acknowledge the following individuals for their help with my thesis:

- Dr. Ki Beom Kim for his time and efforts to guide this thesis and serving as my chairperson.

- Dr. Peter Buschang and Dr. Eustaquio Araujo for their extensive contributions as committee members.
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CHAPTER 1: INTRODUCTION

The periodontium is a dynamic and unique part of the human body, which provides support and nutrition for the teeth. The alveolus, periodontal ligament, cementum, and supporting gingiva are all parts of the periodontium. When pressure and tension are placed on the periodontal ligament during orthodontics, osteoclastic and osteoblastic cells are recruited to area. The teeth are then able to move within the bone by modeling and remodeling.

Orthodontic diagnosis requires a thorough exam of the supporting periodontium.\(^1\) Dehiscences, fenestrations, and other intra-bony defects should be included for the orthodontic diagnosis and treatment plan. Knowledge of these defects could drastically affect the treatment plan.\(^2\) Ectopically positioned teeth could have periodontal defects which could lead to the extraction of those teeth over others.\(^3\) The biomechanics of treatment could also be affected. Expansion treatment and proclination of the incisors are an acceptable alternative to extraction treatment. However, this biomechanical therapy could lead to deleterious effects without proper knowledge of the buccal and lingual bony plates.\(^4\)\(^7\)
Identifying dehiscences before treatment and caused from treatment is of paramount importance. However, this requires a surgical flap procedure or a computed tomography (CT) radiograph. Significant risks from flap surgery are possible including recession, soft tissue dehiscence, and tissue necrosis.\(^8\) CT’s have a very high dose of radiation, large expense to the practitioner and patient, and is not practical for dentistry.\(^9\) A newer technology, cone beam computed tomography (CBCT), has the potential to identify these periodontal defects.\(^{10,11}\) CBCT’s offer tooth and bone assessment without obstruction from overlying structures.\(^{12}\) They also have a reduced radiation dosage and cost compared to CT.\(^9,13\) The purpose of this study is to validate the ability of an orthodontist to use the 3-D Surface Volume Rendering (SVR) CBCT radiograph to accurately measure the size of a dehiscence.
CHAPTER 2: REVIEW OF THE LITERATURE

Dehiscences

Dehiscences are bony defects of the alveolar unit. They are located on the buccal or lingual aspect of a tooth and can extend from slightly below normal (1.5-2mm below the cementoenamel junction) to the apex of the root with normal interproximal bone levels.14

There are two main types of gingiva, thin and scalloped and thick and flat.15,16 The thin and scalloped gingiva is a significant risk factor for developing recession and dehiscences. The gingiva is easily abraded away until the base of the dehiscence is reached. This process is called self-limiting recession.14

The etiology of dehiscences can be attributed to many causes. One cause for dehiscences is ectopically positioned teeth which are outside of the bony limits of the alveolus are often lacking the normal amount of bone on the overlying facial surface.17,18 This is often due to
significant anterior crowding. This crowding does not allow the tooth to erupt into its appropriate position causing it to impact or to erupt outside of the bony limits. Another eruption anomaly is that the roots of a tooth may erupt in a more buccal position compared to the crown creating a dehiscence, especially on mandibular incisors. Frenum attachments are another cause for dehiscences. They can place enough pressure on the bone in certain areas to eventually cause recession of the bone. The maxillary and mandibular mid-labial frenum most often cause the recession on the associated central incisors. Patient habits are a frequent cause of dehiscences. The use of smokeless tobacco products causes defects in the location of use, and the lingual of the alveolus is prone to recession from tongue piercings.

Another study indicates that there is a strong association of periodontal defects with traumatic occlusion. The trauma, along with inflammation in the area, can cause destruction of the bone surrounding the affected tooth. If this traumatic occlusion is removed, there is a significant reduction in the further progression of periodontal disease.
Iatrogenic treatment has also been shown to cause defects whether through moving teeth outside of the alveolus or through impinging on the biologic width with a dental restoration. The normal attachment of the gingiva has 1mm of sulcular depth, 1mm of epithelial attachment, and 1mm of connective tissue attachment above the crestal bone. If a restoration impinges on this space, the bone and epithelial attachment will migrate apically until the normal levels are established again.

Normal aging and traumatic tooth brushing, over the course of time, cause recession of the gingiva and bone. As the gingiva is abraded, the alveolar bone recedes with the gingiva to maintain the biologic width.

Pathological conditions of the periodontium can cause inflammation. This inflammation is associated with the breakdown of the cells and tissues causing the loss of the gingiva and bone height.

As seen above, the etiology of recession, dehiscence formation, and general periodontal breakdown can be due to one single influence or to a more complex interaction within the periodontium.
Dehiscences are widely prevalent among American populations. In a study of 146 adult American skulls, 40.4% of the skulls had at least one dehiscence, and 3315 teeth were evaluated in which 9% had dehiscences. Sixty-seven percent of dehiscences were found in the mandible. The presence of dehiscences and fenestrations (windows in the alveolar bone in which the root is in direct contact with the soft tissues) were positively correlated with thin alveolar bone and negatively correlated with attrition of the teeth. African American males and Caucasian females were significantly more likely to have dehiscences, while African American females were significantly more likely to have fenestrations.\textsuperscript{25} Other reports place dehiscences and fenestrations as high as 20% in the population.\textsuperscript{14} With these rates of dehiscences, an orthodontist must consider dehiscences in their diagnosis and treatment plan.

Often, dehiscences are present but the gingival margin level and probing depth is normal. This is due to a long junctional epithelial attachment of the gingiva to the cementum. In a study to relate dehiscences to the recession of the gingiva, the average depth of a dehiscence was 5.43mm while the average recession on those teeth was 2.67mm. However, the study showed that the depth of the
dehiscence does not always correlate with the depth of the gingival recession. Often the apical extent of the dehiscence is significantly more than 2.76mm from the level of the gingiva and was shown to be as great as 7.5mm different.26

Orthodontics and the Periodontium

The biomechanic treatment plan must be tailored to each individual patient based on the assessment of their periodontium. The facial and lingual bony plates need to be evaluated so as to not impose on the limits of the alveolus.5 The periodontium has incredible regenerative properties from local stem cells, but iatrogenic effects may occur during orthodontic treatment.27 The inclusion of a Periodontal Screening and Recording (PSR) exam along with a referral to a periodontist, if necessary, needs to be a part of every new patient exam.1

A systematic review of the literature identified an absence of reliable evidence describing positive effects of orthodontic treatment on periodontal health. The existing evidence suggests that orthodontic therapy results in small
detrimental effects to the periodontium overall.\textsuperscript{28}

Orthodontic therapy was associated with 0.03 millimeters of gingival recession, 0.13 mm of alveolar bone loss, and 0.23 mm of increased pocket depth when compared with no treatment.\textsuperscript{28}

One of the most important aspects of determining periodontal tissue reaction is the thickness of the gingiva. Thin gingiva is at a much higher risk factor for recession and periodontal defects.\textsuperscript{15,16} Reports show that grafting should be done prior to orthodontics if any gingival recession is present and anticipated to increase or if there is less than 2mm of attached gingiva.\textsuperscript{129} If the grafting is done for cosmetic reasons, then it should be done after orthodontics.\textsuperscript{1}

It has been suggested that the inclination of the lower incisors results in gingival recession and bone loss. Using CT’s, one study found there was no difference in bony support of the lower incisors with different inclinations.\textsuperscript{30} However, these CT’s were from orthodontically untreated individuals. To examine the effects of orthodontic proclination, another study examined the mean difference of recession between proclined and non-proclined teeth during treatment. The mean difference of recession was 0.14 mm,
which was not significant.\footnote{31} Most of the cast studies agree with the previous cast study that proclination does not significantly change the gingival level in adults or children.\footnote{32-36} The width of the keratinized gingiva also does not change during orthodontic treatment even if the clinical crown length increases.\footnote{37} Wingard and Bowers showed in-vivo on monkeys that mandibular incisor proclination from 2-5mm does not result in gingival recession.\footnote{38} However, Steiner et al. showed on monkeys that a 3mm proclination of maxillary central incisors produced significant recession of the gingival margin, connective tissue level, and marginal bone.\footnote{4} Final inclination of greater than 95 degrees and free gingival-margin thickness of less than .5 mm showed greater and more severe recession.\footnote{16} Faced with the alternative between extraction and reasonable labial movement of lower incisors, the present studies indicate that the latter is a valuable alternative leading to no clinically relevant recession of the gingiva.\footnote{31-36} Most of these studies were conducted using pre-treatment and post-treatment models which only looked at the gingival heights. The underlying facial bone could have changed considerably.

Handleman determined that there were orthodontic walls or barriers to orthodontic treatment. These walls were the
palatal cortex and the lingual symphisis due to the thickness of the bone. The labial-lingual widths of the alveolus should be established before treatment to determine the amount of space available to move the teeth. Short face type patients generally present with a greater alveolar bone width than the long face type. Thin alveoli were especially noted for mandibular incisors in high angle cases and average class III cases. It was noted for maxillary central incisors in high angle class II patients. Significant iatrogenic sequelae could be caused by challenging the limits of the alveolus.

Extraction treatment in which the anterior teeth are maximally retracted may reach the bony lingual plate and challenge this wall. Sarikaya et al. used CT scans to evaluate the thickness of the labial and lingual plate after retraction of maxillary and mandibular anterior teeth from first premolar extractions. The study showed there was a reduction of the width of bone following retraction in both arches on the lingual and at the alveolar crest on the buccal of the mandibular incisors. Several patients developed dehiscences that were not visible from visual inspection or cephalometrically. When the available room for tooth movement is limited, the movement may force the
tooth root against the cortical plate and may cause adverse sequelae.’

Expanders have been used for over 100 years. Whether slow or rapid, expanders have been used to correct cross-bites and increase the arch perimeter. It has long been thought that there is no long term effect on the periodontium. However, the expansive forces may cause the teeth to displace themselves outside of the bony limits of the alveolus causing bony dehiscences. Greenbaum and Zachrisson showed that rapid and slow expansion patients compared to normal treatment groups displayed no significant effects to the periodontium.\textsuperscript{40} Although the mean differences were clinically small, individual variation was evident. Among the few persons who exhibited the more marked periodontal breakdown at the central aspect of the first molars, most were found in the rapid expansion group.\textsuperscript{40} Other studies also found no significant gingival recession using slow expansion but did show marked tipping of the teeth.\textsuperscript{41,42} The rarest complication of an expander was extreme root resorption or bony dehiscenses.\textsuperscript{43}

Garib et al. conducted a study to evaluate the effects of a Hyrax and Haas type rapid palatal expander (RPE) appliances using CT’s. RPE reduced the buccal bone plate
thickness of supporting teeth 0.6 to 0.9 mm and increased the lingual bone plate thickness 0.8 to 1.3 mm. RPE induced bone dehiscences on the anchorage teeth's buccal aspect from 7.1 ± 4.6 mm at the first premolars to 3.8 ± 4.4 mm at the mesiobuccal area of the first molars. The subjects with thinner buccal bone plates prior to expansion were more likely to show a more marked reduction of the alveolar crest. The Hyrax expander produced greater reduction of first premolar buccal alveolar bone crest level than did the Haas expander. Rungcharasseng et al. conducted a similar study using CBCT’s and found significant reduction of the alveolar crest around the first premolars (-4.42mm) and molars (-2.92mm). The amount of alveolar bone loss displayed by the CT and CBCT scans shows severe iatrogenic sequelae to RPE treatment if the level of bone loss measured is accurate. These studies show that the overlying gingiva may not always show the effects of treatment on the underlying bone.

The formation of bony dehiscences during treatment is caused when the limit of the biologic structure is reached where the bone becomes too thin for the osteoprogenitor cells to form new bone. Bony dehiscences produced during excessive tooth movement may repair if the teeth are moved.
back within the limits of the alveolus. This is due to the increase in tension on the alveolar crest from the stretching of the supracrestal fibers.\textsuperscript{45} It has been shown in-vivo on monkeys that moving the teeth back into the arch after expansion can cause a spontaneous correction of the dehiscence.\textsuperscript{46} The second CT in Garib et al. and Rungcharasseng et al. study was taken at the removal of the expander after a three month long retention period with the RPE still in place.\textsuperscript{6,44} This would not allow for relapse of the teeth as would be expected post-expansion and potential bony repair of the alveolus.\textsuperscript{47} To correct the defects of the periodontium, research is being conducted on the reformation of bone after dehiscence formation. Bone morphogenic protein, enamel matrix derivative, and guided tissue regeneration have been shown to regain bony support.\textsuperscript{48-50}

Impacted canines also present several periodontal complications to consider for orthodontic treatment. The position of the canine can have impacts on the future periodontal health.\textsuperscript{51} Labially erupted canines (20% of canine impactions), especially high labial, often have recession post-orthodontic treatment.\textsuperscript{3,13,18} Positional location prior to treatment and proper orthodontic and
surgical management allows for a more successful prognosis of the supporting periodontium.\textsuperscript{51,52}

**Radiographic Techniques**

The history of radiographs in dentistry has evolved steadily. Peri-apical, bitewing, and panoramic radiographs were originally used to evaluate the periodontium. Alterations of the interproximal crestal bone could be determined; however, the facial and lingual aspects of the alveolus could not be evaluated.\textsuperscript{53,54} The computed tomography (CT) radiograph allowed for complete visualization of the bony components of the alveolus.\textsuperscript{55} This three-dimensional (3-D) representation of the alveolus has allowed detection of facial and lingual bony defects.\textsuperscript{56}

The first CT scanner was developed by Hounsfield in 1967.\textsuperscript{57} Since then several generations of machines have been developed leading to the CT scanners of today. It is a process of using traditional tomograms and using geometric mathematical formulas to reconstruct a 3-D image.\textsuperscript{58} The spiral and helical CT imaging generates a continuous, fan-shaped beam of photons. The source and the sensor move about the subject in 1mm increments taking multiple scans.
These individual scans are then reconstructed into the 3-D images. This process can be time consuming, and any movement can distort the image. The radiation exposure is also very high due to the length of exposure to the photons, which makes this technique less routinely used in orthodontics, along with the cost of the scan.$^{58}$

CBCT’s were first developed for angiography in the early 1980s at Mayo.$^{57}$ Over the past 5-10 years and several generations of development, CBCT machines have been popularized for its use in dentistry. CBCT’s are captured by using a cone shaped beam of photons which strike a digital flat panel detector. This allows acquisition of the image in one pass with shorter scan times instead of 1mm slices with the conventional CT machines. The benefits of CBCT scans are a lower radiation dosage, shorter acquisition time, lower cost of the machine, isotropic voxels as small as .095mm, and the subjective image quality is high.$^{9,13}$ The scan is also not taken in a horizontal position allowing more accurate soft tissue scans. However, metal artifacts from restorations or implants compromise the image quality. These scans capture anywhere from 160-600 images and are reduced to a volume using a weighted, filtered program using the Feldkamp algorithm.$^9$. 
Cone-beam images also show anatomic structures and relationships without overlay or distortion not previously revealed with conventional imaging. Cross-sectional images and 3-D reconstructions may be viewed in any orientation needed. The practitioner can now readily examine root inclination and the temporomandibular joint, location of impacted and supernumerary teeth, the thickness of bone, space available between tooth roots at sites where mini-implants can be placed to provide anchorage, and for planning surgical cuts. It is also possible to examine maxillo-mandibular facial asymmetries, relationships of soft tissues, and the airway in three dimensions.\textsuperscript{13,59,60} A particular problem orthodontist’s face is to understand the position of impacted canines. 3-D volumetric imaging of impacted teeth can show the presence or absence of a tooth, size of the follicle, buccal to lingual location, inclination of the tooth, amount of the bone covering the tooth, potential paths of eruption into the arch, and proximity to and resorption of roots of adjacent teeth, especially lateral incisors.\textsuperscript{3,61-63} Such information allows for improved treatment planning and diagnosis for bringing these teeth into function with limited gingival recession.\textsuperscript{3,18,61} 3-D Surface Volume Rendering (SVR) images display a 3-D reconstruction and offer an improved means
for assessing treatment outcomes and different patterns of bone remodeling following orthognathic surgery.\textsuperscript{59} Superimposition of 3-D images has been developed to help evaluate changes as a result of orthodontic treatment and growth. There is a need to identify orthodontic conditions and problems most likely to benefit from the use of CBCT scans in comparison with conventional cephalometric radiographs.\textsuperscript{9} Therefore, the patient is subjected to the lowest radiation dose and receives the highest quality treatment. In the dental community, CBCT radiographs are rapidly changing the diagnostic and treatment planning abilities.\textsuperscript{9,13,64,59}

Many professionals are now even considering that using a 3-D radiograph is the new standard of care for certain situations.\textsuperscript{65,66} One study looked at the effect CT’s had on the treatment plan of 80 children with impacted canines. The treatment plans of 35 (43.7\%) of the 80 children were altered due to the increased information from the CT scan. More than half (53.8\%) of the treatment plans were altered from the discovery of root resorption on the incisors adjacent to the impacted canines. Without the CT investigation, 13 who had no root resorption on their incisors would have had lateral incisors extracted, and 11
children would not have been treated for root resorption that had caused a pulp exposure on the incisor root.\textsuperscript{2} Another study showed that root resorption was present in 27.2\% of lateral and 23.4\% of central incisors with an adjacent impacted cuspid.\textsuperscript{62} Nearly all of these resorptions occurred where the impacted canines were in close contact with the incisors.\textsuperscript{62} These studies show the importance that 3-D scans have on diagnosis, and the shift to these scans becoming a standard of care.\textsuperscript{2}

Radiation dosage of the computed tomography scans have far exceeded that of panoramic and bitewing radiographs. However, cone beam computed tomography scans have significantly reduced this exposure to nearly that of a full mouth series of intraoral radiographs.\textsuperscript{67,68} Using risk calculations, the risk of fatal malignancy from a CBCT of the jaws is between 1 in 100 000 to 1 in 350 000.\textsuperscript{69} When considering a large imaging field, the effective dose for a cone-beam examination ranges from 44–50 \( \mu \)Sv for some machines and up to 477 \( \mu \)Sv for others depending on the voxel size. The effective dose is about 20 \( \mu \)Sv for a medium size view and as low as 6–12 \( \mu \)Sv for a 4 cm field of view.\textsuperscript{9,13} For comparison, a conventional full-mouth set of dental radiographs is about 84–150 \( \mu \)Sv, a panoramic view about
6.7-54 μSv, a conventional CT of the same region about 2,270-2,600 μSv, and a flight from Paris to Tokyo is around 137 μSv.\textsuperscript{913}

Several studies have investigated the accuracy of CT and CBCT images with the 2-D multiplanar (MP) reformatting and 3-D SVR. Direct measurements on skulls compared to CT scans have shown to be highly accurate. A 0.377mm average difference between the CT and direct measurements was found with no statistical difference.\textsuperscript{70} Systematic errors were low: 0.88, 0.76, and 0.84 mm for horizontal, vertical, and transverse measurements, respectively.\textsuperscript{71} Using the 3-D SVR CT image, smaller slice thickness showed more accurate measurement with an average difference to be ~0.6mm to the true value.\textsuperscript{72} These accurate reports for CT scans were then compared to CBCT scans. Loubele et al. compared CBCT and CT scans, and both yielded sub-millimeter accuracy for linear measurements.\textsuperscript{73} The volumetric data rendered with CBCT systems provided highly accurate data compared with the physical measures directly from the skulls, with around 1\% relative error.\textsuperscript{74,75} The systematic error in the x, y, and z spacial planes is 0.19, 0.21, and 0.19 mm respectively.\textsuperscript{76} The i-CAT CBCT machine has been shown to be accurate to ±1 voxel.\textsuperscript{77} Other studies also found small differences in
linear measurements comparing i-CAT CBCT’s to dry skulls using the 3-D SVR image in Dolphin 3-D imaging. These errors were due to a lack of fiducial markers, but were still clinically accurate with an approximate measurement error of .8mm.\textsuperscript{78,79} Baumgertal et al. found that both the 3-D SVR CBCT image and the caliper measurements were highly reliable (r >0.95).\textsuperscript{80} The CBCT measurements tended to slightly underestimate the anatomic truth.\textsuperscript{79-81} This underestimation only became clinically significant when multiple measurements are added together, i.e. measuring tooth space-arch length discrepancy. The measurements from CBCT volumes can still be used for quantitative analysis; however, an adjustment for this error allows for improved accuracy. This was accomplished by adding a voxel size to the measurement to account for the underestimation due to “the partial volume effect” (Figure 1).\textsuperscript{80}

![Figure 1: The Partial Volume Effect](image)

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This effect appears as blurring over sharp edges on CT and CBCT scans. It is due to the scanner being unable to differentiate between a small amount of high-density material (bone) and a larger amount of lower density (soft tissues) in the same voxel. The processor tries to average out the two densities or structures, and information is lost. This can be partially overcome by scanning using thinner slices or a smaller voxel size; however, Hassan et al. state that smaller voxels can lead to more distortion on the 3-D SVR image. Another strategy to prevent this information loss is the “full width half maximum” (FWHM) method for CT scans. This is accomplished using the mid-density value between the bone and soft tissue or air and setting the density value (DV) accordingly. This is accomplished for CT scans because each tissue type has a known DV range (Figure 2), although absolute DV vary between machines. However, the densities are inconsistent in CBCT images; therefore, finding a threshold range is more difficult. In a study to determine bone densities for implant placement, the Hounsfield Units (HU) and DV for CBCT were consistently higher than for the CT HU and DV’s.
Schlueter et al. measured dry mandibular condyle widths using the 3-D SVR view in Dolphin imaging. The density values were adjusted into the soft tissue range in order to visualize the low density bone of the condyle. The measurements were found to be accurate with this adjustment.\textsuperscript{90} If soft tissues were present, the ability to determine the condyle size would be compromised. Therefore, more accurate bony measurements should be made on higher density cortical bone when soft tissues are present on the 3-D SVR image. Also, an open-mouth scan

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<td>Skin</td>
<td>700 (−324)</td>
<td>1100 (−76)</td>
</tr>
<tr>
<td>Bone</td>
<td>1200 (176)</td>
<td>3500 (2476)</td>
</tr>
<tr>
<td>Tooth</td>
<td>2500 (1476)</td>
<td>4095 (3071)</td>
</tr>
<tr>
<td>Metal</td>
<td>3000 (1976)</td>
<td>4095 (3071)</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Parenthetical value is Hounsfield number.
position coupled with a voxel size of <.4 mm is recommended when creating 3D reconstructions of the dental arches.\textsuperscript{82}

Ballrick et al. showed that the smaller the voxel size accounted for the best measurement accuracy and spatial resolution followed by increased scan times and finally the size of the scan.\textsuperscript{91} Spatial resolution is the ability to separate 2 objects in close proximity. Theoretically, this resolution should be equal to the voxel size; however this was found not to be the case. The detector’s ability to reduce the noise (energy from other sources not from the x-ray tube including light and scatter) along with the voxel size, scan time, scan size, and human error make the spatial resolution .86mm.\textsuperscript{91} The study also found that the measurement error was .1mm, and 94.4\% of the measurements were slightly smaller, but not clinically significant.\textsuperscript{91} So if the measurement is greater than .86mm, then the measurement could be within .1mm. Overall, the scans had a 1:1 image to reality ratio,\textsuperscript{92,93} and the direct measurements of dry skulls or phantoms were found to be accurate to measurements made on the CBCT images and conventional CT images.

CT Scans and the Periodontium
A thorough knowledge of the periodontium is of primary importance for an orthodontist to create a problem list and diagnosis. CT scans of the head and neck have been the gold standard for identifying periodontal defects. Several studies have been done to validate the accuracy of these scans compared to direct measurements. Pisorious et al. studied whether probing depths could be detected by CT scans, but the values for the CT were on average 2 mm different than for direct probing. The results did show better diagnostic findings for furcal defects. Naito et al. conducted an in-vivo study on 31 teeth and 186 sites of periodontal breakdown. These sites were measured with a periodontal probe to the cementoenamel junction after flap surgery and served as the direct measurement. Then CT’s were conducted and the same sites were measured. The results showed that the mean difference between CT and the true bone level was 0.41 ± 2.53 mm with a correlation of 0.75. The results of this study indicate that CT has the potential to allow precise assessment of bone defects caused by periodontal disease.

The previous studies looked at periodontal breakdown as a whole. Fuhrmann conducted a series of studies using
CT scans to study dehiscences, labial-lingual bone width, and orthodontic treatment effects. Seventy percent of the 60 artificially made dehiscences could be identified on the scans using the multiplanar sections. The ability to identify the dehiscence often was determined by the ability to detect the periodontal ligament space. Of the defects identified, the CT’s were nearly identical to the direct measurement measurements, 4.2mm to 4.0mm respectively. In the study of labial-lingual bony dimensions, 80% of the dehiscences were identified in the area of the mandibular incisors. The labial bone width was measurable in the apical and middle sections of the root. However, when the bone overlying the root became less than .5mm thick, the thickness of the bone was not observable. A visible periodontal ligament space was found to improve the reliability of the measurement of buccal or lingual bone plates up to 0.2mm. This study also showed that regular cephalograms were not accurate to determine labial bone thickness on lower incisors. Only one dehiscence was observed using a lateral cephalogram and the thickness was often overestimated by 1mm. Orthodontic treatment effects were studied in Fuhrmann’s third study. CT scans were taken before and after treatment. No noticeable dehiscences or periodontal breakdown were observed in the
fixed appliances group. However, in the quad-helix expansion group, significant buccal dehiscences were observed on the posterior teeth. The Pre-treatment CT’s showed several dehiscences in the mandibular incisor region which correlated with a small symphisis, reduced labio-lingual bone width, anterior crowding, thin bone plates, or eccentric tooth positions.

Micro CT scans are also becoming available to determine the finer details of the alveolus due to a voxel size in the micrometer range. One author developed methods to allow for highly accurate and reproducible measurements of tooth-supporting alveolar bone using Micro CT. However, the micro CT scan is not currently practical for orthodontists due to the small field of view, large dose, and high cost of the scan.

**CBCT and the Periodontium**

CBCT technology has become increasingly popular for reasons mentioned above. This new radiographic technique has to be validated compared to conventional CT scans. Vandenberghe et al. investigated periodontal bone
architecture using conventional intraoral radiography and 3D CBCT images. The conclusions of this study found that traditional radiography images provided more bone details, but CBCT provided a better morphologic description of the alveolus and periodontal defects. Intraoral radiography scored significantly better for contrast, bone quality, and delineation of lamina dura, but CBCT was superior for assessing crater defects and furcation involvements. In the follow up study, CBCT scans with 0.4 mm thick cross-sections demonstrated more accurate values, indicating enhanced assessment of periodontal bone loss. Another study simulated the ability to detect intrabony defects and showed that CBCT has better detection properties than traditional intraoral radiography. Agbaje et al. studied the ability to determine the volume of bony defects using CBCT scans. Seventy-one defects were filled with water and measured to be 227mm$^3$ on average. CBCT scans determined the volume to be 225mm$^3$. This shows that CBCT scans permit imaging of anatomical structures in three planes and allows for reliable volume estimates. Mol and Balasunduram studied the ability to accurately determine bone levels circumferentially around a tooth, and CBCT scans were found to be more accurate in the premolar and molar areas compared to anterior teeth. The scans were not perfect,
but better than conventional radiographs. Rungcharassaeng et al. investigated the effects of expansion and showed the creation of bony dehiscences around the anchor teeth as discussed earlier.44

Misch et al. investigated the ability to determine artificial osseous defects that were intrabony and dehiscence type comparing the multiplanar views from a CBCT, peri-apical radiographs, and periodontal probing to a digital caliper. The defects had gutta percha markers from the cementoenamel junction to the base of the defects and were on dry skulls. Thirty-three percent of the dehiscences could not be visualized and were therefore not included. The systematic errors for all defects were .34, .27, and .41mm (Probe, PA, CBCT) comparing the CBCT measurements to the direct measurements. No systematic error was reported for dehiscences alone, but the interproximal defects difference was .36mm. Therefore CBCT fared well to traditional measurement styles, but was no more accurate. Several dehiscences were not included in the study but the ones that were included had markers to show the most apical extent.10

Mengel et al. created 14 dehiscences, 14 fenestrations, and 14 intrabony defects on dry pig and
human skulls. Conventional CT scans, CBCT scans, and intraoral radiography were compared. The scans were 3cm by 4cm and .125mm voxel size. All of the defects were measured on the multiplanar views in three planes of space for the CT and CBCT scans. The mean difference for all defects was .16+/- .1mm for the CT scans, and .19+/- .11mm for CBCT scans. For dehiscences of a known size (12mm high, 3mm wide), the deviations were .28, .21, and .88 for height, width, and depth on the CBCT image.  

Mengel et al. duplicated the prior study using dental implants placed into dry pig mandibles. 11 fenestrations, dehiscences, and intrabony defects each were created around the implants. The multiplanar image measures compared to the direct peri-implant defect measurements showed a mean deviation of 0.17 ± 0.11 mm for the CBCT’s and 0.18 ± 0.12 mm for the CT’s. For dehiscences of a known size (6mm height, 4mm width), the deviations were .22, .14, and .16 for the height, width, and depth. The quality of the dehiscence construction in both studies may distort the findings of these studies because the bone was not thinned at the margins to simulate natural dehiscences. Between the two studies, the CT and CBCT scans displayed only a slight deviation in the extent of the defects. Both
radiographic imaging techniques permitted imaging of peri-implant defects in three planes without overlay or distortion. Mengel et al. concluded that CBCT scans have better imaging quality than CT scans.\textsuperscript{105}

To determine the incidence of dehiscences, a study performed mandibular anterior flap surgery and CBCT radiographs on 32 untreated patients. 78% had at least one alveolar defect. Dehiscences were the most common defect and were found most often on the mid-labial of the mandibular canines. However, all mandibular anterior teeth had dehiscences. This report determined a need to validate CBCT scans for the detection and measurement of dehiscences prior to orthodontic treatment.\textsuperscript{106}

CBCT have also been used to quantify the amount of available soft tissue (ST), ST-CBCT. Retracting the lip away from the alveolus during the scan permitted visualization of the soft tissue. This CBCT technique allowed for measurements from the gingival margin to the facial bone crest, the gingival margin to the CEJ, and width of the facial gingiva. These scans allowed for a clear visualization, measurement of the dimensions, and analysis of the relationship of the structures of the
periodontium. However, this study needs to be verified due to the use of only three scans.\textsuperscript{15}

Dentoalveolar CBCT scans provide an improvement for the planning of orthodontic biomechanics based on the presence and size of pre-treatment dehiscences. The mechanics employed would reduce the movement of teeth outside of the bony envelope. The scans will also help to determine any iatrogenic effects caused by orthodontic treatment. Kasaj and Willerhausen conclude that the low dosage and superior image quality of CBCT’s are promising for periodontal applications, especially in the area of dehiscence, fenestration, intra-bony defect, and cyst recognition.\textsuperscript{107} CBCT has the potential to replace conventional radiography and to make diagnostic decisions based on the bony architecture found on the scan.\textsuperscript{108}

**Statement of the Research**

CBCT scans have been shown to be a clinically accurate representation of the skull and its anatomy.\textsuperscript{92,93} These scans can be used by an orthodontist to make diagnostic and treatment decisions for the patient.\textsuperscript{9,13,59} The scans also have
the ability to determine the effects of treatment especially of the bone. The 3-D SVR view is often used by orthodontists to evaluate the dentition and make treatment decisions. This is due to the ease of use of the software and the ability to view the entire skull in 3-D.

This study is being undertaken to determine the ability of orthodontists to evaluate the alveolus especially the bone covering the roots of the teeth using CBCT’s. Prior studies have shown that measuring dehiscence size on the CBCT multiplanar views has been clinically accurate on dry skulls without soft tissues.\(^{10,11,105}\) Prior studies have also shown that measurements made on the CBCT scans, multiplanar and 3-D SVR, are clinically accurate.\(^{78-80,90,91}\) This study will reconstruct natural dehiscences with the soft tissues present. Then CBCT’s will be captured at .2mm voxel size and the measurements of the dehiscences will be carried out by 21 orthodontic residents. All dehiscences will be marked and evaluated using the 3-D SVR view in Dolphin 3-D (Dolphin Imaging 10.5 Premium Chatsworth, CA). The hypothesis is that dehiscences can be measured by orthodontic residents to a clinically significant level comparing direct to CBCT measurements.
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CHAPTER 3: JOURNAL ARTICLE

Abstract

Introduction: Cone beam computed tomography (CBCT) has allowed for the visualization of the entire maxillo-mandibular complex in three dimensions without overlap of structures at a significantly reduced radiation dose and cost to the patient. Purpose: The purpose of this study was to validate the use of 3-D surface volume rendering (SVR) images to quantify the height of alveolar dehiscences. Materials and Methods: Twenty-four dehiscences were created on 9 incisors, 9 canines, and 6 premolars on 4 cadaver skulls. i-CAT CBCT’s were taken of each skull at 2 mm voxel size. Each dehiscence was quantified by 21 orthodontic residents using the 3-D SVR starting at a density value (DV) of 1365. The principal investigator (PI) also quantified each dehiscence using the 2-D multiplanar (MP) image and 3-D SVR image starting at 1200 DV. Results: The results of this study showed an average method error of the residents as a group to be .57 mm with an intraclass correlation (ICC) of .77%. The resident’s method error ranged from .45 mm - 1.32 mm, and the ICC was from .201 - .857%. Only 4 of the residents showed significant systematic differences compared to the direct
measurement. As a group, the paired t-test was non-significant. Systematic error was low at -.01 mm for the direct measurement compared to the resident’s average 3-D SVR at 1365 DV measurement. The 3-D SVR at 1365 DV images were compared to the MP and 3-D SVR images at 1200 DV with no significant differences in the measurements and low systematic error. The method error of the PI was .45 mm, .45 mm, and .41 mm for the 3-D SVR at 1365 DV, 3-D SVR at 1200 DV, and 2-D MP respectively. **Conclusions:** Using the 3-D SVR image, dehiscences of the periodontium can be quantified to a significant level.
Introduction

Traditionally, practitioners have used conventional bitewings, peri-apical, lateral cephalograms, and panoramic radiographs to evaluate the teeth, roots, and periodontium for diagnosis and treatment planning. These radiographs are limited due to the inherent overlap of bony structures and inability to determine buccal and lingual bony defects.\(^1\)

To be able to visualize the entire bony support of the teeth, computed tomography (CT) has been utilized to allow three-dimensional evaluation without distortion. However, CT’s are not practical for dentistry due to the high cost of the machine\(^4\)\(^5\) and large radiation dose to the patient.\(^6\)\(^7\)

A newer technology, cone beam computed tomography (CBCT) is now being used to image the head and neck. The radiation dose is significantly less than a conventional CT and is approximately equivalent to a conventional full mouth series.\(^6\)\(^7\) The lower cost of the machine, lower radiation dosage of the scan, and high image quality make the CBCT more practical for use in dentistry.\(^8\)\(^9\)
CBCT’s have been used to evaluate root angulations, position of canine and supernumerary impactions, the temporomandibular joint, placement of mini-implants, assessing maxillo-mandibular facial asymmetries, and the alveolar morphology of the periodontium. These capabilities enhance an orthodontist’s information to make more accurate diagnostic and treatment decisions. Some authors have even stated that CBCT’s have become the standard of care for certain situations such as canine impactions.

The periodontium provides support and nutrition to the teeth and allows for orthodontic tooth movement. Therefore, it is crucial to consider the periodontium in the diagnosis and treatment plan of each individual patient. Dehiscences are one of the major bony defects to consider because it is difficult to determine their presence. One study showed that 40% of American skulls had at least one dehiscence with 67% of dehiscences in the mandible. Mostofa et al. performed anterior mandibular flaps and CBCT’s on 32 patients. Seventy-eight percent of the patients had at least one dehiscence with the highest rates on the canines. With these rates of dehiscences,
orthodontists must factor this in when creating a treatment plan.

A systematic review of the literature has shown that orthodontic treatment has very small detrimental effect on the periodontium. A significant risk factor for this is the gingival biotype. Thin and scalloped gingiva is more prone to recession than thick and flat. Some orthodontic mechanics, proclination and expansion, have been used to alleviate crowding without showing significant negative effects on the level of the gingiva. However, study models and lateral cephalograms do not adequately show the effects of treatment on the alveolar bone. Löst related the level of the gingiva to the level of the alveolar bone for dehiscences. The bone was on average 2.76 mm more apical than the overlying gingiva; however, there was a wide variation with some distances as great as 7.5 mm. Steiner showed in-vivo on monkeys that excessive movement of the incisors outside of the alveolus leads to dehiscences. Rungcharassaeng et al. took CBCT’s pre and post expansion and found reduction of the alveolar crest around the first premolars (-4.42 mm) and molars (-2.92 mm). Other studies have shown crestal alveolar bony changes from extraction treatment as well. The limits of
the alveolus as well as the ability to accurately quantify the alveolar bone levels pre and post treatment need to be verified.

Traditionally, 2-D multiplanar (MP) images have been used to interpret CBCT’s using the sagittal, axial, and coronal planes. These images have been shown to be able to evaluate the periodontium\textsuperscript{9,38}; however, the 3-D surface volume rendering (SVR) images are becoming more popular to interpret CBCT’s. The aim of this study is to evaluate the usage of 3-D SVR images from CBCT’s to quantify bony dehiscences.

**Materials and Methods**

**Dehiscence Construction**

Four human cadaver heads with soft tissues present and dentate maxillary and mandibular arches were obtained from the Anatomy Department at Saint Louis University. Twenty-four dehiscences were created on the buccal aspect of 9 canines, 9 mandibular incisors, and 6 premolars. Before the defect construction, a surgical flap was made to allow access to the bone (Figure 3). A 1/4 round carbide bur and
handpiece was used to remove the bone overlying the roots. The margins of the bone were thinned to simulate natural dehiscences (Figure 3). The dehiscences were made at all different heights from the cementoenamel junction so that there was no standardization. To reduce method error, a metallic marker was placed at the cementoenamel junction for a consistent fiducial marker. The dehiscences were measured from the metallic marker to the base of the dehiscence directly with a digital caliper to the nearest .01mm. Each dehiscence was measured twice with 2 weeks between measurements to assess reliability. All metallic restorations were removed from the dentition to reduce scatter radiation. Then the soft tissues were replaced and sutured tightly to simulate natural soft tissues.

Figure 3: (a) Completed Dehiscences with thinned margins, (b) Soft tissues sutured back into place.
Imaging

CBCT’s of the 4 skulls were acquired with the i-CAT scanner (Imaging Sciences International, Hatfield, Pa). The skulls were positioned using a head holder. A single 25 second scan comprising 306 basic projections with a 16 cm (Width) by 6 cm (Height) field of view and .2 mm voxel size was captured. The CBCT data was imported into Dolphin 3-D (Dolphin Imaging Version 10.5 Premium Chatsworth, CA). All image reconstructions and measurements were performed on a 20.1-inch flat panel LCD monitor (FlexScan S2000, Eizo Nanao Technologies Inc, Cypress, Calif) with a resolution of 1600 × 1200 and a 0.255 mm dot pitch.

The principal investigator (PI) used the 3-D SVR image generated in Dolphin 3-D imaging to make measurements from each metallic marker to the most apical extent of the dehiscence starting at a density value (DV) of 1200 and 1365 (Figure 4). The PI also used the 2-D MP images to measure each dehiscence (Figure 5). Measurements were made twice for the 2-D MP and SVR at a DV of 1200 images and three times for the SVR DV at 1365 images, with 1 week between measurements to assess reliability.
Twenty-one orthodontic residents (including the PI) at Saint Louis University with at least 1 year of experience manipulating CBCT images in Dolphin imaging, measured the dehiscences using the 3-D SVR image starting at the DV of 1365. The DV of 1365 and lighting adjustments of the images reduced glare and allowed visualization of the fine bony architecture. Each resident was given the same tutorial on use of the software to manipulate the images. All dehiscences were measured in the same order for each skull. The PI was available during the measurements but only answered questions on the use of the software.

Figure 4: (a) 3-D Surface Volume Rendering (SVR) image at 1365 density value, (b) Measurement on 3-D SVR image
Figure 5: The 2-D Multiplanar images using the coronal, sagittal, and axial planes.

**Statistical Analyses**

A standard statistics software program (SPSS Version 17, Chicago, IL) was used to analyze the data. To determine reliability, single measure Intraclass Correlation Coefficients (ICC) was determined for all multiple sets of direct and CBCT measurements. The average of the multiple measurements was then used as the true value. To determine intraobserver error, the direct measurements were compared to the average of the PI’s MP and 3-D SVR (At 1200 and 1365 DV) measurements and to
compare the 3-D SVR at 1365 DV to the MP and the 3-D SVR at 1200 DV measurements in three ways: a 2-tailed paired student’s t-test at <.05 significance level, method error, and single measure ICC’s. To determine interobserver error, the three tests were also used to compare the direct measurements to the 3-D SVR at 1365 DV for each resident and the average of all the residents. The teeth were then separated into three groups: incisors, canines, and premolars. ICC, method error, and Wilcoxon Signed Rank tests were used to compare the direct measurements to each tooth group.

Results

The ICC of the multiple sets of measurements all showed reasonable correlations (figure 6). The 3-D SVR image at 1365 DV showed the lowest correlation due to the experience of the PI manipulating the images and quantifying the dehiscences. The systematic intraobserver error showed low mean differences between the direct measurements compared to the MP and 3-D SVR at 1200 and 1365 DV; as well as, comparing the different CBCT images to
each other with no significant differences (table 1). The random intraobserver error comparing the direct measurements to the different CBCT images showed high intraclass correlations and similar method errors of .45 mm, .45 mm, and .41 mm for the 1365 DV 3-D SVR, 1200 DV 3-D SVR, and 2-D MP respectively (table 2).

The systematic difference between the direct and 3-D SVR measurements was -.01 mm for the average of the residents (table 3). Four residents, out of 21, showed a significant difference between the direct and 3-D SVR measurements with systematic differences ranging from negative .44 mm to .89 mm (table 3 and figure 7). The ICC and ME for the average of the residents was .77% and .57 mm (table 4 and figure 8). The ICC range was from .20-.86%, and the method error ranged from .45 mm - 1.32 mm (table 4 and figure 9). The resident’s average measurement was not consistently above or below the direct measurement (figure 10).

The tooth groups were then compared with incisors showing the best method error at .336 mm and ICC of .906% (table 5). All tooth groups were not significantly different from the direct measurements using the Wilcoxon Signed Rank test (table 5).
Figure 6: Intraobserver Intraclass Correlation showing reliability of multiple direct, 3-D Surface Volume Rendering (1365 density value and 1200 density value), and 2-D Multiplanar measurements.

Table 1: Systematic Intraobserver Error using a Paired t-test

<table>
<thead>
<tr>
<th>Method Error</th>
<th>Mean Difference</th>
<th>Standard Deviation</th>
<th>t</th>
<th>Probability</th>
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</thead>
<tbody>
<tr>
<td>Direct vs 3-D Surface Volume Rendering (SVR) at 1365 Density Value (DV) Measurement</td>
<td>-0.13mm</td>
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Table 2: Random Intraobserver Error

<table>
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<tr>
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<td>Direct vs Surface Volume Rendering (SVR) at 1365 density value (DV) measurement</td>
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<td>0.000</td>
<td>0.45mm 0.89mm</td>
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### Table 3: Systematic Interobserver Error

* Indicates Paired t-test was statistically significant (p<.05)

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<th>Residents</th>
<th>Mean Difference (mm)</th>
<th>Standard Deviation (mm)</th>
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<th>Pair ed t-test Probability</th>
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<td>0.98</td>
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<td>-0.01</td>
<td>0.82</td>
<td>-0.058</td>
<td>0.95</td>
</tr>
</tbody>
</table>
Figure 7: Systematic error mean difference for each resident and the resident’s average on the 3-D Surface Volume Rendering at 1365 density value measurement compared to the direct measurement (* denotes Paired t-test < .05).

Table 4: Random Interobserver Error

<table>
<thead>
<tr>
<th>Residents</th>
<th>Intraclass Correlation</th>
<th>Method Error (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.65</td>
<td>0.85</td>
</tr>
<tr>
<td>2</td>
<td>0.42</td>
<td>0.92</td>
</tr>
<tr>
<td>3</td>
<td>0.70</td>
<td>0.64</td>
</tr>
<tr>
<td>4</td>
<td>0.20</td>
<td>1.32</td>
</tr>
<tr>
<td>5</td>
<td>0.79</td>
<td>0.60</td>
</tr>
<tr>
<td>6</td>
<td>0.66</td>
<td>0.80</td>
</tr>
<tr>
<td>7</td>
<td>0.58</td>
<td>1.02</td>
</tr>
<tr>
<td>8</td>
<td>0.61</td>
<td>0.94</td>
</tr>
</tbody>
</table>

Table 4 Continued

<table>
<thead>
<tr>
<th>Residents</th>
<th>Intraclass Correlation</th>
<th>Method Error (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>0.71</td>
<td>0.72</td>
</tr>
<tr>
<td>10</td>
<td>0.75</td>
<td>0.71</td>
</tr>
<tr>
<td>11</td>
<td>0.72</td>
<td>0.67</td>
</tr>
<tr>
<td>12</td>
<td>0.75</td>
<td>0.70</td>
</tr>
<tr>
<td>13</td>
<td>0.69</td>
<td>0.73</td>
</tr>
<tr>
<td>14</td>
<td>0.34</td>
<td>0.96</td>
</tr>
<tr>
<td>15</td>
<td>0.74</td>
<td>0.74</td>
</tr>
<tr>
<td>16</td>
<td>0.74</td>
<td>0.66</td>
</tr>
<tr>
<td>17</td>
<td>0.50</td>
<td>0.90</td>
</tr>
<tr>
<td>18</td>
<td>0.80</td>
<td>0.60</td>
</tr>
<tr>
<td>19</td>
<td>0.77</td>
<td>0.64</td>
</tr>
<tr>
<td>20</td>
<td>0.76</td>
<td>0.63</td>
</tr>
<tr>
<td>21</td>
<td>0.86</td>
<td>0.45</td>
</tr>
</tbody>
</table>

Average  | 0.77                   | 0.57              |

Figure 8: Single Measures Intraclass Correlation comparing the direct measurements to each resident’s and the
resident’s average measurements on the 3-D Surface Volume Rendering.

Figure 9: Method error comparing the direct measurements against the 3-D Surface Volume Rendering at 1365 density value measurement for each resident and the resident’s average.

Figure 10: Direct measurements compared to the resident’s average on the 3-D Surface Volume Rendering (SVR) starting at 1365 density value (DV).

Table 5: Comparing the different tooth groups with Intraclass Correlation, method error, and Wilcoxon Signed Rank test.

<table>
<thead>
<tr>
<th></th>
<th>Intraclass Correlation</th>
<th>Method Error</th>
<th>Wilcoxon signed Rank test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canines</td>
<td>0.759</td>
<td>0.62</td>
<td>0.953</td>
</tr>
<tr>
<td>Premolars</td>
<td>0.532</td>
<td>0.739</td>
<td>0.917</td>
</tr>
<tr>
<td>Incisors</td>
<td>0.828</td>
<td>0.336</td>
<td>0.779</td>
</tr>
</tbody>
</table>

Discussion

Understanding the alveolar bone morphology using the images derived from a CBCT has been of great interest in the dental community. Comparing CBCT images to traditional intraoral radiography, it was found that CBCT had better
potential to represent the alveolus, especially detecting the 3-D volume of intrabony defects.\textsuperscript{129,30} The detection of dehiscences through traditional radiography or direct evaluation is nearly impossible. However, the CBCT images offer a real advantage in the detection of these defects.

The results of this study show that dehiscences can be accurately measured using the 3-D SVR from CBCT’s. The residents as a group showed only a .57 mm method error and a .77% intraclass correlation. However, the method error range was from .445 mm to 1.36 mm. The incisors had the best method error at .336 mm.

Mengel et al. showed that dehiscence height could be measured with only a .28 mm systematic difference.\textsuperscript{9} Mengel et al. conducted another study measuring dehiscences on implants and found the systematic difference to be .22 mm.\textsuperscript{31} These two studies compared traditional CT to CBCT at .125 mm voxel size with both showing similar results. The authors state that the CBCT showed better image quality. Misch et al. conducted a study measuring intrabony and dehiscence defects using CBCT at .4 mm voxel size. The systematic difference in height of both defects combined was found to be .41 mm.\textsuperscript{28} Fuhrmann used traditional CT with
1 mm slices and determined a .2 mm systematic difference of dehiscence height.³

The prior studies used the 2-D MP images on dry skulls with a known dehiscence size, were interpreted by only a few individuals, and only found systematic differences. The current study has no standardized size of the dehiscences, the soft tissues were present, systematic and random differences were found, and the dehiscences were measured by 21 individuals. These methods better represent the normal anatomy of a random patient and interpretation of the bony morphology on a CBCT by a random observer. The ability to quantify the dehiscence varies on the skill of the practitioner due to the wide variation in method error amongst the residents. There appears to be a learning curve to detecting dehiscences on the image. The PI had the most experience manipulating the images, quantifying the dehiscences, and showed the lowest error of .445 mm.

The interpretation of the 2-D MP images has been shown to be highly accurate with a systematic difference as low as .1 mm and a 1:1 image to reality ratio.³²⁻³⁴ The 3-D SVR image has not shown the same accuracy from some of the current studies, but these studies did not use definite fiducial markers.³⁵,³⁶ Baumgaertel et al. measured the 3-D
SVR images and showed very high correlations for single measurements compared to the direct measurement. When multiple measurements were added together, the measurement sum became significantly smaller than the true value. The smaller measurement’s sum is due to the “partial volume effect”. A voxel may only show 1º of density. The density of the voxel is the average of the respective densities within the voxel. If bone and soft tissue are in the same voxel and the density value is set to show bone and not soft tissue, information is lost and the measurement is smaller than the true value. In the current study, the measurements varied from larger than the direct measure to smaller (figure 10) and were only single measures. So this effect was negligible.

The small amount of error within the study is mainly attributable to human error. This error is due to the ability to distinguish between very thin bone and the root of the tooth (Figure 11). The voxel size and cadaver bone quality play a smaller role as well. According to Ballrick et al., 50% of error is attributable to voxel size alone. The smaller the voxel the clearer the image; however, it is at an increased radiation dose to the patient. For the 4 residents that were significantly different, the
correlation may be higher than other residents, but the measurements are further from the correlation line making the measurements for those residents significantly different.

Figure 11: Human Error. Dehiscences with thinned margins on the direct evaluation (a and c). Difficulty determining the junction between bone and tooth on the 3-D surface volume rendering at 1365 density value(b and d).
The 2-D MP images have been the standard for interpreting CBCT images. However, the 3-D volumetric rendering is becoming more popular due to the user-friendly software. This study also examined the difference in the measurements between the 2-D MP images and the 3-D SVR images at different density values. The method error was nearly equivalent for each, with good correlations to the direct measurements. The 2-D MP was the most reliable and had the lowest random error. However, there was no significant difference between the three image reconstructions. The 3-D SVR starting at 1365 DV was used to measure the dehiscences because it offered the clearest view of the alveolar bone without interference from adjacent tissues. With conventional CT, there are definite known density values of different tissues. The density value range is then set accordingly to only visualize the tissues of interest, i.e. bone. With CBCT, the density values are inconsistent based on the field of view. The CT DV starts at 1200 for the lowest density bone, but CBCT values may be slightly higher. Therefore, the selection of 1365 DV as the lowest DV would be within the normal range of low density bone and the interpreter could visualize the fine, low density bony architecture.
For evaluating surface defects including dehiscences of the periodontium, either the 2-D MP or 3-D SVR images may be used for interpretation. The 3-D SVR image from a CBCT with 0.2mm voxel size has the ability to accurately quantify dehiscences with sub-millimeter accuracy.

**Conclusions**

Using the 3-D SVR image, dehiscences of the periodontium can be quantified to a significant level.

The 3-D SVR image can be used for orthodontic diagnosis, treatment planning, and post-treatment evaluation for dehiscences.
List of References


37. Shapurian T, Damoulis PD, Reiser GM, Griffin TJ, Rand WM. Quantitative evaluation of bone density using the


Nicholas Steven Ising was born December 13th, 1981 in Louisville, Kentucky. He is the second child of Steven and Karen Ising both of Louisville, Kentucky where he was raised.

Nicholas graduated from Saint Xavier High School in 2000. He then attended the University of Kentucky until 2003 when he was accepted to dental school. He received his D.M.D. degree from the University of Louisville Dental School in 2007 and is planning to receive his M.S.D. from Saint Louis University in January, 2010. From there, he will enter into private practice in his hometown of Louisville, Kentucky.

Nicholas is happily married to his wife, Natalie, and they are due for their first child, Noelle, in December, 2009.