Accuracy of Cone-Beam Computed Tomography (CBCT) in Determining Root Canal Working Length

BY

BRYAN ESLINGER

B.S., Purdue University, West Lafayette, 2003

D.D.S., Indiana University, Indianapolis, 2008

THESIS

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Defense Committee:

Bradford R. Johnson, Advisor
Mohamed Fayad
Ellen BeGole

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LIST OF ABBREVIATIONS

ALARA	As low as reasonably possible
3D	Three-dimensional
AAE	American Academy of Endodontics
B	Buccal
CBCT	Cone-Beam Computed Tomography
CBVT	Cone-Beam Volumetric Tomograph
CCD	Charged-coupled devices
CDJ	Cemento-Dentinal Junction
CDR	Computed Dental Radiography
CT	Computed Tomography
DB `	Disto-buccal
DICOM	Digital Imaging and Communications in Medicine
DL	Disto-lingual
EAL	Electronic apex locator
IRB	Institutional Review Board
L	Lingual
MB	Mesio-buccal
ML	Mesio-lingual
mm	millimeter
P	Palatal
PA	Periapical
Sig.	Significance
SPSS	Statistical Package for the Social Sciences

Summary

Working length determination is a key element to root canal therapy. Current techniques to determine working length include using apex locators and periapical films. A new technology, cone-beam volumetric tomography (CBVT), has been validated for accurate measurements with the root canal system. However, few studies have been done to assess its use in determining working length.

A retrospective study was done in order to determine whether the CBVT imaging was as accurate as other accepted techniques. There were four groups measured: CBVT coronal, CBVT sagittal, periapical (PA), and conventional groups, which used an apex locator. These groups were assessed against the control group in this study which was the conventional group. The data suggested that the periapical group measurements may have been least accurate but it did not reach statistical significance.

1. INTRODUCTION

1.1 Background on Working Length Determination

When a clinician is performing a root canal procedure, there are certain key elements that aid in achieving a successful outcome. Besides diagnosis and anesthesia, the first key element is isolation with a rubber dam. Once isolated, accessing the pulp, which includes the neural and vascular supply for the tooth, is critical in order to locate the canals of each root. Shortly after locating these canals, the working length must be determined to achieve the best prognosis for the tooth being treated.

Working length determination is a key aspect of endodontic treatment. The American Association of Endodontists' Glossary of Endodontic Terms (2003) states: "working length is the distance from a coronal reference point to the point at which canal preparation and obturation should terminate" (AAE, 2012). What does this mean though? The point at which the preparation and obturation should terminate is not well-defined. There are some different schools of thought regarding where the canal preparation and obturation should terminate. Some experts claim that the radiographic apex is where this reference point should be located. (Schilder, 2006). Some argue that the CDJ should be used for this termination point. Others claim that the major foramen allows for the best healing apically. The working length is used in order to determine the proper length of obturation, and seal off the canals to prevent re-infection. If the proper length is not reached, failure may result. If the length is too long, the obturating material may act as a constant source of inflammation and irritation due to the obturating material acting as a foreign body. Thus, it is important to have accurate methods of determining working length. There are many methods that have a high accuracy of approximately 90 percent and above. However, no method leads to 100% accuracy in working length determination or a successful outcome in endodontics.

One method of determining working length is referred to in this study as the conventional method. The conventional method is determined through using an apex locator, which has a high accuracy. Measurements are typically taken from a coronal reference point to a point at which the apex locator reads 0.5 on the display. Another way of using an apex locator is using the point at which the electronic apex locator reads "out" of the apex and subtracting 0.5-1 mm. For this study, the former technique of establishing patency and taking the measurement from the 0.5 on the display was used. Obturating and sealing a root canal to within 0-2 mm. from the radiographic apex has been shown to result in a favorable outcome more frequently than overextension beyond the apex or filling greater than 2 mm short of the apex (Ricucci and Langeland 1998). The clinician's judgment also plays a large role in this method as there may be multiple apical constrictions (Dummer et al., 1984).

Another method called the PA method in this study includes the use of radiographic images. A preoperative radiograph is taken to prejudge where the measurement of the working length should be located. After accessing the canal, files and gutta-percha points are used to confirm the length radiographically. Following the procedure, another radiograph should be taken, which indicates the location of the length at which the root canal was filled and sealed. The angulation at which the radiograph is taken may be different between the preoperative film and subsequent films, and the lengths can be altered, which can affect the outcome. The distortion and magnification of the periapical films can also play roles in the lengths being different from the preoperative film and subsequent films.

One method that has not been investigated to a large degree for accuracy in working length measurement is the use of a newer three-dimensional CBVT (cone-beam volumetric tomography) imaging technology, which in this study will be known as the CBVT coronal and sagittal method. CBVT has been validated by Michetti et al. (2010), to allow for exploring root canal anatomy and has high accuracy. There are three views with this new technology: coronal, sagittal, and axial. The axial view does not offer much information regarding the length of each canal but it does indicate the number of canals present and the location of each canal. The coronal view and sagittal view are valuable because they provide different dimensions of the tooth.

1.2 **Significance**

Many clinicians use a combination of various methods over the years for determining working length of the canals. The main methods used include electronic apex locators and periapical radiography to confirm the lengths used during root canal procedures. Other methods that are used include tactile sense and use of paper points. In this study, it was important to separate the combination of techniques to allow for comparison between the conventional method of using an electronic apex locator and the PA method in which periapical radiography is mainly used. With all of these techniques, there is room for improvement. Both periapical radiography and electronic apex locators can be inaccurate. When a combination of techniques is used, it is more likely that the measurement for working length is reliable and consistent. It also may lead to a higher accuracy.

The CBVT imaging technology has been investigated for many applications in endodontics. However, it has not been thoroughly evaluated for its use in determining the working length. CBVT has some important features that may make it a more valuable adjunct than two-dimensional imaging such as eliminating noise from other anatomical structures viewed on two-dimensional radiographs. However, it has not been evaluated for its accuracy in determining working length measurements. Periapical radiographic methods and electronic apex locator methods have been evaluated for accuracy, and these methods have been deemed reliable enough, and they are used by clinicians regularly in root canal therapy (Haffner et al., 2005).

1.3 **Specific Aims**

Working length is important for the success of root canal procedures. The goal of this study is to evaluate the accuracy of CBVT imaging in determining root canal working length measurement. In this evaluation, analysis of the data will be done to show if there are any differences worth noting qualitatively by comparing the measurements in the CBVT coronal, CBVT sagittal, and PA groups. For example, the data will be reviewed, and considered inaccurate if any of the CBVT coronal, CBVT sagittal, and PA group measurements differ more than 0.5 mm in either direction from the conventional group measurements.

1.4 **Hypotheses**

The null hypothesis is that there is no difference in working length determination among the conventional, periapical, CBVT coronal, and CBVT sagittal groups.

2. REVIEW OF LITERATURE

Many methods of determining the ideal working length have been proposed, including the use of radiologic imaging, electronic devices, and clinician's judgment. However, there are different schools of thought on where the apical termination of instrumentation and obturation of the root canal system should be located.

2.1 **<u>How should working length be determined?</u>**

One such school of thought involves using the length in which the smallest diameter in the apical region is present from a reference point on the tooth. Weine agreed with Kuttler's study (1955) which identified a smaller diameter or 'apical constriction' as the point where the canal preparation should end and where the deposition of calcified tissue is most desirable (Ricucci and Langeland, 1998). If this point could be determined clinically, it would theoretically lead to smaller wounds and better healing as long as microorganisms were completely removed through root canal therapy. Unfortunately, no technique exists to determine where the apical constriction is located 100% of the time.

Another school of thought states that instrumentation and obturation should end at the CDJ. Weine (1982) suggested instrumentation to the CDJ, which he believed was located at the same level as the apical constriction (Riccuci, 1998). It is believed that instrumentation and obturation to the apical constriction will lead to the smallest wound possible, and thus, more predictable healing can occur. Additionally, Ingle (1973) agreed that the narrowest diameter of the apical foramen was located at the CDJ, which was usually found about 0.5 mm from the external surface of the root (Ricucci and Langeland, 1998). However, the CDJ is a histologic structure which cannot be found clinically, and it is not uniform throughout the entire root canal system. For instance, on the mesial aspect of a canal, the CDJ could be located 2 mm. from the minor foramen whereas it may only be 1 mm. from the minor foramen of the distal aspect of the same canal. Importantly, termination at the CDJ is not practical. First, the junction is not where most practitioners believe it is located. Not only can the CDJ be located in variable places throughout the canals but it cannot be found clinically in any case (Ricucci and Langeland, 1998).

Other schools of thought suggest that the working length should end at the foramen which is clinically distinct from the apical constriction or CDJ. The foramen is a portal of exit for the canal in which the vast amounts of vascular and neural tissue enter the tooth. It would make logical sense that this reference point should be used for determining working length as it is the end of the root canal system. Currently, the closest instrument that can measure the foramen is the electronic apex locator, which also is not 100% accurate. The measurement given by the electronic apex locator is the best “gold standard” to compare accuracy of measurements clinically available without histologically sectioning a tooth to determine the lengths (Haffner et al., 2005).

2.2 **Working length determination between 0-2 mm. from the radiographic apex**

There is a large amount of evidence (Ricucci and Langeland, 1998) to support the clinical practice of determining working length to within 2 mm of the radiographic apex to achieve successful outcomes, which is clinically relevant because it can be measured. Epidemiological studies have reported that the best prognosis is obtained when the root filling lies within 2 mm of the radiographic apex (94%) (Sjogren et al., 1990). By contrast, in cases with excess root filling the success rate decreased to 76% (Sjogren et al., 1990). An in vivo histological study found that the most favorable histological outcome was when the instrumentation and obturation remained short of the apical constriction (Ricucci and Langeland, 1998). When working length is properly maintained through instrumentation and filling of the canals, there is a greater likelihood of success. There are a number of ways to determine working length. Traditional methods for establishing working length have been (a) the use of anatomical averages and knowledge of anatomy, (b) tactile sensation, (c) moisture on a paper point and (d) radiography (Gordon and Chandler, 2004).

2.3 **Working length determination using anatomical averages**

Using the anatomical averages of root canal lengths to the radiographic apex is a valuable adjunct in determining working length. However, each tooth has unique anatomy, and the average values alone will cause many canals to be under- or over-extended if anatomical averages were used as the sole means of determining working length. Therefore, other methods may provide for more successful outcomes by being more dependent on individually assessing each tooth.

2.4 **Working length determination using tactile sensation and using moisture on a paper point**

Tactile sensation has its limitations. Seidberg et al. (1975) found that experienced clinicians could only locate the apical constriction about 60% of the time by tactile sensation. Stabholz et al. (1995) found that preflaring of the root canal significantly increased the ability to determine the apical constriction by tactile sensation about 75% of the time. While this is a valuable tool in working length determination, it is far from ideal.

Moisture on a paper point is an indicator of root canal length. The moisture or a bleeding spot may indicate that the working length is overextended beyond the canal. Bleeding or moisture coming into the canal may cause a prudent clinician to underestimate the length, too. For instance, if a paper point shows moisture that is consistently 3 mm on the paper point, the clinician may misjudge that he or she is 3 mm beyond the apical constriction. Once the length is verified, the clinician may be surprised that bleeding from pressure outside of the canal in the bone may cause the clinician to be 3 mm. short. Additionally, moisture on a paper point has a wicking action which will make its use somewhat inaccurate and inconsistent. While this technique may be used as a valuable adjunct, a more consistent primary method is required.

2.5 **Working length determination using periapical radiography**

Radiography has allowed the dental practitioner to visualize and adjust the working length if it appears to be over- or under-extended. It has been used widely for confirming working length. However, this is an indirect measurement, because angulation, distortion, and other factors may interfere with accurate interpretation. Many studies have shown that canal lengths determined radiographically vary from actual root canal lengths by a considerable amount (Kuttler, 1955; Kuttler, 1958; Green, 1956; Green, 1960; Dummer et al., 1984; Forsberg, 1987a, b; Martinez-Lozano et al., 2001). Traditional and digital radiography are two-dimensional representations of the three-dimensional structure of the tooth. It does not indicate curvature or other anatomical complexity in the root canal system. If the major foramen deviates in the lingual or buccal plane, it is difficult to locate its position using radiographs alone, even with multiplane angles (Schaeffer et al., 2005). Secondly, anatomical structures can obscure this measurement. Dense bone and anatomical structures can make the visualization of root canal files impossible by obscuring the apex (Gordon and Chandler, 2004). The superimposition of the zygomatic arch has been shown to interfere radiographically with 20% of maxillary first molar apices and 42% of second molar apices (Tamse et al., 1980). Magnification and distortion of images is also a factor in determining the working length as different angulations will lead to wide differences in measurement. ElAyouti et al. (2001) found that using radiographic working length calculations alone led to instrumentation beyond the apical foramen in 56% of premolars and 33% of molars. Also, using radiographic length calculations is not as accurate as desired. A study was done by Williams et al. (2005) comparing the difference between the in vivo working length established by viewing a periapical radiograph and the in vitro measurement from the file tip to the apical foramen of the extracted tooth. They concluded that when the file is short it is actually closer to the apical foramen than it appears radiographically; when it is long it is actually longer than it appears radiographically.

2.6 **Working length determination using electronic apex locators**

A more state of the art technique is the use of electronic apex locators. ElAyouti et al. (2002) found that the use of the Root ZX decreased overestimation of working length of the premolar group to 21%. One widely used apex locator is the Root ZX. The Root ZX has been exhaustively studied for accuracy in working length determination in many clinical conditions. Shabahang et al. (1996) tested accuracy in vivo with irrigants and found 96% accuracy (± 0.5 mm) when compared to the extracted tooth. Even when teeth are necrotic or vital, the accuracy of the Root ZX is still high. A study testing the accuracy of the Root ZX in vital versus necrotic teeth in vivo when compared to the extracted tooth length exhibited 82% accuracy (± 0.5 mm) (Dunlap et al., 1998). Overall, modern EAL offered a reliable method for endodontic working length determination (Haffner et al., 2005). The function of apex locators was consistent in 85% of the patient's teeth (ElAyouti et al., 2009). Having a working length that is between 0-2 mm from the radiographic apex leads to more successful outcomes (Ricucci and Langeland, 1998). Modern apex locators can determine the working length with accuracies of greater than 90% but still have some limitations. (Shabahang et al., 1996).

Some limitations include inaccurate readings due to inflammation. Intact vital tissue, inflammatory exudates and blood can conduct electric current and cause inaccurate readings so their presence should be minimized before accepting apex readings (Trope et al., 1985). Other conductors may include metallic restorations, caries, saliva, and instruments in a second canal, which may all lead to inaccuracies in working length determination.

2.7 **How does CBVT work?**

"Cone Beam Computed Tomography (CBCT) is a diagnostic imaging modality that provides high-quality, accurate three-dimensional (3D) representations of the osseous elements of the maxillofacial skeleton. CBCT systems are available that provide small field of view images at low dose with sufficient spatial resolution for applications in endodontic diagnosis, treatment guidance, and posttreatment evaluation" (Scarfe et al., 2009).

CBVT imaging is a rotational imaging technique in which an x-ray source and detector are fixed. During rotation of the x-ray source apparatus, radiation is released and read by a sensor multiple times at specified time intervals. This imaging technology differs from a traditional medical CT, which uses a fan-shaped x-ray beam in a helical progression to capture an image. (Scarfe and Farman, 2008).

Computer technology has progressed since the 1990s to allow for the computational complexity necessary to make CBVT technology a practical alternative to conventional films. Two things made this possible: development of a quick chemical detector that can re-load to take up another image quickly and improvements in the algorithms to the CBVT technology. The four components of CBVT image production are (1) acquisition configuration, (2) image detection, (3) image reconstruction, and (4) image display. (Scarfe and Farman, 2008).

The acquisition phase takes place as an x-ray source releases photons that are detected by an image detecting device while in reciprocation around a patient's head (Scarfe et al., 2009). The x-ray source is taken multiple times while it is moving to capture different angles of the desired object.

The image is read by a detecting device. There are two different groups of CBVT units based on the detector type. One is an image intensifier tube/charge-couple device combination or a flat-panel detector (Scarfe and Farman, 2008). The flat-panel detector provides for a better performance than the II/CCD technology (Scarfe and Farman, 2008).

The reconstruction process consists of two stages, each comprised of numerous steps. Raw images require systematic offset and gain calibration and a correction of defect pixels or "defect interpolation." These calibration steps are referred to as "detector processing." The systemic offset and gain calibration and defect interpolation are computed by the software of the manufacturers. These steps are necessary to create a better image. The images then are related to each other and assembled. Reconstruction algorithms are then used to complete the two-dimensional slice. Once the computational effects are finished, the image is loaded on to a screen.

The image display is what the clinician sees on the screen. Typically, there are three views: axial, sagittal, and coronal displayed to the clinician. These images can also be adjusted with software to manipulate the scans and visualize the three-dimensional image of the object.

2.8 **Working length determination using CBVT imaging**

CBVT may improve the determination of the number of canals present and working length determination. Potential applications in endodontics of CBVT scans include diagnosis and evaluation of most aspects of endodontic treatment, such as determination of the configuration and length of the root canal, presence of accessory canals (Nair and Nair, 2007). Some endodontists are employing this technology to aid in preoperative working length measurement. It is of interest to determine if CBVT imaging is as accurate as digital imaging at determining the working length. One such CBVT device, the Kodak 9000 3D appears to be a very interesting, reliable, noninvasive, measuring tool. The CBVT unit with the highest resolution and the smallest field of view (KODAK 9000 3D) involves patient radiation exposure varying from as little as 0.4 to 2.7 digital panoramic equivalents depending on the part of the mouth studied (Scarfe and Farman, 2008). The Kodak 9000 3D has been evaluated for accuracy of extracted teeth validating it as a valuable tool in endodontics to explore root canal anatomy (Michetti et al., 2010). Comparison of the measurements showed the cone beam measurements to be slightly smaller than the measurements obtained through indirectly measuring an extracted tooth by 2.85% for the area and 2.81% for the Feret diameter (Michetti et al., 2010).

Feret's diameter defines the longest distance between 2 parallel straight lines that are tangents to the shape.

The main limitation to CBVT is that the spatial resolution is inferior to that of conventional two-dimensional films. The number of line base pairs is much lower for any CBVT unit on the market when compared to most two-dimensional films. Possible issues with a CBVT can arise from patient-based artifacts such as patient movement or the presence of metallic materials in or on the patient, scanner based artifacts, and image reconstruction artifacts caused by helical and multisectional technique artifacts. Three factors in the acquisition process inherently limit contrast resolution: (1) scattered radiation contributing to the potential for increased noise, (2) CBVT systems pronounced "heel effect" due to the divergence of the X-ray beam over the area detector producing nonuniformity of the incident X-ray beam, and (3) detector imperfections affecting linearity in response to x-radiation (Scarfe and Farman, 2008). The types of artifacts that can occur are as follows: (a) streaking, which is generally due to an inconsistency in a single measurement; (b) shading, which is due to a group of channels or views deviating gradually from the true measurement; (c) rings, which are due to errors in an individual detector calibration; and (d) distortion, which is due to helical reconstruction (Barrett and Keat., 2004). However, the accuracy in all three dimensions and elimination of anatomic noise is a huge benefit of CBVT, and may be superior to two-dimensional images for specific situations.

Some of these problems with CBVT can be corrected, and others are out of the clinician's control. The software of the CBVT scanners contains built-in features to aid in producing a better image. The areas within the clinician's control may include limiting voluntary movement by using positioning aids on the scanner itself. Using as short of a scan time as possible also may minimize artifacts when scanning regions prone to movement. The optimum selection of scan parameters can create a better image. Periodic maintenance of the scanner will also keep the images at a high quality.

3. METHODOLOGY

3.1 **Study Design**

A retrospective analysis was performed on clinical treatment records (CBVT scans, digital radiography, and measurements from the electronic determination devices) at a private practice. An experienced practitioner has taken limited CBVT scans (Kodak 9000 3D, Carestream, Rochester, NY) on most patients he has treated since 2008. The experienced endodontist has also taken a preoperative and postoperative radiograph (CDR DICOM 4.5, Schick, Long Island City, NY). He also has recorded the working length as determined from the electronic determination device (Root ZX, J Morita, Irvine, CA) in a software program (Endovision, American Fork, UT) while using his best clinical judgment.

The sample included fourteen human teeth of varying types, and they were randomly selected. The number of canals for which lengths were taken was forty. The sample was generated by a random number sequence from a list of all patients treated between February 1, 2009 and February 1, 2011.

A. Inclusion Criteria

1. Patients treated between February 1, 2009 and February 1, 2011.
2. Working length data recorded in the Endovision software program.
3. Presence of a diagnostic quality radiograph along with a diagnostic quality CBVT image to allow measurements to be taken from the images already present.

B. Exclusion criteria

1. Any CBVT scan or digital radiograph without any part of the tooth being investigated were excluded because they were not of diagnostic quality and measurements would be inaccurate.
2. Teeth with temporary crowns were excluded because they may have been removed during the procedure, therefore altering canal length measurement during the treatment process.
3. Presence of a restoration that could produce scatter on the CBVT images. The main reason for excluding these cases is because the scatter may create difficulty in the determining where to measure the canals.
4. Previously treated teeth as the filling in the canals also produces scatter, which may affect the measurements.

3.2 <u>**Materials and Methods**</u>

A. CBVT

The records were reviewed to determine diagnostic quality of the CBVT. It was evaluated according to the inclusion/exclusion criteria. The axial planes were reviewed to determine how many canals were present along with which canals were present, which was then recorded in a spreadsheet program (Microsoft Excel, Microsoft, Seattle, WA). CBVT records were aligned parallel to the long axis of the root measured and a scrolling tool was used to locate the maximum length of each root in both the coronal and sagittal sections of the CBVT image. The measurements of the different roots and/or canals were taken through use of the Kodak software measurement tool. The lengths were determined by measuring from the cusp tips to the radiographic apex after scrolling through to find this maximum length. This information (length associated with the canals that were measured) was recorded into a spreadsheet program (Microsoft excel). No identifiable information was seen by the primary investigator through the process. The private practitioner loaded the records on a screen which did not show any protected health information (the chart number which could be seen on the screen was covered with a card prior to accessing any of the information). The information being sought does not require any identifiable information. The following figure shows an example of how the measurements were taken from the images. This figure allowed the measurements of #15 MB root and DB root from the cusp tip as indicated by the green circle to the radiographic apex indicated by the green circle. The measurements are to the left and were recorded from these images to the Excel spreadsheet.

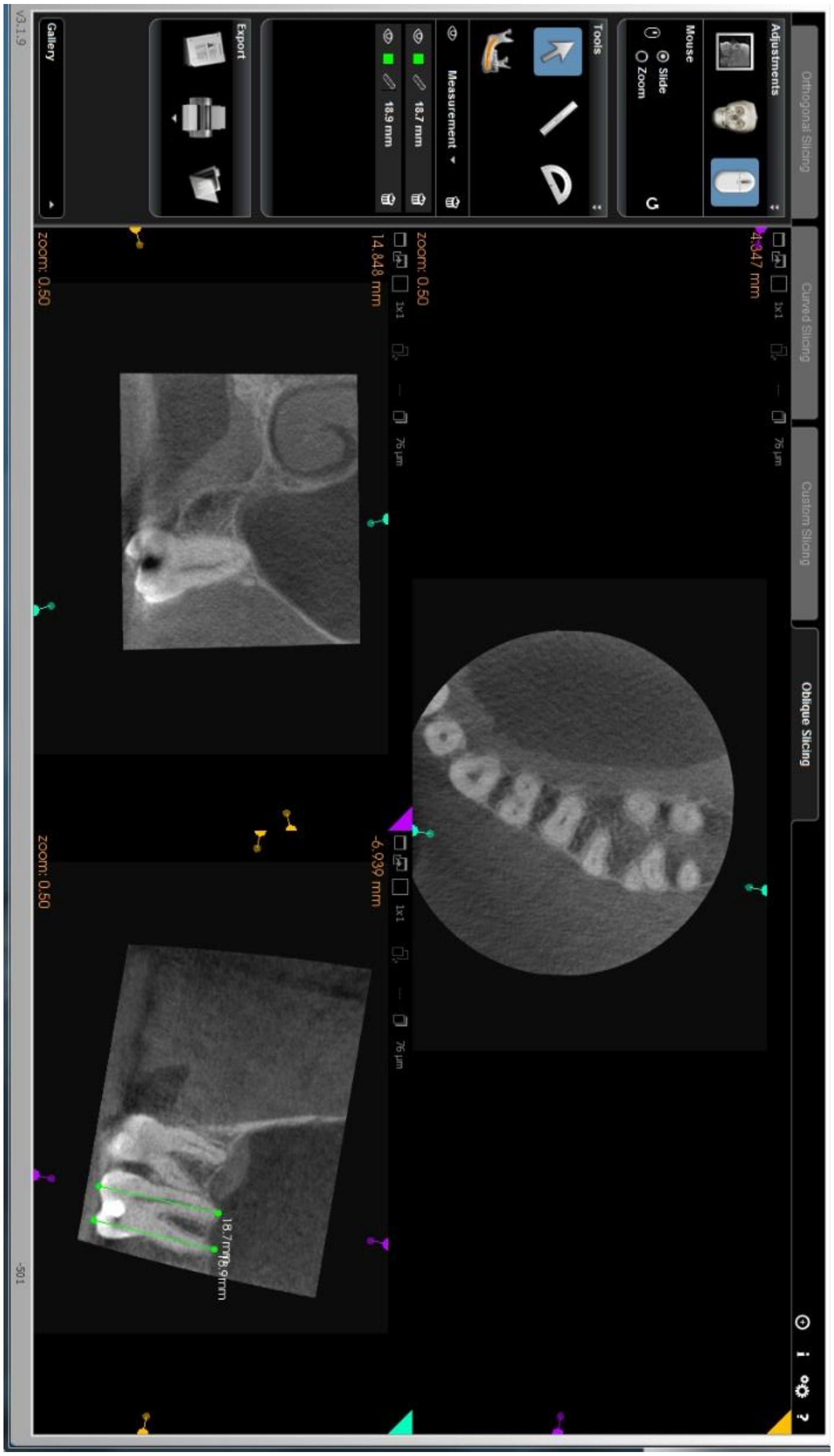

Figure 1-Example of how working lengths were taken on CBVT scans

B. PA

The records were loaded using the Schick software to determine diagnostic quality of the film. Records were evaluated according to the inclusion/exclusion criteria. The film was then evaluated for the number and location of the canals that could be seen. The measurements of the different roots and/or canals were taken through use of the Schick software measurement tool. The lengths were determined by measuring from the cusp tips to the radiographic apex. For example, the mesio-buccal cusp tip was used for the MB root. The lengths were then recorded in a spreadsheet indicating the tooth, canal, and measurement (Microsoft Excel).

C. Electronic apex locator

The measurements of the CBVT and PA radiographs were viewed and recorded for each of the canals prior to viewing the records on Endovision. The numbers were copied verbally by the private practitioner from the Endovision software into an Excel spreadsheet by the primary investigator. No identifiable information was recorded.

3.3 **Statistical Analysis**

Statistical analysis was done using a statistical program (SPSS, Version 19, Chicago, IL). Prior to running any of the tests, a qualitative assessment was done on the data to understand and describe the data set.

Paired samples t-tests were done for comparison between the groups to evaluate the data with $p<0.05$. There were two groups of CBVT measurements (coronal vs. sagittal). Therefore, 6 different comparisons were done. These include: CBVT coronal vs. CBVT sagittal, CBVT coronal vs. PA, CBVT coronal vs. conventional, CBVT sagittal vs. PA, CBVT sagittal vs. conventional, and PA vs. conventional groupings. The level of significance was set at alpha = 0.05.

3.4 **IRB Approval**

IRB approval was granted by the graduate college at University of Illinois-Chicago. Exemption was granted for this study. The research protocol number is #2011-0795.

4. RESULTS

4.1 **Results**

The data demonstrate some interesting findings. Based on looking at the data as an overview, there is some variation in measurements. To evaluate the amount of variation, one method chosen was to see the amount and percentage outside of the acceptable range for accuracy. In this study, we chose the conventional group as the "gold standard." An acceptable variation for accuracy was set at ±0.5 mm from the conventional group measurement. On the following page is a table of the collected data.

TABLE I

WORKING LENGTH MEASUREMENTS (IN MM)

Tooth number	canal	CBVT coronal (mm)	CBVT sagittal (mm)	PA (mm)	Conventional (mm)
14	MB	18.7	18.4	18.2	19
14	DB	20.8	20.5	18.6	20
14	P	21.1	21.4	24	21
24	Only one	19.6	19.5	20.3	19
5	B	23.2	23.2	24	22
5	L	22.7	23	23	22
3	MB	18.8	18.6	18.1	18
3	DB	17.5	17.3	17	18
3	P	18.3	18.2	20.6	19
3	MB	21.4	21.9	21.2	22
3	DB	22.2	19.6	21	21
3	P	20.4	21.3	24.8	22
30	MB	19.8	19.4	19.9	18
30	ML	17.9	18	19.9	18.5
30	D	18.2	17.9	18.8	18.5
19	MB	18.1	18.5	17.6	18
19	ML	18.2	18.3	18.3	18
19	DB	18.1	18.7	18.8	18
19	DL	19.5	18.4	18.8	18
19	MB	17.2	17.6	17.2	17
19	ML	17.5	17	16.6	17
19	D	17.8	18.6	17.6	17
8	One canal	24.5	25.3	26.4	21.5
19	MB	20.2	19.8	20.5	20
19	ML	18.5	19.4	20.5	20
19	D	19.9	19.5	20	20
30	MB	21.7	22.5	21.9	22
30	ML	22.1	21.2	21.9	23
30	DB	23.4	21.8	22.9	22
30	DL	21.7	22.5	22.9	22
3	MB	20.1	20	17.4	20
3	DB	19.1	19.7	17	21
3	P	22.2	22.5	25.8	23
3	MB	21	20.1	18.5	19
3	DB	20.4	20.2	18.2	20
3	P	23.5	23	25	22
30	MB	21.8	22.2	21.7	22
30	ML	22.3	21.9	21.7	22
30	DB	21	20.4	20.7	20
30	DL	20.9	21.5	20.7	20

Based on the data in Table I, there were a number of findings. When comparing the CBVT coronal group vs. the conventional group, 23/40 CBVT coronal measurements or 57.5% were either longer or shorter than the conventional group measurement by ±0.5 mm. The data were separated into the measurements that were more than and less than 0.5 mm from the conventional group measurement. The CBVT coronal measurements were longer than the conventional group measurements in 15/40 measurements or 37.5%. The CBVT coronal measurements were shorter than the conventional group measurements in 8/40 measurements or 20%.

When comparing the CBVT sagittal group vs. the conventional group, 20/40 CBVT sagittal group measurements or 50.0% were either longer or shorter than the conventional group measurement by ±0.5 mm. The data were separated into the measurements that were more than and less than 0.5 mm from the conventional group measurement. The CBVT sagittal measurements were longer than the conventional group measurements in 11/40 measurements or 27.5%. The CBVT coronal measurements were shorter than the conventional group measurements in 9/40 measurements or 22.5%.

When comparing the PA group vs. the conventional group, 26/40 PA group measurements or 65.0% were either longer or shorter than the conventional group measurement by ±0.5 mm. The data were separated into the measurements that were more than and less than 0.5 mm from the conventional group measurement. The PA group measurements were longer than the conventional group measurements in 18/40 measurements or 45.0%. The PA measurements were shorter than the conventional group measurements in 8/40 measurements or 20.0%.

TABLE II

PERCENTAGE OF ACCURACY

	Accurate	Inaccurate
CBVT coronal	42.5%	57.5%
CBVT sagittal	50%	50%
PA	35%	65%

The periapical group has a slightly higher percentage of inaccurate readings when compared to the CBVT coronal and sagittal groups.

TABLE III

THE PERCENTAGES OF LONG VS. SHORT READINGS

	Longer	Shorter
CBVT coronal	37.5%	20%
CBVT sagittal	27.5%	22.5%
PA	45%	20%

When comparing the percentages of the experimental groups vs. the conventional group in terms of being longer more than 0.5 mm, the periapical group had the highest percentage of inaccuracies followed by the CBVT coronal groups, and the CBVT sagittal group had the fewest long inaccurate measurements.

The CBVT coronal, CBVT sagittal, and PA groups are shorter by more than 0.5 mm than the conventional groups in similar percentages.

TABLE IV

PAIRED SAMPLES CORRELATIONS

Paired Samples Correlations			
		Correlation	Sig.
Pair 1	CBVT coronal & CBVT sagittal	.931	.000
Pair 2	CBVT coronal & PA	.804	.000
Pair 3	CBVT coronal & conventional	.857	.000
Pair 4	CBVT sagittal & PA	.845	.000
Pair 5	CBVT sagittal & conventional	.865	.000
Pair 6	PA & conventional	.793	.000

Correlations were computed for the pairs of groups. Table IV indicates that there is a relationship among all of these pairs of groups. It is statistically significant at a level of $p<.001$ so that all of the six pairs are highly related.

TABLE V

PAIRED SAMPLES T-TEST

Paired Samples t-test					
		Mean	Std. dev.	t	p
Pair 1	CBVT coronal-sagittal	0.07	0.72	0.57	0.57
Pair 2	CBVT coronal-PA	-0.17	1.56	-0.67	0.51
Pair 3	CBVT coronal-conventional	0.27	1.01	1.71	0.10
Pair 4	CBVT sagittal-PA	-0.23	1.43	-1.02	0.31
Pair 5	CBVT sagittal-conventional	0.21	0.98	1.34	0.19
Pair 6	PA-conventional	0.44	1.62	1.77	0.10

These tests were done to determine if there was a difference between each group in terms of accuracy. A difference may indicate that one of the groups may not be accurate in determining the working length measurements. For all groups tested, there was no significant difference at $p<0.05$. The null hypothesis is accepted that no differences exist based on this statistic.

5. DISCUSSION

5.1 Discussion

The conventional group was determined as the gold standard because it has a high accuracy for determining working length. While there could potentially be some experimenter bias, studies that use apex locators to find the working length, cement the file in place, extract the tooth and locate the file in the root canal are the most pertinent studies for clinical practice (Haffner et al., 2005). A study done by Shabahang et al. (1996) which was trying to evaluate the Root ZX and confirm where the file was located histologically showed a high accuracy in locating the apical foramen. In Shabahang's study, the Root ZX was used to locate the apical foramen and a file was cemented at the length where the Root ZX read 0.5. The Root ZX located exactly the apical foramen in 17 canals (65.4%), was short in 1 canal (3.8%), and was overextended in 8 canals (30.8%).

The goal of this research was to determine if CBVT imaging could be used as a valuable adjunct in working length determination during endodontic procedures based on accuracy within ±0.5 mm of the conventional group measurements. This ±0.5 measurement variation was considered acceptable given the criteria that CBVT images are usually smaller by ~3% (Michetti et al., 2010). Based on the results, there are no statistical differences among the groups when compared to the conventional group measurements in working length determination. From a clinical perspective, since endodontics has a high degree of success with the current techniques, it would lend support that CBVT imaging does not provide an extra benefit to patients in having a more accurate measurement than current techniques in working length determination. It may cause more harm than good because a patient experiences more radiation when having a CBVT scan done than a periapical film. It is more expensive for a CBVT scan than a periapical film. The CBVT is not as quick of an imaging methodology as obtaining a periapical film. Therefore, the quantitative statistical analysis supports that our current techniques are adequate in working length determination.

However, when assessing the individual data and assessing each individual experimental group measurement compared to the conventional group measurement, it offers a slightly different perspective, which is more pertinent to the clinician. When accuracy is determined by ±0.5 mm from the conventional group measurement, it was shown that the periapical group measurements were the least accurate at 35%. The CBVT coronal group was the second most accurate at 42.5%, and the CBVT group measurements were 50% accurate.

These results may not be statistically significant. However, these data demonstrate that the periapical group may be less accurate than the CBVT coronal and sagittal groups in the accuracy of working length determination.

When assessing the data individually for the percentage of the experimental groups which were longer than the conventional groups, it demonstrated that there was a higher frequency of the periapical group measurements being longer than the conventional group measurements. The periapical group measurements were longer than the conventional group measurements 45% of the time. In the CBVT coronal group, the percentage of these measurements being longer than the conventional group was less at 37.5%. The CBVT sagittal group measurements were longer the most infrequently when compared to the conventional group measurements at 27.5%.

The percentage of the experimental groups measurements (CBVT coronal, CBVT sagittal, and PA) being shorter when compared to the conventional group measurements were lower in frequency than the longer inaccurate measurements. In the CBVT coronal group, this frequency was 20%. In the CBVT sagittal group, this frequency was 22.5%. In the periapical film group, this percentage was 20%. These lower percentages were expected as the conventional group measurements were attempting to stay within the canal and short of the radiographic apex. A study done by Caldwell (1976) was done to determine the effect of instrumentation on the working length. Each canal was measured before and after instrumentation. What they found was that those canals having the greatest curvature demonstrated the largest decreases in working length. Some of the teeth used in this study had some curvatures associated with their roots.

These results may be explained due to the curvatures and other variable anatomy that are present in the root canal system. The electronic apex locator measurements may have a longer way to go due to the apical foramen exiting at a curvature near the end of the root. It is highly likely to occur in many teeth and could skew the electronic apex locator measurements. These measurements may be longer than measurements that are just taken from the cusp tip or incisal edge from the radiographic apex. The distortion that is present with periapical films may have also played a role. It is well known that when a file appears short on the periapical film, it is much closer to the apical foramen than it appears radiographically (Williams et al., 2005). The periapical radiographs may have been longer based on angulation that the films were taken because this technique was not standardized.

The measurements during the study were taken from the cusp tip to the radiographic apex. This method of measurement was chosen because it is a more consistent method for comparison than using something such as the major foramen which would be difficult to determine clinically. Unfortunately, the CDJ, portal of exit, and apical constriction cannot usually be seen on a traditional radiograph or CBVT imaging. Also, there has been no method developed that can reliably determine the CDJ or apical constriction (Martinez-Lozano et al., 2001). Therefore, the best results were determined by using the radiographic apex in this study.

A recent pilot study by Janner et al. (2011) evaluated the utility and precision of already existing limited cone-beam computed tomography scans in measuring working length, and to compare it with standard clinical procedures. In this study, 3 patients (9 teeth or 10 canals) were evaluated for the length from the incisal edge to the major foramen prior to the initiation of root canal therapy. This measurement was then compared to the length obtained with an electronic apex locator. The basic conclusion this study had was that a strong correlation was found between the endodontic working length as measured in the CBVT images and the EAL measurements. They also stated their viewpoint that an already available CBVT scan can be used in combination with clinical measurements such as the EAL.

While this pilot study and the present study have much in common, there are many differences. The basic conclusion is that the CBVT group is similar to an electronic apex locator group in measuring the working lengths. They did not correlate whether periapical imaging would also be similar as in the present study. There were very few canals (n=10) in this pilot study which could have skewed results. The majority of the teeth had one canal, and the teeth included had straight teeth such as incisors, canines, and premolars. In the present study, any tooth qualified with curved roots and multiple roots. It would be interesting to see how these results would have differed if it had been done in with teeth with much more variability.

The measurements were taken from the incisal edge to the major foramen. However, it is difficult to be able to determine exactly where the major foramen is located as this is a histologic structure that can vary throughout the walls of the root canal. Also, the “apex” mark described in the methodology of the electronic apex locator was defined as the major foramen when in fact it is likely measuring an apical constriction.

There are many similarities to these studies as well. The teeth were reoriented to get the most accurate measurement from the CBVT scan as possible. The measurement line was placed in the center of the pulpal cavity and followed each visible canal deviation to get accurate measurements. The basic conclusion that no difference existed among the apex locator group in their study and the CBVT group measurement in determining accuracy of working lengths supporting this study's findings. Both studies came to a similar finding from different statistical analyses. Both studies had relatively few teeth included and could be improved by larger prospective trials.

This same group of researchers has another article waiting to be published, which was accessed online. The goal of their prospective, controlled clinical study was to analyze endodontic working length measurements in preexisting cone-beam volumetric tomography (CBVT) (Jeger et al., 2012). The patients included in this study also had a CBVT scan taken independent of the need of root canal therapy of anterior teeth visible in the field of view. The measurements were taken in a similar manner with an evaluator determining the working length from the CBVT scan prior to initiation of root canal therapy twice for reliability. A separate endodontist recorded the electronic apex locator measurements while performing root canal therapy. Forty anterior teeth were included. What they found was that this prospective, controlled clinical study showed that limited CBVT scans can be used for endodontic working length measurements.

This study differed from the current study in that the teeth included were only anterior teeth, which does not show the true picture of all teeth in determining working length with CBVT. Molars have much more variation and curvature making it more difficult to measure and more difficult to get the canals in one plane to allow for their measurement technique. Also, the measurements were taken from the incisal edge to the major foramen, which is a histologic structure difficult to measure on a CBVT reliably.

Some strong aspects in this study included trying to obtain the most accurate measurements as possible by vertically positioning the tooth in the CBVT scans prior to measurement, having a separate examiner of the CBVT than the person obtaining the electronic apex locator measurements, and having the CBVT scan evaluator do it again one week later for determining an intrarater reliability measurement, which was high.

There are concerns about the amount of ionizing radiation a patient receives with different imaging modalities. The goal of this study was to determine if CBVT imaging was as accurate as other methods in determining working length. However, it is important to keep the ALARA principle in mind when prescribing CBVT imaging. One advantage of CBVT is that it has much less radiation than a regular CT scan. However, there is more radiation with CBVT than a periapical film. The findings in this study indicate that the CBVT coronal and sagittal groups demonstrate no difference with the conventional group. The amount of radiation in a CBVT may be doing more harm than good for the patient.

5.2 **Limitations of the study**

There are some limitations to this study. For instance, fourteen teeth were evaluated and only forty measurements. The power of this study could have been increased with more samples. Results of the present study may not have shown a difference when indeed there may be a difference between some of these groups, which could be related to not having enough samples.

This study was retrospective in nature. A prospective study would have led to a stronger level of evidence. A prospective study could have controlled for more variables during the course of treatment. For instance, the study could have had more evaluators, which could also show the variation in measurements. The inclusion and exclusion criteria tried to minimize any possible experimental error related to having this study as a retrospective study.

With a prospective study, histologic controls may have been a possibility. It could have been beneficial in a prospective study to include a histological group which is the best control in determining the actual lengths through sectioning of the tooth. However, studies have been done to verify the validity of using a CBVT image to explore root canal anatomy from the Kodak 9000 machine used and comparing it to digitized images of a tooth. The study found that most CBVT images have a slightly smaller measurement when compared to digital photo measurements by approximately 3% (Michetti et al., 2010). The CBVT was validated in this study to explore the accuracy of this three-dimensional imaging (Michetti et al., 2010).

Related to the study design, the measurements were somewhat variable in all groups. The measurements could have differed quite a bit depending on the reference point in which the measurements were taken. For instance, on a periapical film, a cusp tip on a mandibular molar could either be a lingual cusp or a buccal cusp. On a CBVT image, it was sometimes difficult to figure out exactly where the radiographic apex was located due to some curvature. In a few of the periapical images, the same measurement was used for two separate canals in one root just because they were not separated in an angled film, which could have affected results. Thus, the maximum value found was used between each specific cusp as well as each radiographic apex in both CBVT imaging and periapical film modalities. These reference points were found slowly by aligning the images to make each canal visible for measurement and using a scroll bar on the mouse to maximize length and accuracy in this study. There was only one person making these measurements, however, which could limit the variability in how the measurements were taken.

Despite the results, it is this clinician's viewpoint that the methods of PA, CBVT coronal, CBVT sagittal, and conventional are equivalent in determining the working length. It is well known that apex locators, and especially the Root ZX, are highly accurate in reading when the file is outside of the tooth. However, periapical films are subject to magnification and distortion. What the CBVT imaging allows is a very accurate measurement, which can be within less than 3% of the actual measurements (Michetti et al., 2010). Also, it is this clinician's viewpoint that the CBVT may offer other benefits in determining working length not evaluated in this study. One such benefit is removing the anatomical noise allowing the clinician to locate the radiographic apex more easily on a CBVT scan. For instace, a zygomtic process on maxillary molars and external oblique ridge on mandibular molars make it challenging to measure the working lengths on periapical films. It would be best to use a preoperative CBVT imaging in conjunction with an apex locator. While not statistically significant, the CBVT offers many advantages that the periapical film does not such as viewing the tooth in multiple dimensions. However, the prudent clinician must decide when to prescribe CBVT imaging because limiting radiation is of paramount importance.

5.3 **Future Research**

Future research could be done prospectively using histologic sections. It would be valuable to use histologic sections after performing a root canal in a human study postmortem or in an animal study to determine the most ideal length for successful outcomes. The prior methods could be used prior to histologic sectioning, which may show the most ideal length required.

A study could be done to prospectively evaluate whether the use of CBVT leads to a more successful outcome. CBVT imaging could be done to aid in attaining a preoperative measurement. These measurements could be adjusted based on current conventional techniques. The patient's teeth then could be followed up to determine the outcome of the endodontic treatment and compared to a group that did not use CBVT imaging.

Another study that may be of value is to evaluate the different methods of working length determination and follow the prospective outcomes given the different diagnoses. It may offer some insight on what reference points should be used for the different diagnosis and whether there is a lesion on a CBVT.

6. CONCLUSION

The purpose of this study was to evaluate how accurately the newer CBVT imaging would be when compared to some older methods of working length determination. Four groups were evaluated: CBVT coronal group, CBVT saggital, PA, and conventional groups. Measurements were taken in order to determine if there were any differences in the measurements using these different methods on the same teeth. Statistical analysis was performed. The findings indicated that there was no statistical difference between the four groups in comparing them pairwise. This data lends support that using CBVT imaging is as accurate as other methods in determining working length. However, it may not add extra benefit for the patient.

A further analysis was done on the percentages of inaccurate readings and percentages on the ±0.5 mm short or long groupings. The data suggest that the periapical film has the worst accuracy but it did not reach statistical significance.

There may be other potential benefits to the use of the CBVT imaging that have not been realized yet. However, this study lends support that CBVT imaging is an accurate and valuable adjunct in determining working length.

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VITA

Dr. Bryan Eslinger

EDUCATION

University of Illinois Chicago Chicago, IL July 2010-current

Indiana School of Dentistry Indianapolis, IN July 2004-May 2008

D.D.S.

- Dean's Silver award-Awarded to graduates who received a 90+ score on National Dental Board part 1

Purdue University West Lafayette, IN August 1999-May 2003

B.S., General Health Sciences with minors in Biology, Chemistry, Psychology and Sociology

- Freshman Scholar Student- selected for this scholarship based on academic achievement which involved an in depth exploration of an area of interest, investigated Parkinson's Disease and served as a standardized patient for Indiana University School of Medicine
- Golden Key member- honors organization based on academic achievement which recognizes the top 15% of students in their class

RESEARCH

Biochemistry Laboratory, Purdue University August 2002-June 2003

- Primary investigator, Jean Chmielewski, Phd.
- Synthesized amino acids for peptide synthesis and tested for membrane activity

EXPERIENCE

May 2010-July 2010	Independent contractor with Staffcare
Dec 2008-Feb 2010	Associate Dentist with Aspen Dental
May 2007-May 2008	Laboratory Assistant, Indiana Dental School
July 2006-September 2006	Head and Neck Anatomy Teaching Assistant, Indiana Dental School
July 2002-June 2003	Volunteer, Chapin Street Medical and Dental Clinic

LEADERSHIP

- Health Science Ambassador- recruited prospective students to Purdue University and specifically the school of Health Sciences.
- Boiler Gold Rush team leader- selected to lead a group of incoming Freshmen during their orientation

PROFESSIONAL AFFILIATIONS

- American Dental Association, Indiana Dental Association, IDDS, AAE

ACTIVITIES/INTERESTS

Enjoy football and most sports, exercising, real estate investing, boating, movies, traveling, trying new foods, and good conversation