EVALUATING THE USE OF 3D IMAGING IN CREATING A CANAL-DIRECTED ENDODONTIC ACCESS

by

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INTRODUCTION

Treatment of the infected root canal requires adequate access to the root canal system (RCS). Access is achieved through the crown of the tooth. An adequate coronal access preparation provides a smooth free-flowing tapered channel from the orifice to the apex that allows instruments, irrigants, and medicaments to attempt cleaning and shaping of the entire length and circumference of the canal, with as minimal a loss of structural integrity to the tooth as possible.[1] The traditional endodontic access (TEA) to the RCS may sacrifice tooth structure-enamel and dentin and significantly weaken the tooth. Alternative endodontic accesses have been suggested that conserve the tooth structure, specifically the pericervical dentin that is more disposed to fracture long-term.[2] The goal of an endodontic access is to locate the canals and provide adequate access to the RCS anatomy, facilitating the practitioner during the cleaning and shaping procedure.

Determining the number and location of the canal orifices can be difficult, specifically on teeth with calcifications and full coverage restorations. Krasner and Rankow evaluated the pulp chambers of 500 teeth and proposed some guidelines to follow when trying to locate the canal orifice.[3] Krasner and Rankow evaluated the relationships of the pulp chamber to the clinical crown and the relation of the orifice to the pulp-chamber floor.[3] These guidelines are helpful in many situations; however, when accessing through a heavily restored tooth or a tooth with a-full coverage restoration, it can be easy for the clinician to get misguided and disoriented within the tooth. In these scenarios, there is a higher possibility for procedural errors such as coronal or radicular perforations.[4]

Once the canals are located, it is very important to obtain straight-line access. Straight-line access is adequately achieved when "an endodontic file can approach the apical foramen or the first point of canal curvature undeflected."[5] Without proper straight-line access, the instruments will be exposed to more stress during working, increasing the risk for separation. Also, the instruments will not have adequate access to the original canal, and therefore, will not clean and shape effectively. Therefore, it is important to obtain a straight-line access or a "canal-directed endodontic access" that leads directly to the orifice of the canal.

In order to further minimize the possibility of a procedural error, one can utilize the information obtained from a cone-beam computed tomography (CBCT) image. CBCT images are commonly used in the field of endodontics.[6] CBCT scans produce three-dimensional images with minimal image distortion.[7] Since the clinician has the ability to view the image in different slices and segment the hard tissues, the soft tissue does not interfere with the accuracy of the CBCT scan. CBCT images have been particularly useful in locating canals and determining canal anatomy in challenging cases.[8] This was shown to be helpful when endodontic treatment was performed on teeth that were heavily restored and when the natural anatomic landmarks were covered by the restoration.[9] Ultimately, the CBCT images of the RCS anatomy help the practitioner determine the location of the canals and the endodontic access may be more conservative.

Utilizing the information from the CBCT image, the practitioner is able to visualize the root canal anatomy and to design an appropriate access preparation prior to initiating treatment. In conjunction with the CBCT imaging, the Dolphin 3D software can be used to trace an ideal 3D access path. Currently, 3D software is used in the field of orthodontics for diagnosis and treatment planning.[10] Specifically, Dolphin 3D software allows the clinician to import CBCT images and to analyze the 3D reformatted data in multiplanar views. The clinician is able to obtain accurate measurements of the anatomical structures using the precise measurements tool.[11,12] The Dolphin 3D software can be used in the field of endodontics to trace and ideal 3D canal directed endodontic access (CDEA) path.

Therefore, the purpose of this *ex vivo* study was two-fold:

1. Evaluate the ability of information obtained from CBCT images and the Dolphin 3D software to create an accurate CDEA path.
2. Compare the overall tooth structure loss in a traditional endodontic access (TEA) to a CDEA. Parameters that were assessed were volume of remaining tooth structure, cross-sectional surface area at the occlusal surface, and remaining dentin thickness at the CEJ.

A 3D guided access stent was digitally designed to fit each particular tooth using Rhino 3D V5 Software. The stl files of the custom stent were then sent for 3D printing to Shapeways, a 3D printing company in New York. This 3D stent was only utilized to verify the accuracy of the path determined with the CBCT image and Dolphin 3D software. This method of a CDEA may assist practitioners in endodontic access preparations while minimizing the removal of unnecessary tooth structure and avoiding procedural errors, such as coronal or radicular perforations.

CLINICAL SIGNIFICANCE

By maintaining a CDEA, the clinician may be able to access teeth with blocked pulp chambers/canals, teeth with extensive or full coverage restorations, perhaps through the use of a stent or other devices.

HYPOTHESES

First Hypothesis

Null: The use of CBCT and Dolphin 3D software will not provide an accurate path for establishing a "canal-directed" endodontic access.

Alternative: The use of CBCT and Dolphin 3D software will provide an accurate path for establishing a "canal-directed" endodontic access.

Second Hypothesis

Null: The overall loss of tooth structure will not be less for teeth with a "canal-directed" endodontic access compared with a traditional access preparation.

Alternative: The overall loss of tooth structure will be less for teeth with a "canal-directed" endodontic access compared with a traditional access preparation.

REVIEW OF LITERATURE

HISTORY OF ENDODONTICS

Odontogenic pain is a phenomenon that has been occurring for many years with records dating back to the 14th century BC in China. It was speculated at that time that caries was caused by an invasion of worms in the teeth.[13] This "tooth worm" theory continued to remain popular throughout the Babylonian times. It was suggested that the tooth worm caused a toothache by "gnawing at the tooth structure of the tooth."

This theory was believed to be true until 1728. Pierre Fauchard is considered to be the "founder of modern dentistry" and authored the book, *The Surgeon Dentist*. In this book, Fauchard describes the procedure of "opening teeth to relieve abscesses and to evacuate pus." He recommended that after leaving the teeth open for an extended period of time to allow drainage, typically two to three months, one should fill the pulp chamber with a lead foil. He even went on to describe applying the oils of cloves or cinnamon on affected teeth with deep carious lesions.[14]

In 1756, another individual named Phillip Pfaff described a more advanced pulp capping procedure. He recommended placing an approximated piece of gold or lead foil over the pulp exposure. However, he suggested placing the foil in a way that the concave surface was near the pulp exposure, so the metal does not contact the pulp.[14] Robert Woofendale is known to have documented the first endodontic procedure in the US. In 1766, he described a method in which the pulp was cauterized by a hot instrument, relieving pain. Robert Woofendale also wrote a book, *Practical Observations on the Human Teeth*, in which he proposed methods of treating a nerve exposure.[14]

Around the end of the 18^{th} century, a German practitioner, Frederick Hirsch, discussed that diseased teeth can be diagnosed by tapping or percussion. Soon after, in 1839, S.P. Hulihen classified various causes for toothaches, establishing a diagnostic system for odontogenic pain.[14] Not only were there advances in the diagnostic testing and classification of odontogenic pain, but there were also advances in the techniques and root canal obturation materials.

In 1809, Edward Hudson was credited as the first practitioner to place root canal fillings with gold foil.[14] Edward Maynard was the first to introduce root canal instruments such as a broach, along with several other instruments that were used to clean the canal.[15,16] Baker has been known to document the first publication of a root canal procedure (pulp extirpation, canal cleaning and root canal filling) in 1839. This was published in the *American Journal of Dental Science*.[14] In 1847, Edwin Truman introduced "mazer wood" as gutta percha that could be used as a root canal filling material. In the 1850s, practitioners used wood soaked in creosote to obturate the root canals. A liquid cement was used in conjunction with the wood and served as the "sealer."[14] Later in 1865, E.L. Clarke and other practitioners started filling root canals with a "hot mass of base plate gutta-percha."[14] However, G.A. Bowman has been credited to be the first to use solely use gutta percha as the root canal filling material.[15]

An important aspect of endodontic treatment is isolation and an aseptic environment. S.C. Barnum was the first to devise a thin rubber sheet that resembles a rubber dam in order to isolate the tooth during the procedure.[17] In 1873, G.A. Bowman was known to also co-invent the rubber dam forceps that help aid in the placement of the rubber dam.[14] All of these innovations allowed a greater acceptance and interest in root canal therapy throughout the late 1890s and early 1900s.

Prior to the 1900s, patients did not have a method for safe and adequate anesthesia while having these procedures completed. In 1836, pain was controlled using arsenic trioxide that would devitalize the pulp prior to treatment.[15] In the late 1880s, Carl Koller introduced the idea of using cocaine as a topical anesthetic agent.[14] In 1905, Einhorn developed Novocain.[18] This paved the way for safe and more effective anesthesia for patients receiving treatment.

The next major advancement in endodontic practice was the discovery of radiographs. Wilhelm Roentgen discovered x-rays in 1895. Edmund Kells took this discovery a step further and placed a lead wire in the root canal when taking a radiograph. Kells did this to measure and to evaluate if the wire fit the length of the canal.[19-21] After 1913, x-ray machines were commercially available, and after 1917, dentists began using radiographs to evaluate endodontic procedures.[19] Radiographic techniques have continued to improve over time, becoming become more effective and reducing exposure times for the patient.

All these advances allowed pain management and endodontic procedures to gain popularity and acceptance. However, in 1910, an English physician by the name of William Hunter questioned the treatment of odontogenic infections. Hunter gave his famous lecture, "*The Role of Sepsis and Antisepsis in Medicine,*" in which he explained the focal infection theory. Hunter attacked American dentistry and stated teeth serve as a focal area of infection where microorganisms are found. He continued to argue that these microorganisms found on teeth were the source of serious systemic diseases.[22,23] This theory remained popular for approximately 25 years, and many patients who were diagnosed to have “pulpless teeth” ended up having extractions to prevent focal infection.[22]

Finally around the 1930s, there began to be a shift in opinion and treatment started to revert back to a more conservative approach. An editorial written in *Dental Cosmos* started that the practice of extracting teeth that have pulpal involvement is irrational and destructive for the patient and should no longer be practice.[22] In 1937 Logan advocated that the presence of bacteria does not simply imply infection. He stated that bacteria are also present in normal tissues without any pathology.[24] In the 1940s, there was adequate research and clinical evidence to prove that pulpless teeth are not the causative factor for systemic disease.[25] This continued to strengthen the acceptance of endodontic treatment as an appropriate treatment of choice.

As more and more practitioners began to accept root canal treatment, it became its own specialty within the field of dentistry. Harry B. Johnston from Atlanta has been acknowledged to have coined the term “endodontics” meaning “within a tooth.” The year 1943 saw the event in which endodontists began a group of 20 men who met in Chicago to form the American Association of Endodontists. In 1946 the first journal dedicated solely to endodontics, *The Journal of Endodontia*, was published.[22] The American Board of Endodontics was established in 1956. By the year 1963, there were more than 200 dentists who limited their practices only to endodontics. In the same year, the American Dental Association (ADA) recognized endodontics as a specialty in the field of dentistry.[22] Since then, the specialty has continued to grow and strengthen.

THEORY OF ENDODONTICS

The most important article that has been published in the endodontic literature is an article written in 1965 by Kakehashi et al.[26] This study provides evidence that the development of any apical periodontitis is due to the presence of bacteria.[26] Several other studies that were completed after 1965 also supported the theory that bacteria are the source necessary for the development and manifestation of apical periodontitis.[27,28] Research completed in the last 10 years has shown that fungi, viruses, and archaea, in addition to bacteria, have been found in endodontic infections.[29-31] Although these other microorganisms have been found in endodontic infections, it has not been proven that they contribute to the development of apical periodontitis.

The main goal of endodontic therapy, as described by Schilder in 1967, is to remove the bacteria present in the root canal system (RCS), eliminating the RCS as the source of infection and inflammation.[32] Schilder proposed that the bacteria could be removed from the RCS by cleaning and shaping the RCS followed by a three-dimensional obturation that would act as a barrier between the RCS and the surrounding tissues.[32] Therefore, the main goal of endodontic treatment is to eliminate and to minimize the bacterial source from within the RCS, aiding in creating a more favorable environment for periradicular tissue healing.[33]

Grossman published an article that states 13 principles that should be followed in order to have a successful result.[34] These principles listed below are still applied to the field of endodontics today.

1. Use an aseptic technique.
2. Confine instruments to within the root canal system.

3. Avoid forcing instruments apically.
4. Biomechanical instrumentation to enlarge the canal space from its original size to ensure proper debris removal.
5. Use irrigation solutions throughout the procedure in order to decrease the amount of microorganisms and remove dentinal debris.
6. Retain irrigation solutions with the canal space to avoid irritation of the periapical tissue.
7. Allow fistula to heal with routine treatment.
8. Ensure a negative culture prior to obturation.
9. Create a complete three-dimensional seal using the obturation material, specifically at the cemento-dentinal junction (CDJ).
10. Avoid using obturation material that is irritating to the periapical tissues.
11. Acute alveolar abscesses should be drained, whether through the tooth or an incision/drainage.
12. Do not inject directly into the area that has an active infection, in order to prevent the spread of microorganisms into deeper tissue.
13. Apical surgery may be necessary to assist in the healing of a pulpless tooth.

Once the root canal therapy has been completed, more often than not, it is recommended for the patient to receive a permanent restoration. In a study completed by Ray and Trope in 1995, the authors concluded that the quality of the coronal restoration is more important than the quality of the endodontic treatment completed.[35] In a systematic review completed by Gillen et al, it was concluded that teeth with apical periodontitis that had an adequate coronal restoration and root canal therapy experienced a significantly higher healing rate than teeth with adequate root canal therapy with inadequate coronal restorations.[36]

SUCCESS RATES OF ENDODONTIC THERAPY

The first question that arises in most patients' minds is the long-term success rate for endodontic treatment. It is a valid question that varies depending on the clinical and radiograph presentation of the tooth. The practitioner should be well educated in the success rates of various treatments (surgical vs. non-surgical) in order to help guide the patient while discussing the endodontic treatment options. Success rates have been well documented throughout the literature. A study done by Lazarski et al. stated the overall success of endodontic treatment has been evaluated using clinical signs and symptoms, radiographic presentation, and histopathologic evaluation of excised tissue.[37] A classic article written by Bender et al. stated the criteria for success was: absence of pain and swelling, disappearance of any sinus tracts, no loss of function, and radiographic evidence of resolved or reduced areas of radiolucency at one-year recall appointments.[38]

A classic study completed, known as the "Washington Study," stated the success rate for both surgical and non-surgical endodontic therapy was 91.4 percent. This study evaluated 1229 cases that had been completed in the mid-1950s.[39] Another study completed by Seltzer et al. has stated the endodontic success rate to be 92 percent when teeth had no periapical radiolucent lesion and 76 percent if there was a periapical radiolucent lesion present.[40] A third classic study was one completed by Grossman et al. that reported a success rate of 89.3 percent for necrotic teeth without periapical radiolucent lesions and 85.7 precent for necrotic teeth with definitive periapical radiolucent lesions.[41] Based on the three studies mentioned above, the possible causes for failure of endodontic treatment could be attributed to: age of the patient, overfilled canal, lack of proper restoration, and pre-existing radiolucency.[39-41]

A very important factor that affects the overall success rate for endodontic treatment is location of the obturation in relation to the apex of the tooth. A more recent study completed by Sjogren et al. in 1990 evaluated the success rates of primary endodontic treatment, specifically in relation to the obturation length.[42] The study noted that, regardless of vitality, the overall success rate for a tooth with no preoperative periapical radiolucency was 96 percent. The success rate decreased to 86 percent if the tooth had a preoperative periapical radiolucency.[42] In regard to the obturation length, if the material was within 0 mm to 2 mm from the apex, the overall success rate was 94 percent. If the obturation material was past the apex, or overfilled, the overall success rate decreased to 76 percent. However, if the obturation material was more than 2 mm from the apex in a tooth with pulpal necrosis and a periapical radiolucency, the success rate decreased to 68 percent.[42]

Another important area of discussion that is usually addressed in regard to overall success rates for endodontic treatment is the number of visits required to complete the treatment. In 2005 a systematic review completed by Sathorn et al. stated that single-visit endodontic treatment was slightly more effective than multiple-visit endodontic treatment.[43] In fact, Sathorn et al. showed that one-visit endodontic treatment had a 6.3 percent higher healing rate compared with multiple-visit endodontic treatment.[43] One major concern with one- versus two -visit endodontic treatment is the amount of pain a patient may experience after treatment, or the incidence of post-operative flare-ups. A clinical study completed by Oliet found that there was no increase in post-operative pain or healing when comparing one- or two-visit endodontic treatment at an 18-month follow- up.[44] Pekruhn stated that one-visit endodontic therapy had a success rate of 94.8 percent, and there was no increase in the incidence of post-operative flare-ups, even in cases with periapical radiolucencies or retreatments.[45] It is important to advise the patient of possible post-operative complications, such as flare-ups. A study completed by Eleazor concluded that there is approximately an 8-percent chance for a flare-up in teeth that undergo multiple-visit endodontic treatment; however, there is only a 3-percent chance for a flare-up in teeth that undergo one-visit endodontic treatment.[46] There is no definitive right or wrong method of treatment in regards to one- vs. multiple-visit endodontic treatment. The practitioner should make an educated decision about which treatment method is the best depending on the case presentation, risks, and benefits.

Although the quality of the endodontic treatment is important in determining the overall long-term success, the quality of the coronal restoration is just as important. As mentioned earlier, an article written by Ray and Trope concluded that the quality of the coronal restoration was significantly more important than the quality of the endodontic treatment.[35] In this study, they had evaluated 1010 endodontically treated teeth via radiographic examination for long-term success.[35] A systemic review by Stavropoulou found that for a 10-year survival rate, endodontically treated teeth that were crowned had a success rate of 81 percent, while teeth with direct restorations such as amalgams and composites had a success rate of only 63 percent.[47]

Failure of endodontic treatment can be due to a variety of reasons. Crump has written an article addressing a differential diagnosis list for endodontic failure. This article summarizes the possibilities of endodontic failure under the acronym POOR

PAST.[48] POOR PAST stands for: Perforation, Obturation, Overfill, Root canal missed, Periodontal disease, Another tooth, Split, Trauma.[48] Once the diagnosis of why the initial root canal failed is made, the practitioner can decide whether non-surgical retreatment, surgical retreatment, or extraction is the best treatment option. The long-term success rate of non-surgical retreatment depends on the initial cause of failure. If it is something the practitioner is able to improve upon, the non-surgical retreatment has the potential for being successful long-term. However, if the practitioner is not able to improve upon the initial endodontic treatment, surgical treatment is considered.

Surgical treatment techniques have improved significantly over the years and that has translated to increased long-term success rates. Testori completed a longitudinal retrospective analysis of success and failure in periradicular surgery and found that there have been significant improvements over the last 10 decades in the techniques that have increased the success rates of surgical therapy.[49] Seltzer completed a meta-analysis comparing contemporary root-end surgery (CRS) and endodontic microsurgery (EMS) and found that EMS has a significantly greater probability for success than CRS.[50] The success rates for CRS was found to be 88 percent while the success rate for EMS was found to be 94 percent.[50] Both non-surgical and surgical endodontic treatment have improved significantly over the years, improving the overall long-term success rates for said treatments. If the patient desires to save the tooth, and if there is completion of adequate endodontic and restorative treatment, the tooth will have a favorable long-term outcome.

ROOT CANAL ANATOMY

Understanding the anatomy of the root canal is the most important concept to know prior to root canal therapy. The goal of endodontic therapy is to adequately clean and shape the root canal system in order to allow the body to heal. One of the most common failures for root canal treatment is the lack of knowledge of the anatomy.[51] Therefore, if the practitioner has a good understanding of root canal anatomy, he or she will be able to locate the canals to clean the root canal system. A root canal system is not a straight, tapering canal with a single foramen at the apex; rather, it is an intricate, complex system with numerous grooves, fins, apical foramina, and deltas.[52]

Numerous studies have evaluated root canal anatomy. G.V. Black has been known to be one of the first to describe the various types of anatomy in his book, *Descriptive Anatomy of Human Teeth*.[53] In 1890 Black described the overall anatomy of the crown and tooth and then continued to describe the anatomy of the pulp chamber and the root canal system. He stated:

> Every tooth has a cavity in the center of the crown, and one or more canals extending through the long axis of the root, or roots, to the apex. This cavity contains a tissue composed of cellular elements imbedded in semi-gelatinous matrix, filling every part of the space, and is richly supplied with blood vessels and nerves. This known as the pulp of the tooth.[53]

Through pictures of serial sections of the tooth, Black illustrated the variety in root canal anatomy.[53] In 1925 Hess was known to have completed a study in which vulcanized rubber was injected into the root canals of teeth. These teeth were decalcified and impressions of the vulcanized rubber canal anatomy were taken.[54] This was a significant study, because it demonstrated that a root canal system were not just a single, smooth-tapered canal, but rather a system of numerous fins, grooves, isthmuses, and irregular canal spaces.[54]

There are two main classification systems to describe root canal anatomy. The first classification system was developed by Weine in 1969.[55] Weine evaluated the mesiobuccal root of 208 first maxillary molar teeth and found the following canal configurations:

- Type I: A single canal from pulp chamber to the apical foramen.
- Type II: Two separate canals at the pulp chamber that merge into one towards the apical foramen.
- Type III: Two canals that remain separate from pulp chamber to two separate apical foramina.

The fourth canal configuration, Type 4, was added at a later time. The Type 4 canal configuration is one canal at the pulp chamber that splits into two canals with separate foramina.[55]

In 1974 Vertucci developed a different root canal anatomy classification system. Vertucci evaluated 200 maxillary second premolars that were decalcified, injected with hematoxalin dye, and cleared.[56]

- Type I: A single canal from pulp chamber to the apical foramen.
- Type II: Two separate canals at the pulp chamber that merge into one towards the apical foramen.
- Type III: One canal that separates into two canals within the root and then merges as one canal with a single apical foramen.

- Type IV: Two canals that remain separate from pulp chamber to two separate apical foramina.
- Type V: One canal at the pulp chamber that separates into two canals within the root and has two separate apical foramina.
- Type VI: Two separate canals that merge into one within the root and then separate again to exit in separate apical foramina.
- Type VII: One canal that divides into two canals that rejoins as one and finally divides as two canals with separate apical foramina.
- Type VIII: Three separate canals from pulp chamber to the apex.

In addition to knowing the Weine and Vertucci root canal anatomy classification, it is important to know the anatomical variations that can occur among the different ethnic groups. The Asian population is more likely to have a fused root with C-shaped anatomy in mandibular second molars.[57] African Americans are two to three times more likely to have more than one canal present in mandibular second premolars.[58] It is important to become familiar with the various root canal configurations prior to accessing the root canal system.

Unfortunately, not every root canal system follows the textbook configurations. Therefore, it is important to be familiar with the rules of the pulp chamber/floor anatomy that have been set by Krasner and Rankow in 2004.[3] This study examined 500 teeth and concluded that the cementoenamel junction (CEJ) is typically the anatomical landmark for the pulp chamber and the location of root canal orifices, known as the law of centricity.[3] The law of concentricity, as mentioned by Krasner and Rankow, stated that the walls of the pulp chamber are concentric with the external walls of the tooth at the level of the CEJ.[3] There are six rules of the pulp chamber floor as described in the study[3]:

- Rule 1. Law of Symmetry 1: The orifices of the canals are equidistant from a line drawn in a mesial to distal direction through the floor of the pulp chamber. This is accurate for all teeth except for maxillary molars.
- Rule 2. Law of Symmetry 2: The orifices of the canals are located on a line that is perpendicular to a line drawn in a mesial to distal direction on the floor of the pulp chamber. This is accurate for all teeth except for maxillary molars.
- Rule 3. Law of Color Change: The color of the floor of the pulp chamber is darker than the walls of the pulp chamber.
- Rule 4. Law of Orifice Location 1: The canal orifices are always located at the junction of the pulp chamber walls and floor.
- Rule 5. Law of Orifice Location 2: The canal orifices are always located at the angles at the pulp chamber floor and wall junction.
- Rule 6: Law of Orifice Location 3: The canal orifices are located at the terminus of the root developmental fusion lines.

Once the root canal system has been accessed, it is important to clean, to shape, and to disinfect the canal to the apex. The apical foramen was extensively investigated by Kuttler in 1955.[51] Kuttler was the first to describe the apical constriction, which is the minor diameter of the canal at which it constricts in the dentin before exiting to the cementum past the cemento-dentinal junction (CDJ). He continued on to mention that the canal widened past the CDJ into a funnel shape, known as the apical foramen.

Therefore, the canal should be cleaned, shaped, and disinfected from the pulp chamber to the apical constriction located at the CDJ.[51]

PRE-ACCESS RADIOGRAPH EVALUATION

In order to clean, to shape and to disinfect the root canal system, access to the root canals should be obtained. Four steps are involved in the cleaning and shaping of the pulp and root canal system: pre-access analysis; removal of the pulp chamber roof; identification of the pulp chamber, floor and canal orifices; and instrumentation of the root canals.[59]

The pre-access analysis involves clinically evaluating the anatomy of the tooth as well as taking pre-operative radiographs. There are two techniques for taking a radiograph: parallel and bisecting angle. The parallel technique, which is also known as the “long-cone” or “right-angle” technique, is the preferred method for obtaining radiographs during endodontic treatment. The sensor is positioned parallel to the long axis of the tooth and the x-ray beam is aligned at a perpendicular, or ninety-degree angle, to the sensor. This allows the clinician to get the most accurate radiographic image of the tooth.[5] The other technique for taking a radiograph is known as the bisecting-angle technique. This technique requires the sensor to be placed directly against the teeth, not being concerned about having it line up with the long axis of the tooth. The x-ray beam will be placed so it is “perpendicular to an imaginary line that bisects the angle between the tooth and the film.” The bisecting angle technique is not recommended due to a high possibility for distortion of the image.[5]

Since a periapical radiograph is attempting to capture a two-dimensional image of a three-dimensional object, it is necessary to take more than one radiograph for diagnostic purposes. According to Brynolf, only taking one periapical radiograph is only 73-percent accurate with one film; however, the diagnosis is 87-percent accurate when three films are taken.[60] With three images (mesial, distal, and straight), the clinician is able to evaluate the number of canals and curvatures. In order to evaluate the angled radiographs, it is important to be familiar with the "same lingual, opposite buccal," also known as the SLOB rule.[61,62] If a mesially shifted radiograph is taken, and the canal or root in question moves more mesial on the image, then it indicates that the root or the canal is located lingual. This allows the clinician to obtain as much information from a radiograph as possible prior to beginning treatment.

ROOT CANAL ACCESS

Once the pre-access analysis is finished, it is time to access and to locate the canals. The conventional access form is one in which the entire roof of the pulp chamber is removed, and straight-line access to the canals, obtained.[63] Straight-line access to the canals is important in assuring that all the canals will be located and that the instruments will be able to clean and shape the root canal system with ease.[64]

Recently, in today's world of conservative and minimally invasive dentistry, the trends are evolving to smaller access preparations. The minimally invasive preparations are advocated in order to help maintain as much natural tooth structure as possible for optimal strength and longevity of the tooth. As Clark and Khademi stated, they wanted to "coronally shift" the focus to the cervical area of the tooth, which would create "awareness for the endorestorative interface."[2] Emphasis is placed on conserving the peri-cervical dentin (PCD). PCD is the dentin near the alveolar crest, specifically at the CEJ of the tooth. There are three factors dictating why maintaining the PCD is important:

ferrule, fracturing, and dentin tubules' orifice proximity from inside to out.[2] The long-term success and retention of the tooth and resistance to fracturing is correlated with the amount of remaining tooth structure.[65]

Unfortunately, not all root canal systems are straightforward. When accessing through teeth that are heavily restored or teeth with full coverage restorations, it can be easy for the clinician to get misguided and disoriented within the tooth. In these scenarios, there is a higher possibility for procedural errors such as coronal or radicular perforations, and separated instruments.[4] In order to minimize such errors, the clinician can utilize the information obtained from a 3-D cone-beam computed tomography (CBCT) image.

3D IMAGING

CBCT images are commonly used in the field of endodontics.[6] CBCT machines have a rotating machine with a fixed x-ray source and detector. Electrons are converted into photons as they pass through a fluorescent shield. This emits a cone-shaped x-ray beam that acquires a 3D image of the area of interest.[66] This 3D rendering provides an image in three different sections: axial, coronal, and sagittal. This allows the clinician to evaluate the anatomy of the tooth and the surrounding structures in a more detailed manner in multiple views. For example, a study completed by Hassan et al. in 2010 concluded that the axial view is best for the detection of vertical root fractures.[67]

There are different types of scan volumes for the CBCT images. The one that is most commonly used in endodontics is known as the limited field of view (FOV). This refers to an image that is taken of a localized area that is 5 cm or less.[66] The other types of scans are single arch (5 cm to 7 cm), inter-arch (7 cm to 10 cm), maxillofacial (10 cm to 15 cm), and craniofacial (greater than 15 cm).[66] These categories may change or vary slightly depending on the machine used. The amount of spatial resolution does increase as the volume of the scan decreases; therefore, the limited field view scans tend to have a higher spatial resolution.[66]

Many times, CBCTs are used to locate calcified canals that tend to be smaller or to evaluate for any periapical pathology. Therefore, the CBCT resolution should be good enough in order to support the ability to locate these canals or notice small changes periapically. Since the best sign of periapical pathology is the widening of a periodontal ligament space (PDL), the resolution of the CBCT image used for endodontics should not be greater than 200 μm, the average width of a PDL space.[66] The Kodak 9000 machine (Carestream Dental, Atlanta, GA) has a voxel size of 0.076 mm. In traditional and digital two-dimensional radiographs, the image consists of pixel; however, the CBCT images consist of voxels, also known as volumetric pixels.[68]

One concern that always comes to every patient's and clinician's mind is the amount of radiation exposure. The amount of radiation dose depends on several factors: the region of the jaw being scanned; the exposure settings of the CBCT scanner; the size of the field of view (FOV), exposure time (s), tube current (mA), and the energy/potential (kV).[69,70] Miliamperage (mA) and time affect the density of the image.[5] If the mA is set too low, there will be more "noise" in the image; on the other hand, if the mA is high, the image quality will improve and the radiation dose increase.[68,71] Kilovoltage (kVp) directly influences the contrast of the image.[5] The higher the kVp setting, the more contrast in the image. This also increases the amount of radiation dose administered to the patient.[69] It is important to make adjustments to the settings in order to reduce the amount of effective radiation dose for the patient.

The radiation exposure is measured in Sieverts (Sv); however, since Sieverts is a large unit, it is usually measured as microSieverts (μSv) in maxillofacial imaging. The annual effective radiation dose is 3000 μSv from background radiation.[72] The amount of radiation exposure varies based on the size of the scan. Limited FOV scans have a lower radiation dose compared to craniofacial scans.[72] Table I shows the effective radiation dose (μSv), comparing CBCT images with digital radiographs.[72-74]

Although the radiation dose for CBCT images is lower or comparable to the digital radiographs, it is important to keep the amount of radiation exposure for the patient as low as reasonably achievable (ALARA).[68] A CBCT image is not required for each case prior to endodontic treatment; however, there are specific indications when the CBCT will provide additional beneficial information. These indications include: detection of apical periodontitis, assessment prior to surgical procedures, evaluation of root canal anatomy, vertical fractures, trauma, and resorption.[68,72] In teeth with calcified canals, the CBCT image can help in determining the location of the canals. Once the canals are located, the information from the CBCT image can be applied to a 3D imaging software.

The Dolphin 3D software is a Digital Imaging and Communications in Medicine (DICOM) viewer that allows visualization and analysis of data produced by CBCT, MRI, etc.[11,75] Currently, 3D software is used in the field of orthodontics for diagnosis and treatment planning.[10] The Dolphin 3D software can be used in the field of endodontics to trace an ideal 3D-canal-directed access path.

MATERIALS AND METHODS

Extracted Teeth: This study used 30 extracted human mandibular premolar teeth. IRB approval for the use of these extracted mandibular premolars was given (study #: 1409147065). A preliminary periapical radiograph of the tooth was taken. Immature teeth or teeth with large pulp chambers and wide canals were excluded. Fifteen premolars were randomly assigned to the TEA group and 15 were assigned to the CDEA group. The teeth were stored individually in a 0.1-percent thymol solution.

Pre-operative CBCT: The extracted premolar was mounted onto a wax occlusal rim and a CBCT image was taken using the Kodak 9000 machine (Carestream Dental, Atlanta, GA). The CBCT settings will be as follows: 6.3 mA, 60 kvP, and .100 voxel. The settings for the CBCT were determined based on a prior study completed at IUSD.[76] A preliminary CBCT image was taken of all 30 extracted premolar teeth.

Dolphin 3D software (version 11.0, Dolphin Imaging, Chatsworth, CA): For teeth in the CDEA group, the CBCT images were imported into Dolphin 3D imaging software to determine and to trace an ideal pathway for establishing a CDEA. The scatter present in the CBCT image was eliminated and a 3D rendering of the tooth was created. The amount of dentin thickness at the CEJ was measured on the Dolphin Software for all 30 teeth, preoperatively. Then, the 3D image of each tooth was converted into stl format. The stl format file was then imported to Rhino 3D V5 software (McNeel North America, Seattle, WA) for designing a custom fit stent "guided access" for each tooth. The dimensions of the guided access stent was 6 mm in height with a 1.7 mm round cylinder pilot hole passing vertically through each stent based on the predetermined access path of each tooth. Then, the virtual 3D data was sent to the 3D printing company (Shapeways, New York) for printing the physical models in the same scale of the natural tooth. The printed guided access stents were used to verify the accuracy of locating the ideal path for each tooth and to investigate if CDEA conserves more tooth structures than TEA.

Access: A TEA was completed in the 15 teeth in the traditional access group. For the teeth in the CDEA group, the 3D stent was used to access the corresponding tooth to evaluate if it indeed led to a "canal-directed" access preparation. A #330 carbide bur was used to initiate the access through the enamel and then a #1 Munce bur was used to complete the access through the dentin to the canal. Once access was achieved, a #10 stainless steel endodontic hand K- file was used to verify access to the canal. A periapical radiograph was taken to confirm that access to the canal was achieved.

CBCT: Once access was achieved in all 30 teeth, the extracted tooth was mounted onto a wax occlusal rim, and a CBCT image was taken using the Kodak 9000 machine (Carestream Dental, Atlanta, GA). The CBCT settings will be as follows: 6.3 mA, 60 kvP, and .100 voxel.

Dolphin 3D software (version 11.0, Dolphin Imaging, Chatsworth, CA): The CBCT image was imported into the Dolphin 3D software. The volume of tooth structure was measured pre- and post-access preparation to compare percentage of tooth structure loss as measured from the CBCT scans between the CDEA and TEA. In addition, the surface area of the root canal access in both CDEA and TEA was measured at the occlusal surface of the crown of the tooth, as viewed in the axial section. The last measurement was the amount of remaining dentin thickness at the level of the CEJ, as viewed in the axial section, to compare both CDEA and TEA. The thinnest portion of the root surface was determined visually based on the image in the axial view. The same location was measured in the pre-operative and post-operative scans to standardize the measurements for comparison. A line was drawn in that area from the canal to the outside surface of the root, and the distance was measured as the amount of remaining dentin thickness.

RELIABILITY TEST

A reliability test was completed with measurements of 10 teeth from the TEA group. The same set of measurements was repeated after two weeks for the same teeth.

STATISTICAL ANALYSIS

A reliability test was completed to compare the two sets of measurements.

The “canal-directed” and traditional access groups will be compared for differences in percent loss of tooth structure volume, the cross-sectional area of access at the occlusal surface, and the amount of remaining dentin thickness at the level of the CEJ using two-sample t-tests. These outcomes have not been previously analyzed. However, in a prior study, the observed differences between traditional and conservative methods for values representing dentin volume removed and the percentage of untouched canal walls showed that the differences among groups were approximately equal to one (1) standard deviation.[77] With a sample size of 15 teeth per group, the study will have 80-percent power to detect a one-standard-deviation difference between the “canal-directed” and traditional access groups, assuming two-sided two-sample t-tests conducted at a 5-percent significance level.

RESULTS

RELIABILITY TEST

All the ICC measurements for the reliability testing were 0.9 or above.

STATISTICAL ANALYSIS

1. Remaining dentin thickness at the CEJ. Pre-post change: The mean remaining dentin thickness for the TEA -0.333 mm and the CDEA was -0.280 mm. This indicates that the amount of tooth structure removed at the CEJ during access preparation was 0.333 mm for the TEA and 0.280 mm for the CDEA. The p-value was 0.6728 ($p > 0.05$).
2. Percent Loss ([Pre-Post]/Pre): The mean percent loss for the TEA was 13.6 percent and the CDEA was 14.2 percent. The p-value was 0.7982 ($p > 0.05$).
3. Surface Area of access preparation at the occlusal surface: Pre-post change: The mean change value for the TEA was 1.693 mm^2 and for the CDEA was 0.920 mm^2.The p-value for surface area change was $p < 0.0001$.
4. Volume. Pre-post change: The mean volume change for the TEA was -13.752 mm^3 and for the CDEA was -7.213 mm^3. This indicates that 13.752 mm^3 of tooth structure was removed in the TEA and 7.213 mm^3 of tooth structure was removed in the CDEA. The p-value for the volume change was 0.0007 ($p < 0.05$).

5. Percent Loss ([Pre-Post]/Pre): The mean percent loss for the TEA was 2.7 percent and for the CDEA was 1.8 percent. The p-value for volume percent loss was 0.0086 ($p < 0.05$).

See Table II through Table IV in the Figures and Tables section for the overall numbers and measurements.

FIGURES AND TABLES

FIGURE 1. Extracted teeth stored in 0.1% thymol.

FIGURE 2. Preoperative periapical radiograph.

FIGURE 3. CBCT image imported into Dolphin software with scatter present.

FIGURE 4. 3D image of tooth once the scatter has been eliminated using the Dolphin software.

FIGURE 5. The amount of dentin thickness at the CEJ was measured in millimeters in the preoperative image using the Dolphin software.

FIGURE 6. STL file imported into Rhino 3D V5 software.

FIGURE 7. The dimensions of the 3D acrylic stent and design are created and fitted onto the tooth

FIGURE 8. Long axis of the tooth is determined.

FIGURE 9. Straight-line access to the canal is mapped out.

FIGURE 10. The 3D acrylic stent is separated from the tooth as two separate pieces to be sent to the 3D printer

FIGURE 11. 3D rendering of the tooth and acrylic stent that shows the occlusal anatomy present on the intaglio surface of the acrylic stent.

FIGURE 12. A periapical radiograph was taken to confirm access (using a #10 hand file) to the canal was achieved.

FIGURE 13. Measurement of surface area of the access at occlusal surface, as viewed in the axial section, using the postoperative CBCT image using the Dolphin software.

FIGURE 14. Measurement of volume of tooth structure using the postoperative image using the Dolphin software.

FIGURE 15. Measurement of remaining dentin thickness at the CEJ, as viewed in the axial section, in the postoperative image using the Dolphin software.

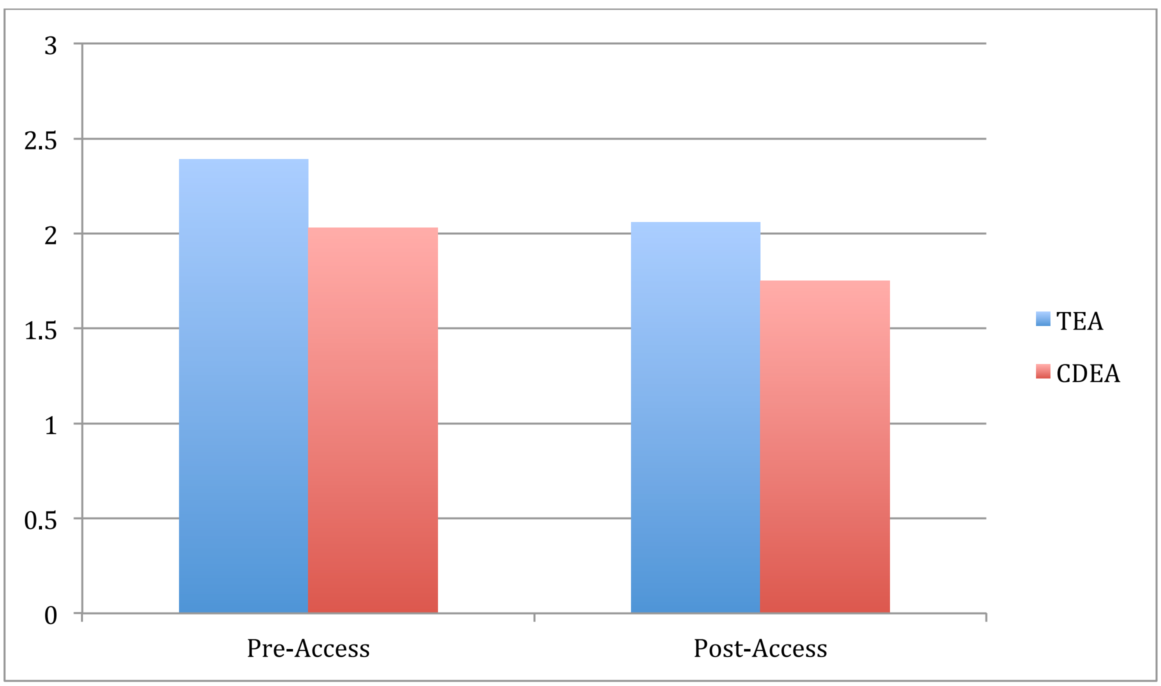

FIGURE 16. Remaining dentin thickness (mm) at CEJ.

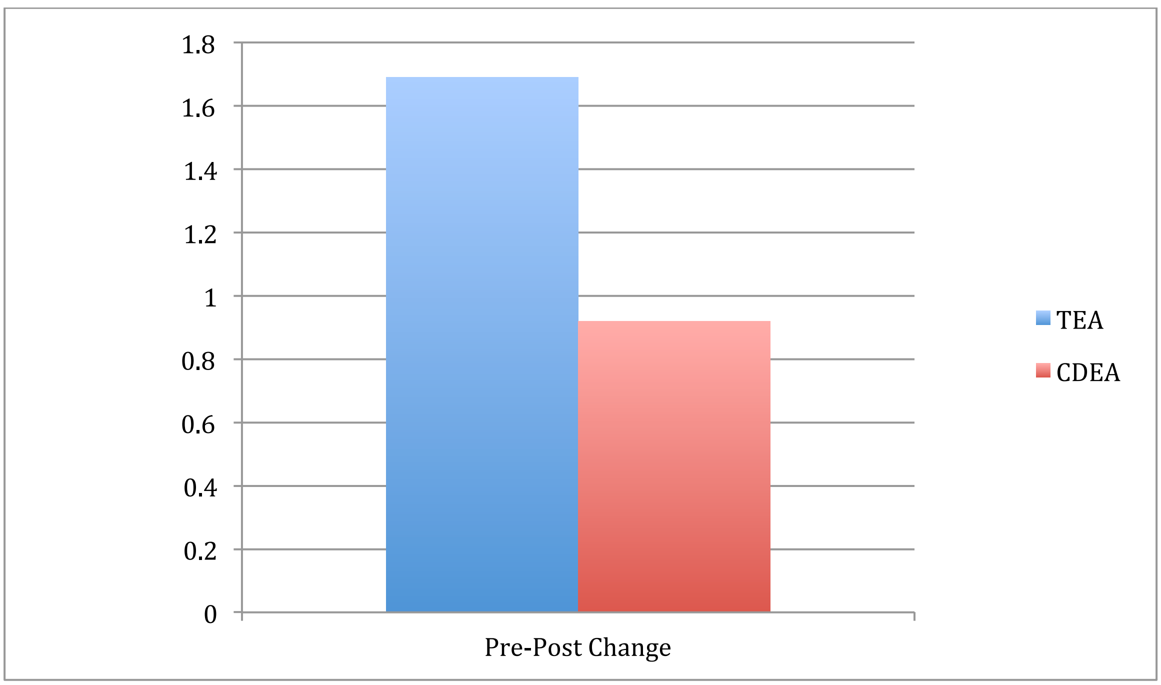

FIGURE 17. Surface area pre-post change (mm^2) between the two groups.

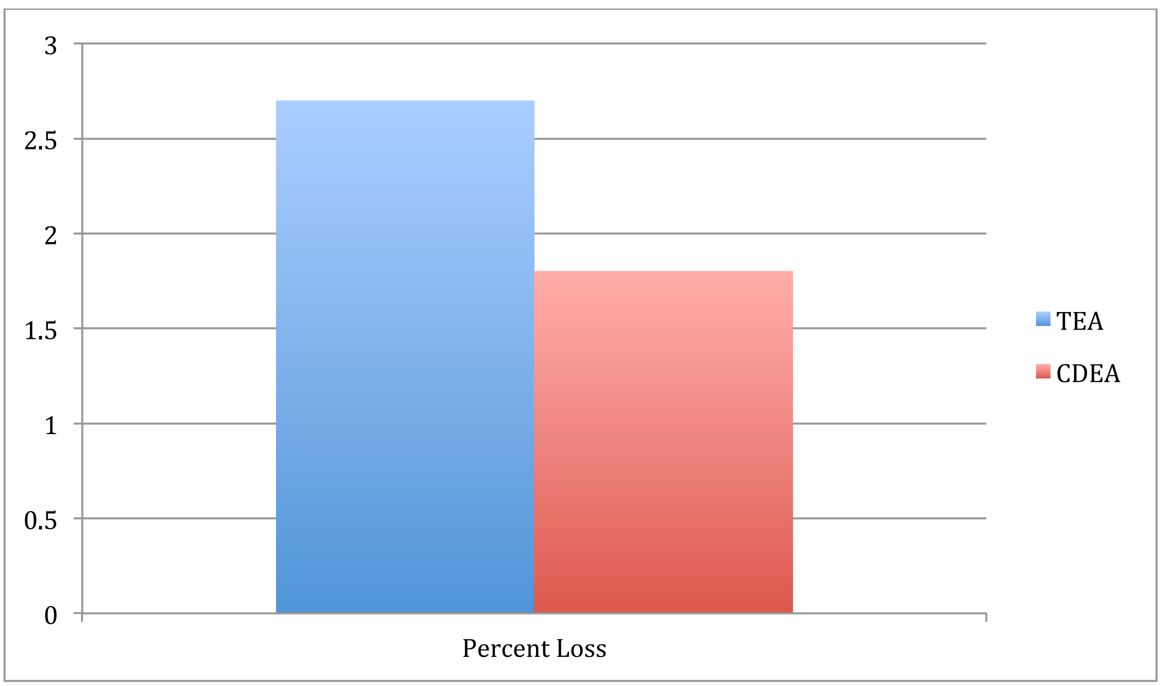

FIGURE 18. Percent loss in volume between the two groups.

TABLE I

Ionizing radiation dosages (approximate)

Activity	Effective Dose (μSv)	Dose as days of equivalent background radiation
1 day background radiation, sea level	7-8	1
1 digital PA radiograph	6	1
4 dental bite-wing radiographs, F-speed film	38	5
FMX; PSP or F-speed film	171	21
Kodak® CBCT focused field, anterior	4.7	0.71
Kodak® CBCT focused field, maxillary posterior	9.8	1.4
Kodak® CBCT focused field, mandibular posterior	38.3	5.47
3D Accuitomo, J. Morita	20	3
NewTom 3G, ImageWorks	68	8
Chest x-ray	170	25
Mammogram	700	106
Medical CT, head	2,000	243
Medical Cat Scan (Spiral CT abdomen)	10,000	1,515
Federal Occupation Safety Limit per Year	50,000	7,575

TABLE II

Summary differences in repeated measurements
(Conventional Access only) – reliability test results

Measurement	Mean (SE)	Minimum	Maximum	p-value	ICC
Remaining Dentin Thickness at CEJ – Pre	-0.03 (0.03)	-0.20	0.10	0.28	0.90
Remaining Dentin Thickness at CEJ – Post	0.04 (0.03)	-0.10	0.20	0.17	0.92
Surface Area – Pre	--	0.00	0.00	--	--
Surface Area – Post	0.01 (0.03)	-0.20	0.10	0.76	0.94
Volume – Pre	0.25 (1.17)	-4.66	8.90	0.84	1.00
Volume – Post	0.28 (0.85)	-2.98	5.23	0.75	1.00

TABLE III

Mean, SE, minimum and maximum for outcomes, by group

Outcome	Group	Mean	SE	Minimum	Maximum
Remaining Dentin Thickness at CEJ (Pre)	CDEA	2.033	0.049	1.80	2.40
	TEA	2.393	0.050	2.10	2.70
Remaining Dentin Thickness at CEJ (Post)	CDEA	1.753	0.099	0.80	2.40
	TEA	2.060	0.060	1.60	2.40
Remaining Dentin Thickness at CEJ (Post-Pre Change)	CDEA	-0.280	0.072	-1.20	0.00
	TEA	-0.333	0.068	-0.90	-0.10
Remaining Dentin Thickness at CEJ (Percent Loss: [Pre-Post]/Pre)	CDEA	14.2	3.6	0.00	60.0
	TEA	13.6	2.6	4.0	33.0
Surface Area (Pre)	CDEA	0.000	0.000	0.00	0.00
	TEA	0.000	0.000	0.00	0.00
Surface Area (Post)	CDEA	0.920	0.074	0.60	1.60
	TEA	1.693	0.106	0.90	2.60
Surface Area (Post-Pre Change)	CDEA	0.920	0.074	0.60	1.60
	TEA	1.693	0.106	0.90	2.60
Volume (Pre)	CDEA	422.183	21.310	333.85	601.88
	TEA	494.955	15.893	373.31	579.36
Volume (Post)	CDEA	414.971	21.291	326.04	596.10
	TEA	481.203	15.035	369.67	561.99
Volume (Post-Pre Change)	CDEA	-7.213	0.690	-14.59	-4.09
	TEA	-13.752	1.782	-27.92	-3.64
Volume (Percent Loss: [Pre-Post]/Pre)	CDEA	1.8	0.2	1.0	3.0
	TEA	2.7	0.3	1.0	6.0

TABLE IV

P-value for the outcomes

Outcome	p-value
Remaining Dentin Thickness at CEJ (Pre)	<0.0001
Remaining Dentin Thickness at CEJ (Post)	0.0116
Remaining Dentin Change (Change)	0.6728
Remaining Dentin Thickness (Percent Loss)	0.7982
Surface Area (Pre)	--
Surface Area (Post)	<0.0001
Surface Area Change (Change)	<0.0001
Volume (Pre)	0.0113
Volume (Post)	0.0113
Volume Change (Change)	0.0007
Volume (Percent Loss)	0.0086

DISCUSSION

One objective of the study was to determine if the use of 3D imaging with the CBCT, Dolphin 3D, and Rhino 3D V5 software is an accurate method for determining a CDEA. In this study, the canal was determined by using the stent in all 15 teeth that were accessed. This shows that the use of the 3D imaging in fact led to a direct endodontic access preparation. The use of 3D imaging and stents is a common practice in many fields of dentistry, particularly in regard to implants. In many cases, the surgeon will have a stent designed based on the exact location and angulation that will help guide during implant placement. The stent is designed based on CBCT images that provide the three-dimensional views necessary to determine the best location for the implant.[78] This practice that can be applied to the field of endodontics.

The second objective of the study was to determine if more tooth structure was conserved with a CDEA than with a TEA. There was a statistically significant difference between the surface area of the access preparation at the occlusal surface between CDEA and TEA ($p < 0.0001$). This indicates that the clinician is more likely to remove more tooth structure while searching for the canal rather than creating a direct straight-line access to the canal. In most cases, it is difficult for the clinician to know the exact location on the occlusal surface that will lead to a direct access preparation to the canal. It is likely that the clinician will begin by preparing an ideal access shape outline on the occlusal surface. With the CDEA, the clinician does not have to prepare an ideal access shape in order to locate the canals; instead, the process for access preparation is reversed. First, the canal is located with the help of the stent, and then, the access preparation is opened to an ideal shape that will unroof the pulp chamber and horns. With the guidance of the stent, the clinician will eliminate the removal of unnecessary tooth structure outside of the dimensions of the pulp chamber that may result in gouging or even perforation.

The results of the study showed that there was a statistically significant difference between the percent loss of volume between the CDEA and TEA ($p = 0.0086$). CDEA percent volume loss was 1.8 percent while the TEA percent volume loss was 2.7 percent. As shown in the study completed by Krishan et al., the volume of tooth structure removed is an important and accurate method for evaluating the amount of tooth structure that was removed during treatment.[77] The volume of tooth structure removed in the TEA was 50-percent greater than in the CDEA.

The last measurement that was evaluated in this study was the percent loss of the dentin thickness remaining at the CEJ. There was not a statistically significant difference between the CDEA and TEA groups ($p = 7.982$). This may be due to the burs and process used for access preparation in this study. The access preparation was started with a #330 bur that was only used through the enamel. The #1 munce bur was used to drill through the dentin. This consistent method for access preparation throughout the study eliminated the variability of dentin removal at the CEJ between the TEA and CDEA. The pericervical dentin, the dentin present at the CEJ, is very important to conserve and maintain. If the pericervical dentin is weakened by excessive removal of tooth structure, it can compromise the long-term success, and then the tooth may be more prone to fracture.[2]

One limitation and improvement for this current study is in regard to the measurement methods for the remaining dentin thickness at the CEJ. The investigator visually determined, as seen on an axial surface, the area that had the thinnest area of dentin. Although there was an attempt to standardize the measurements by evaluating the same location in the pre- and post-access scans for the corresponding teeth, the location may not have been standardized between all 30 teeth in the study. It may have been a more accurate comparison if the measurements were taken in four different areas – buccal, lingual, mesial, distal – based on the long axis of the tooth.

This study proposes a new and innovative idea for the application of three-dimensional imaging that can be applied to the field of endodontics. The majority of teeth that require endodontic therapy have had multiple large restorations and full coverage crowns. These teeth tend to have more calcified chambers and canals that can be difficult to locate. Teeth with full coverage restorations can also misguide the clinician because the angulation and size of the crown may not be an accurate representation of the angulation and the size of the root. Although there are many rules of anatomy and methods to follow to help to locate canals, it is easy to be misguided when drilling inside the tooth.

Another application for the use of guided access in endodontics is for teeth with anatomical anomalies. Here is a case report of treatment completed on a dens invaginatus where a CBCT was taken to help determine the relationship of the RCS to the invagination. A 3D plastic model was printed that allowed the clinician to plan the correct plane, depth, and direction of access.[8] These more unique cases are the ones in which the use of 3D imaging and stents will be applicable for clinicians. It is not efficient for the clinician to order a CBCT and to design a stent to assist in access preparations for the routine endodontic cases.

The use of stents to help guide the clinician in locating the canal is a new method in endodontics; however, it is a very common method in other fields, specifically implant placement. It is important to note that the main purpose of the stent will be to assist the clinician in locating the calcified canal, while minimizing the amount of tooth structure that is removed. Once the canal is located, the stent should be removed, and it will be crucial to unroof the pulp chamber and to remove the tissue present within the chamber to adequately clean and shape the root canal system.

This study serves as a preliminary study to evaluate the various three-dimensional imaging programs and the accuracy in determining a CDEA. Future studies can evaluate the ideal design and development of a stent that can be used in a clinical setting. Once the stent design has been evaluated, the same study design of three-dimensional imaging and stent fabrication should be applied in a clinical situation to evaluate the accuracy of the guided access. The use of three-dimensional imaging and guided access preparations could be a monumental advancement in the field of endodontics.

SUMMARY AND CONCLUSIONS

The use of the CBCT and Dolphin 3D imaging provided an accurate and more conservative CDEA with the guide of an acrylic stent. The null hypothesis was rejected as statistically significant differences were present in the amount of tooth structure removed between the two groups, as measured by the surface area of the access preparation at the occlusal surface, and the percent of volume loss of tooth structure. Although there was no statistically significant difference in the amount of remaining dentin at the CEJ, it can be concluded that the use of the stent with a CDEA did not result in the removal of more tooth structure at the CEJ in comparison with the TEA.

This new method of locating canals and guided access preparations could potentially provide a significant improvement in endodontic procedures. There are a significant number of patients who have calcified canals and chambers where this method of "guided access" could be applied. The clinician will be able to search for calcified canals with more confidence that the access preparation is removing the minimal amount of tooth structure necessary. Dentistry is moving to the use of more conservative and minimally invasive techniques; this new method for locating canals and the use of guided access preparations will help practitioners perform endodontic therapy while following minimally invasive techniques.

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ABSTRACT

EVALUATING THE USE OF 3D IMAGING IN CREATING A CANAL-DIRECTED ENDODONTIC ACCESS

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Introduction: During root canal treatment (RCT), an opening is made through the crown of the tooth to access and to disinfect the root canal system (RCS). Traditional endodontic access (TEA) may sacrifice tooth structure and weaken the tooth. Cone beam computed tomography (CBCT) provides information about the exact location of the root canals. This information can be used for the design of a canal-directed endodontic access (CDEA). It may also be used for the 3D printing of an acrylic endodontic stent that could help to create a conservative CDEA.

Objective: 1) Evaluate the ability of the Dolphin 3D imaging software to assist in creating a CDEA; 2) Compare tooth structure loss in a CDEA to that in a TEA by measuring the volume of remaining tooth structure, surface area of the access opening at the occlusal, and remaining dentin thickness at the CEJ.

Materials and Methods: Thirty extracted human mandibular premolars were used. Teeth with large, wide canals were excluded. CBCT images will be taken for all teeth using Kodak 9000. Fifteen teeth were randomly assigned to the TEA group and 15 teeth were assigned to the CDEA group. The CDEA path was mapped using Dolphin 3D imaging software. Acrylic access stents were designed using Rhino 3D software and printed using a 3D printer. The teeth were accessed through the corresponding stents. The 15 teeth that are part of the traditional access group were accessed without a stent. A CBCT scan was taken post-access for all 30 teeth. Wilcoxon Rank Sum Tests were performed to compare the following outcomes for the two groups: the volume of remaining tooth structure, the surface area of the access opening at the occlusal, and remaining dentin thickness at the CEJ.

Results: The remaining dentin thickness (percent loss) was not significantly larger for TEA than for CDEA. The surface area (post-treatment) was significantly larger for TEA than for CDEA, and volume (percent loss) was significantly larger for TEA than for CDEA.

Conclusion: The use of the CBCT and Dolphin 3D imaging provided an accurate and more conservative CDEA with the guide of an acrylic stent.

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