Comparison of reliability of an endodontic three dimensional and CBCT softwares to measure working length of root canals

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A Research Report submitted to the Department of Prosthodontics, School of Oral Health Sciences, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa in partial fulfilment of the requirements for the degree of MDent in Prosthodontics.

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DEDICATION

I dedicate my research report to my family. A special feeling of gratitude goes to my loving parents, Muhamed and Saleha whose words of encouragement and push for tenacity ring in my ears. My wife Muneerah who supported me throughout my journey with this research report. I dedicate this work and give special appreciation to my brothers and sisters for being there for me throughout the entire study programme. I devote this piece of work to my beloved son Muhammad and my adorable daughter Shefaa. I dedicate my work to my beloved country Libya.

DECLARATION

I, Ahmed Muhamed Abdualhafid, declare that this research report is my own work. It has been submitted for the degree of Master of Dentistry in Prosthodontics in the Faculty of Health Sciences at the University of the Witwatersrand, Parktown, Johannesburg, South Africa. It has not been submitted before for any other degree or examination at this or any other University.

……Ahmed Abdualhafid ……

This 02_day of October 2020

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ABSTRACT

Purpose

The purpose of this study was to evaluate reliability of the 3D Endodontic Software (3-D endo) and conventional CBCT software in accurately determining the preoperative working lengths of root canals, when compared to conventional linear measurement.

Materials and Methods:

A periapical radiograph of each of 30 preselected teeth was acquired, the teeth were mounted in an artificial bone block and a CBCT scan was acquired. Working length measurements for each tooth were obtained using conventional CBCT and 3D endo softwares, as well as linear measurements using endo files and digital calliper. For each method the measurements were repeated. Test-retest reliability was assessed for each method. The Bland Altman analyses were used to compare both CBCT and 3D endo with linear measurements to determine their limits of agreement and whether these were clinically relevant.

Results

Both readings for each method were found to be reliable (>0.9). The Bland-Altman analyses determined the limits of agreement to range between 0.13 mm and 0.25 for linear and CBCT measurements, and between -0.14mm and 0.12 mm for linear and 3D-Endo measurements, with 95% of the values residing within this range for both analyses.

Conclusion

The margin of error for both methods compared to linear measurement translated to between -140 µm and 250µm of canal length. Clinically, this is far less than the critical margin of error for termination of canal obturation (≤ 2mm short of radiographic apex). This study suggests that CBCT and 3D-Endo softwares are reliable methods for determining working length in endodontic treatment. The limits of agreement for linear vs. CBCT measurements were higher

than those for linear vs. 3D endo measurements. The mean difference of the latter was closer to zero. This suggests that the 3D endo method could be more accurate than CBCT.

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NOMENCLATURE

2 D: Two dimensional

3D Endo: 3D endo software

3D: Three dimensional

CBCT: Cone Beam Computed Tomography

CDJ: Cementodentinal junction

CT-Computed Tomography

EAL: Electronic apex locators

FOV: Field of fox

MB2: Mesiobuccal Canal

WL: Working length

CHAPTER 1. INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

In the practice of endodontics, the treatment outcome for a tooth with necrotic pulp and periapical radiolucency is affected by several elements, for instance, the presence or absence of a preoperative periapical pathosis, proper removal of necrotic tissue and irritating materials from the root canal system to the apical terminus, coronal restoration, periodontal status of the tooth and clinician skills (Sjogren et al, 1990; Alley et al, 2004; Ng et al, 2011). The shaping and obturation of the root canal system to the exact working length is a key determining factor of success in root canal treatment (Sjogren et al, 1990; Ricucci and Langeland 1998, European Society of Endodontology, 2006).

Working length is defined as "the distance from a coronal reference point to the point at which canal preparation and obturation should terminate" (Glossary of Endodontic Terms, Tenth Edition).

Inaccurate determination of the root canal's apical end is a common error in root canal treatment which may lead to over-filled root canals, which in turn cause irritation, delayed healing of the periapical area, or incomplete cleaning and shaping of the root canal system (Hoen and Pink, 2002). These can lead to colonisation of bacteria in the root canal space and subsequent periapical infection (Holland et al, 1980; Gutmann, 2016). Both scenarios decrease the success and prognosis of the root canal treatment (Ricucci and Langeland, 1998; Ingle et al 2002; Schaeffer, 2005).

The apical constriction and the cementodentinal junction have been used as anatomical landmarks to determine the root canal terminus (Wu et al, 2000; Keratiotis et al, 2019).

The exact termination of the root canal preparation and subsequent obturation has been controversial as it is strenuous to determine the histological end of the root canal (Bergenholtz

and Spångberg, 2004). Various working length methods have been established over the years with one focus, that is, the ideal approach to establishing these anatomical landmarks (Keratiotis et al, 2019).

Until 1908, there was no documented method on how to measure working length. Root canal treatments consisted of the opening of an access cavity, followed by removal of the pulp chamber and treatment of the apical part of the pulp with - medications such as oil of cloves or cinnamon. A hot instrument or boiling oil was utilised to cauterise the apical part of the pulp. Another method documented in the early days, comprised extracting the affected tooth, filling the canals and then re-implanting the tooth (Curson, 1965 cited by Cruse and Bellizzi, 1980; Hackensack and Dickinson, 1972 cited by Cruse and Bellizzi, 1980; Cruse and Bellizzi, 1980). Gold painted copper points were also used as a root canal filling by Gramm and Chicago in 1890 (Anthony and Grossman, 1945, cited by Cruse and Bellizzi, 1980; Cruse and Bellizzi, 1980).

The first attempt to measure working length was done by Rehein in 1908 with the advent of diagnostic dental radiography. He used a metal wire in conjunction with a radiograph to assess the extension of the wire tip in relation to the root apex (Cruse and Bellizzi, 1980). The development of new technologies has generally made dental treatment and specifically endodontic therapy more rational, easier and more accurate for the clinicians and less stressful for the patients (de Morais et al, 2016).

The introduction of electronic devices has significantly improved the accuracy in measuring the working length and the level at which the apical constriction resides (Tsesis et al, 2015). In 1918, the use of electronic devices was proposed by Custer to determine the working length (Custer, 1918; Tselnik et al, 2005). In 1942, the first electronic apex locators (EAL) were presented by Suzuki who investigated the stream of the electric current throughout the teeth of

a dog. He recorded regular rates in current resistance between a metal wire inside the root canal and a conductor on the oral soft tissue and believed that this could determine the length of root canal (Suzuki, 1942; Gordon and Chandler, 2004). A review by Gordon and Chandler (2004) showed that modern EAL can determine the position of the CDJ with an accuracy of more than 90%. To this date, electronic apex locators are broadly utilised in the practice of endodontics. Their advantage is that they decrease the number of radiographic acquisitions required during endodontic treatment, and furthermore reduce the subjectivity associated with radiographic interpretation (de Morais et al, 2016).

There are, however, some factors which affect their accuracy in determining working length. A study by Kovačević & Tamarut (1998) showed that accuracy of some generations of the EAL can be affected by certain biological conditions such as presence of inflammatory exudate, vital tissues and blood, as they may conduct electric current which in turn, affect the reading accuracy of the EAL (Trope et al. 1985; Gordon and Chandler, 2004). ElAyouti et al (2005) found that inaccurate readings were obtained from obliterated canals, and factors such as the presence of metallic restorations, caries and presence of metallic instruments in the adjacent canal/s could potentially cause electrical short circuiting.

Diagnostic imaging facilitates the development and implementation of a cohesive and comprehensive treatment plan for the patient and clinician. Diagnostic imaging was first used in dentistry by William Roentgen in 1895 and specifically in endodontics by Rehein in 1908 (Cruse and Bellizzi, 1980). Up until the late 1980s, conventional two dimensional radiographic techniques such as intraoral, cephalometric and panoramic views were the accepted standard of practice for dental diagnosis (Harris et al., 2012)

With rapid advancement of radiographic technology, varieties of three-dimensional (3D) imaging systems are now available and have become increasingly popular (Misch, 2007).

3D imaging has a wide variety of clinical applications in dentistry i.e. in endodontics, forensic dentistry, temporomandibular joint diagnostics, guided surgery, implant planning and orthodontics.

The advent of Cone Beam Computed Tomography (CBCT) technologies has played a major role in the evolution of diagnostic imaging in endodontics. The ability to visualise each individual tooth's anatomy with an interactive 3D assessment takes the guesswork out of the equation, and allows clinicians to make educated decisions regarding treatment, based on sound accurate diagnostic tools. Using this technology may assist clinicians to avoid potential clinical errors and decrease the incidence of complications and failure through improved preoperative planning (Jain et al, 2019). The scope of this study will focus on its role in endodontic treatment particularly in the measurement of working length.

Three dimensional imaging, has in turn, enabled the recent development of proprietary softwares that allow clinicians to manipulate digital images on computers (Harris et al., 2012). In 2017, Dentsply Sirona (dental equipment manufacturer) developed a cone beam computed tomography (CBCT) based software (3D Endo) which enables the clinician to examine a tooth in a three dimensional view. The clinician is able to determine the position of the apical foramen, the number and morphology of the canals of the roots, and measure working length accurately (as claimed by the manufacturer). All these factors can make root canal treatment easier and with more predictable and successful outcomes. The aim of this study was to verify the reliability of the conventional CBCT and the CBCT-based software (3D Endo) by comparing working length measurements obtained through each method as well as with linear measurements which is the gold standard method.

According to guidelines of the European Society of Endodontology cleaning, shaping and obturation should be included to the root canal system terminus (European Society of Endodontology, 2006). This terminus or apical limit of a root canal system has been variously expressed either to the apical constriction or to the cementodentinal junction (CDJ) (Grove, 1930 cited by Rahgu et al, 2014; Ponce and Fernándezl, 2003). The CDJ is located where the dental pulp ends and the periodontal ligament commences. This allows for a tight seal which prevents colonization of the root canal by microbes, inflammatory reactions, induced by bacteria and subsequent re-infection (Ricucci and Langeland 1998; Holland et al 2007). Guidelines of the European Society of Endodontology stated that root canal preparation should be extended to the apical constriction which is located 2-5mm from the radiographic apex.

1.2 Literature review

The apical constriction and CDJ are the determinant histological references for obtaining working length (Grove, 1930 cited by Raghu et al, 2014; Kuttler, 1955cited in Ponce and Fernándezl, 2003,; Weine, 1982; Nguyen, 1985 Cited by Ricucci, 1998.; Vieyra et al 2010). Gutierrez and Aguayo (1995) reported that the CDJ is highly irregular and can be located up to 3mm higher coronally on one side of the root from the apical foramen (Gutierrez & Aguayo 1995). It is, therefore, universally accepted to terminate the preparation and obturation of the canal at the apical constriction, where the blood supply is minimal, resulting in only a minor wound site (Ricucci and Langeland, 1998). In anterior teeth, one study found that the CDJ coincided with the apical constriction in 53% of individuals between the ages of 18 and 25 years (Ponce and Fernándezl, 2003), while in a previous similar study which comprised an older age group (older than 55years), the incidence increased to 60% (Kuttler, 1955 cited in Ponce and Fernándezl, 2003). The study by Kuttler (1955), however, did not identify the type of the teeth used.

The apical foramen, on the other hand, has been found to be located up to 3mm from the radiographic apex in 50 to 98% of individuals (Kuttler, 1955 cited in Ponce and Fernándezl, 2003; Green, 1956; Pineda and Kuttler, 1972). The distance between the apical foramen and the apex of the tooth tends to increase in posterior teeth, and with increase in age (Gordon and Chandler, 2004).

The distance from the apical constriction to the apical foramen has been shown to be approximately 0.5mm in the younger age group (18-25years) as opposed to 0.8mm in the older (≥50years) age group (Kuttler, 1955 cited in Ponce and Fernándezl, 2003; Dummer et al, 1984; Stein and Corcoran, 1990). The inconsistencies in the measurements from these studies could have been influenced by the difference in tooth age and type of tooth studied, variations in the minor apical foramen, as well as the presence or absence of periapical lesions (Gordon & Chandler, 2004).

Some authors, thus, emphasise that the preparation and obturation should end 0.5 to 1mm short of the radiographic apex (Ricucci, 1998); while others suggest that termination of obturation up to 2mm short of the radiographic apex is acceptable (Kojima et al, 2004; Schaeffer et al, 2005). Epidemiological studies have confirmed that obturation within 2mm of the radiographic apex had the best prognosis. Roots which were obturated within 2mm from the apex had 94% success compared to 68% for teeth that were obturated shorter than 2mm from the root apex and 76% for those that were over filled after 8-10 years postoperative follow up (Sjogren et al, 1990).

1.3 Methods of measuring working length

There are several methods to measure the working length such as manual tactile sensation, wetness of the tip of paper points, radiographs, use of electronic apex locators and recently, the use of a three dimensional endodontic CBCT-based software (Keratiotis et al, 2019). Both

manual tactile sensation and use of paper point moisture techniques have not been used for a considerable period of time due to their unpredictability and inaccuracy (Diwanji et al, 2014).

1.4. Intra-oral radiography

Two-dimensional (2-D) radiographs have been the conventional method for determining the working length when performing root canal treatments. They, however, present with several shortcomings. Firstly, they remain only a 2-D demonstration of a three-dimensional object, rendering the detection of the apical constriction difficult in some cases (ElAyouti et al 2002; Gordon and Chandler, 2004; Nair & Nair 2007). Secondly, 2-D radiographs show the radiographic apex and not the apical foramen. The radiographic apex is defined as the anatomical terminus of the root, where the apical foramen is located, and the apical foramen is the point where the canal exits the root adjacent to the periodontal ligament (American Association of Endodontists, 1984). Thirdly, the superimposition of surrounding structures or increased density bone may make the visualization of the apex difficult (ElAyouti et al 2002). Tamse et al (1980) reported that the zygomatic arch obscured the apex of the maxillary first molars in 20% of cases and that of the second molar in 42% of cases. Moreover, viewing the apical foramen on the 2-D radiographs becomes challenging when it is located on the buccal or lingual side of the root. Other limitations of the 2-D radiographs include sensitivity of the technique in post exposure and interpretation, as well as magnification and distortion of the radiograph (Gordon and Chandler, 2004; Real et al, 2011). Some researchers found that the radiographic working length was inaccurate and caused over-instrumentation in 51% of the teeth due to inaccurate determination of the apical foramen(Gordon and Chandler, 2004; ElAyouti et al 2002). Even though 2D intraoral radiographs are still utilised in endodontic treatment as a working length measuring method; the above-mentioned limitations highlight the need for a more accurate method of measuring working length.

1.4.1. Techniques for acquiring intra-oral radiography

There are two techniques used for conventional and digital intraoral radiography; the paralleling technique and the bisecting angle technique:

1.4.1a. Paralleling technique

The concept of this technique is based on parallelism whereby a film is placed parallel to the long axis of a tooth, and the x-ray beam is directed perpendicular to the long axis of the tooth and the film. Directing the x-ray beam perpendicular to the film reduces the geometric distortion and magnification thus increasing the definition of the x-ray (Fig 1). Film holders have been developed to ensure parallelism and to direct the x-ray beam perpendicular to the film (Biggerstaff and Phillips, 1976; Forsberg, 1987).

1.4.1b. Bisected angle technique

This technique is achieved by placing the receptor as close as possible to the tooth; the x-ray beam is directed perpendicular to an imaginary line that splits the angle made by the long axis of the tooth and the film (Fig 2). This technique tends to cause some linear (shortening or elongation), and dimensional distortion. It is often- applied as an alternative when paralleling technique cannot be used ,for example, when acquiring intraoral radiographs in restless children, emergency diagnostic cases, and in weak, spastic, or gagging patients (Manson-Hing, 1980).

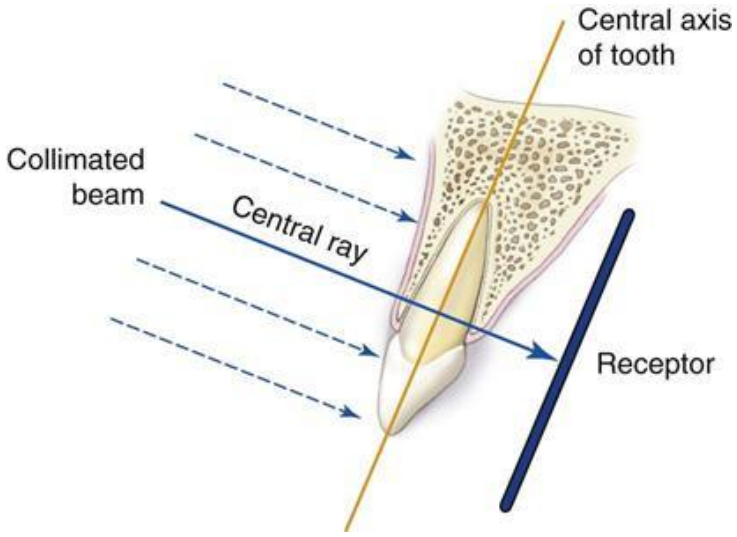


Figure 1: paralleling technique. In order to place the film and the tooth parallel they should be placed some distance apart (Pocket Dentistry, https://pocketdentistry.com/7-intraoral-projections/)

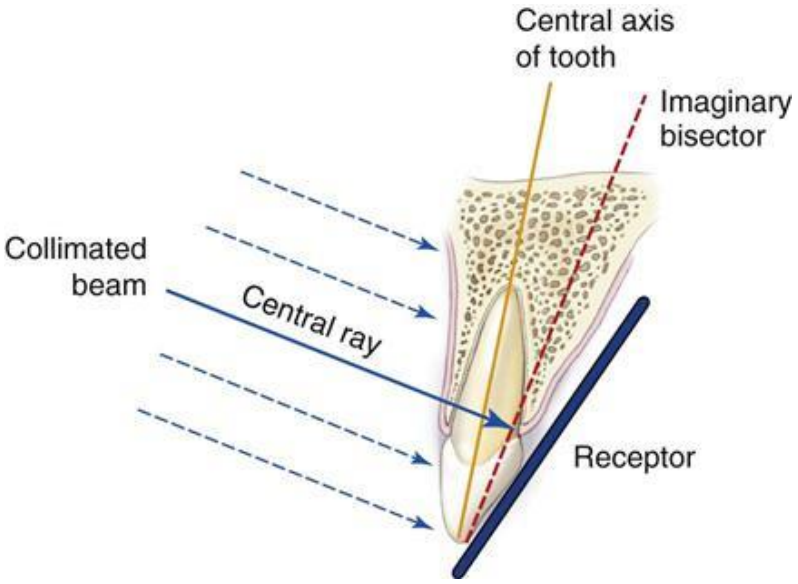


Figure 2: Bisected angle technique (Pocket Dentistry, https://pocketdentistry.com/7-intraoral-projections/)

1.5. Extra-oral radiography

1.5.1. Tomography

Tomography is an umbrella term derived from the Greek words tomo (slice) and graph (picture) (Misch, 2007). It was adopted by the International Commission on Radiological Units and Measurements in 1962 to describe all forms of body section radiography. Body section radiography is a technique whereby a section of the patient's anatomy is visualised and acquired by blurring out regions of the patient's anatomy above and below the section of interest (Misch, 2007).

Tomography is used to obtain cross sectional images of the maxillofacial skeleton. These images are perpendicular to the curvature of the jawbones thus displaying the angulation and shape of the jawbone, alveolar process, teeth and associated structures (Harris et al, 2012). As a result, tomography is the only method which offers reliable estimates of bone and dentition dimensions than panoramic and intraoral radiography (Harris et al, 2012).

There are three main groups of tomographic techniques used; motion (conventional) tomography, computed tomography (CT) and cone beam computed tomography (CBCT) (Harris et al, 2012).

1.5.2. Conventional tomography

Although largely replaced by CBCT, conventional tomography is still available, and can produce cross-sectional tomographic images from many areas of the maxillofacial skeleton (Misch, 2007; Harris et al, 2012). This imaging modality demonstrates the geometry of the alveolus and the teeth as well as the spatial relationship between critical structures in relation to the teeth. It is an operator sensitive technique and superimposition of structures outside the plane of focus can cause significant "blurring" of the image, making them difficult to interpret.

Furthermore, multiple images are needed incurring more radiation dose to the patient (Misch, 2007)

1.5.3. Computed tomography (CT)

The innovation of CT has transformed medical imaging. It was invented by Hounsfield in 1973 (Hounsfield, 1973) and was so successful that it largely replaced conventional tomography by the early 1980's. It was the first time in medical imaging that hard and soft tissues could be visualised together on an image without performing invasive procedures on a patient such as contrast media (Misch, 2007).

CT is a digital and mathematical technique which generates tomographic sections where the tomographic layer is not tainted by blurred structures from the adjacent anatomy (Misch, 2007). The X-ray source is attached to a fan-beam geometry detector, which rotates 360 degrees around the patient and collects volumetric data (Misch, 2007). A relatively large computer workstation processes the data to produce CT images. CT images are innately three dimensional with the thickness described by the slice spacing of the image technique. The individual element of the CT image is called a voxel which has a value that describes the density of the CT image and is referred to in Hounsfield units. Each voxel contains 12 bits of data and ranges from -1000 (air) to +3000 (enamel/dental materials). CT scanners are standardized at a Hounsfield value of 0 for water (Misch, 2007).

CT can also generate a panoramic view and cross-sectional images of the jaws, although, being largely referred to in the literature as "medical multislice computed tomography". Its main advantage is volumetric reconstructions with the ability to measure anatomical landmarks on the slices (Guerrero et al, 2006). CT acquisition however induces high radiation doses to the patient and its use in routine dental care cannot be justified except for the imaging of large jawbone segments (Guerrero et al, 2006). It has been postulated that radiation exposure for a

CT scan involving the maxilla and mandible is equivalent to the exposure caused by approximately 20 panoramic radiograph acquisitions (Mah et al, 2003).

The uses of CT in endodontics is limited due to the high dosage of radiation and financial cost to the patient, potential scatter caused by presence of metallic objects and low resolution compared to the conventional 2D radiograph. In addition, poor availability of the CT machines, their large computer workstations, high cost to the clinician and the limitation of space in private practice settings make the use of such machine to be limited and impractical (Gümrü and Tarçın, 2013).

1.5.4. Cone beam computed tomography (CBCT)

CBCT is an umbrella term for a technology whose principle is a cone- shaped X-ray beam with the X-ray source and detector (image intensifier or flat panel detector) rotating swiftly once around a point of interest on the patient (Misch, 2007). A 3-D dataset is produced by a desktop computer into volumetric data through acquisition of multiple two-dimensional projections (Harris et al, 2012).

Depending on the brand of CBCT, the patient is in a seating, standing, or supine position during the examination (Harris et al, 2012). The CBCT units can also be categorised into large, medium, and small volume units based on the size of the field of view (FOV). The FOV can be altered in certain machines to suit the purpose of examination. Small fields are usually used for dental imaging and large fields for maxillofacial examinations (Harris et al, 2012). Consequently, the radiation dose varies considerably between machines and settings (Pauwels et al, 2012). Some CBCT machines require larger data volumes than others with data acquisitions ranging from volumes of 4X4cm squared to 22X22cm squared.

Depending on the unit, CBCT for dental radiology will generally offer higher spatial resolution, at a considerably lower dose as compared to CT without compromising on diagnostic accuracy.

This is due to the smaller FOV, flat panel detector, and reduced scan time (Ganz, 2011; Harris et al, 2012). Once the scan is taken, it can be viewed on a desktop computer using an interactive treatment planning software such as SimPlant (Materialise Dental, Glen Burnie, MD, USA) (Ganz, 2011).

The image of the area of interest produced by the CBCT can be viewed in mesio-distal, bucco-lingual and coronal planes as well as in three orthogonal planes (Patel, 2009). This enhanced view of the root canal morphology can improve the accuracy of the working length determination (Jeger et al, 2012).

CBCT has the potential to clearly identify anatomic structures, the density and shape of bone as well as any associated pathology with minimal distortion (Harris et al, 2012). Margins of errors for CBCT are less than 0.1mm, as reported in a study by Hashimoto showing CBCT to be more accurate than conventional CT for viewing maxillofacial features (Hashimoto et al, 2006).

In endodontics, CBCT is preferred to be used over the conventional CT due to the significant decrease in the radiation exposure, the smaller size of the CBCT unit and an easily accessible desktop computer workstation making it suitable to fit in private dental offices. The CBCT image resolution has proven to be superior to the conventional CT therefore it is preferable for assessing dental hard tissues. The limitation of the CBCT images is that their resolution is less than that of conventional radiographs for both soft and hard tissues (Patel, 2009). In addition, scatter caused by the increased density of adjacent structures such as enamel, metallic restorations, and metallic post or fractured instrument in root canal, may make it difficult to accurately interpret the radiographic images (Gümrü and Tarçın, 2013).

1.6. Application of CBCT in Endodontics

1.6.1 Preoperative assessment

Identifying all the canals to be cleaned and obturated is an important factor in root canal treatment success (Vertucci, 1984). In multi-rooted teeth, this can be difficult to achieve when using 2-D radiography due to superimposition of other structures. Studies have reported that the prevalence of second mesiobuccal canals (MB2) in the maxillary first molars ranges from 66% to 93% and about 60% of the maxillary second molars (Stropko, 1999; Scarfe et al, 2009; Betancourt et al, 2016; Alves et al, 2018). A study by Ramamurthy et al (2006) reported that conventional 2D radiographs detect only 50% of the MB2 canals. CBCT has been reported as a suitable tool of identifying missed MB2 with accuracy of up to 98% (Bauman, 2009; Mirmohamnmadi et al, 2015). It further assists in examining root canal anomalies and determining root curvatures (Cleghorn et al, 2008; Estrela et al, 2008). In addition, CBCT has been reported to be more accurate to identify periapical pathosis compared to conventional and digital radiographs (Stavropoulos and Wenzel, 2007; Estrela et al, 2008). The preference of the CBCT over the 2D radiograph is attributed to the fact that CBCT can visualise the periapical tissues separately without being superimposed by the adjacent structures, in all three orthogonal planes. Lastly,it enables the clinician to accurately determine the three dimensional size of the periapical lesion (Cotton et al. 2007; Patel et al. 2007; Sog˘ur et al. 2007)

The use of 3-dimensional cone beam computed tomography (CBCT) has been advocated to measure the working length (Jeger et al, 2012; Metska et al, 2014; Üstün et al, 2016; Yılmaz et al, 2017). In these studies where both single and multi-rooted teeth were used, it was demonstrated that CBCT imaging can provide an accurate measurement of working length compared to periapical x-rays and apex locators. A similar outcome was obtained by de Morais et al, (2016).

1.6.2. Postoperative assessment

CBCT has been successfully used to monitor healing of periapical lesions after completion of root canal treatment and also to assess the quality of the root canal filling (Patel et al, 2007; Soğur et al, 2007).

1.7 CBCT-based software

In 2017, Dentsply/Sirona released CBCT-based endodontic software named the "3D Endo". The manufacturer claimed that the software is able to accurately measure the working length, locate canal orifices, plan for an optimal cavity access and the size of the final instrument to be used for canal preparation (http://www.3dendo-na.com/en-us.html). To the author's knowledge, only one study by Segato et al (2018), testing the accuracy of this software, has been published. This study reported an accuracy value of 3D Endo of 86% in measuring working length using this system. The limitations of the study was that they used only single rooted premolars with a limited root curvature ($>10^0$). No other study was conducted to assess the accuracy of this software in multi-rooted premolars and molars.

CHAPTER 2. AIM AND OBJECTIVES

2.1 Aim

The aim of this study was to evaluate the reliability of the 3-D endo software in accurately determining the working length of different root canals, relative to the conventional CBCT software, and the physically measured linear working length method.

2.2 The objectives:

1. To measure the distance from the coronal reference to the apical foramen of each extracted tooth using CBCT software.
2. To measure the distance of the same coronal reference to the apical foramen of the same teeth using 3D Endodontic Software (3D Endo).
3. To determine linear measurements from the same coronal reference to the apical foramen of each tooth, after having established a glide path using a size 15 k endodontic file (Dentsply, Maillefer) and a digital calliper (brand name: Digital Caliper 150mm6”). To compare the CBCT measurements as well as the 3D endo software with the linear measurements

CHAPTER 3. MATERIAL AND METHODS

3.1 Inclusion Criteria:

1. Permanent maxillary and mandibular teeth (central and lateral incisors, canines, premolars and molars including 3rd molars).
2. Teeth with sound roots and fully formed apices.

3.2 Exclusion Criteria:

1. Teeth with large carious lesions extending to the roots.
2. Teeth with roots affected by external or internal root resorptions.
3. Teeth with obliterated pulp space.
4. Previous endodontically treated teeth.

3.3. Study setting and design:

This was an analytical laboratory study, performed at Wits Oral Health Centre. The research site was chosen due to the availability of the equipment needed to carry out the study such as the x-ray machine, CBCT machine and the microscope.

3.4. Study Population

The study population comprised 30 root canals which were reported to be adequate for this type of study by Segato et al (2018). The measurements of each tooth were re-taken at a later time for reliability of the measurements. The total number of readings would thus amount to 60 with repetition for each method, yielding a total of 180 measurements. The Bland Altman analysis requires a sample size of at least 60, preferably 100 (Bland and Altman 1986). The population thus met the minimum requirements for the test.

3.5. Null hypothesis

There was no statistically significant difference between the linear measurements acquired through a digital calliper and those obtained through CBCT and 3D endo software.

3.6. Methods and materials

3.6.1. Tooth Preparation

In order to fulfil the inclusion and exclusion criteria, the teeth were examined clinically using a Carl Zeiss Microscope (5.1 X magnification) ZEISS Microscopy, Jena Germany (Fig. 3). The selected teeth were radiographed bucco-lingually and mesio-distally using a periapical intraoral sensor plate (Xios XG Supreme) (Fig.4). Thereafter, the teeth were immersed in 6% sodium hypochlorite (NaOCL) for two hours to remove the remnant periodontal tissues and to disinfect the teeth. Any residual attached bone or tissue was removed using a diamond bur (IOS 173/014, TF-11) attached to high speed hand-piece (Contra-angle Ti-MAX Z 95L, Japan) and/or scalpel blade number 15 (Swann-Moston, Sheffield-England).

Figure 3: Dental Microscope ZEISS Microscopy, Jena Germany.

Figure 4: Periapical intraoral phosphor plate (South Africa - Dentsply Sirona)

The teeth were then stored in Formalin (pH 7.25) at room temperature. Before use, the teeth were mounted on separate artificial bone block in groups of four (Solid Rigid Polyurethane Foam) of size 4×4×4cm (Fig 5.1). This was done to accommodate the limitation of the size of the bone block which was pre-determined by the scan size (5.x5.5cm).

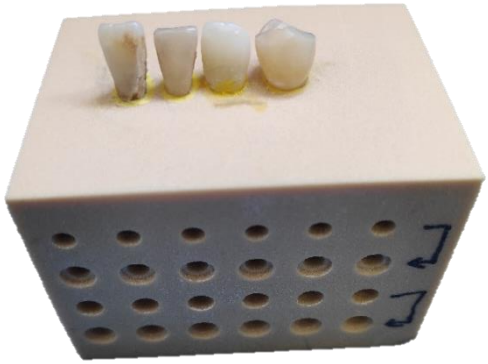


Figure 5: Artificial teeth mounted in the artificial bone block

Separated single holes were drilled in the bone block (Fig 5.2) using a straight hand piece (NSKH1014002 FX65 Straight Handpiece, 1:1 Direct Drive, Japan) and Cross cut standard acrylic bur (L14.0 mm, size6.0 mm, ISO 275190060, Shanghai) To ensure stability of the teeth in the prepared sockets, a high consistency polyvinylsiloxane material (Jet Bite, Coltene-Switzerland) was applied around the teeth in the created sockets (The teeth were coated with petroleum jelly (Vaseline) to facilitate easy removal of the teeth after the jet bite sets.

3.6.2. CBCT Imaging Procedure

The scans were performed by a skilled radiographer; four teeth were scanned during one exposure using Orthophos XG 3D/Ceph (Dentsply Sirona) (Fig. 6). VOL2: FoV 5*5.5cm, high definition mode for proper scan resolution was selected on the CBCT machine with an exposure time of 40.2 seconds.

Figure 6: Orthophos XG 3D/Ceph (Dentsply Sirona)

3.6.3. Determination of the working length using conventional CBCT software

After the teeth had been scanned, the coronal reference point and the apical foramen were established. The distance from the coronal reference point to the apical foramen was measured for each canal, and the readings were recorded as the working length.

3.6.4. Determination of the working length using 3-D endo software

The data obtained by the CBCT was transferred in a DICOM format from Sidexis (Dentsply/Sirona, Germany), a conventional CBCT software, to the 3-D endo software (Dentsply/Sirona, Germany).

When using the 3-D endo software, each tooth was analysed individually by extracting the tooth from the 3-D image (Fig.7.1).

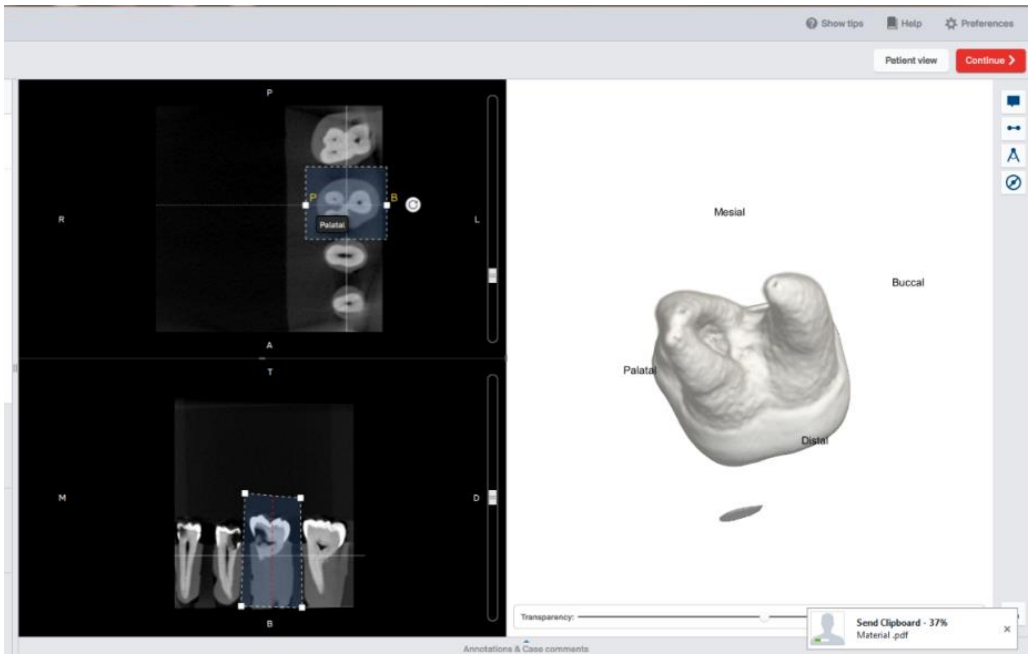


Figure 7: 3D endo software extracting each tooth to be examined individually

Each canal was marked at two points (orifice and apical terminus) which are the same points that were established by the CBCT. A virtual line was drawn between the two points and further adjusted to follow the configuration of the root canal system. An automatic measurement of the working length was generated by the software using a size 15K file. The inclination of the file coronally was adjusted as required. A silicone/ rubber file stopper was placed at the reference point (Fig. 8).

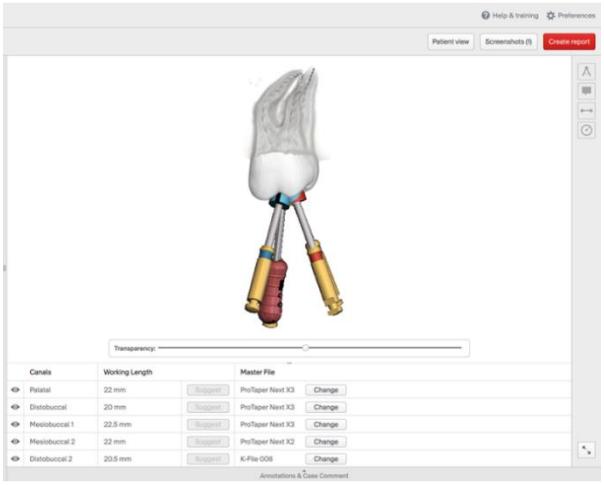
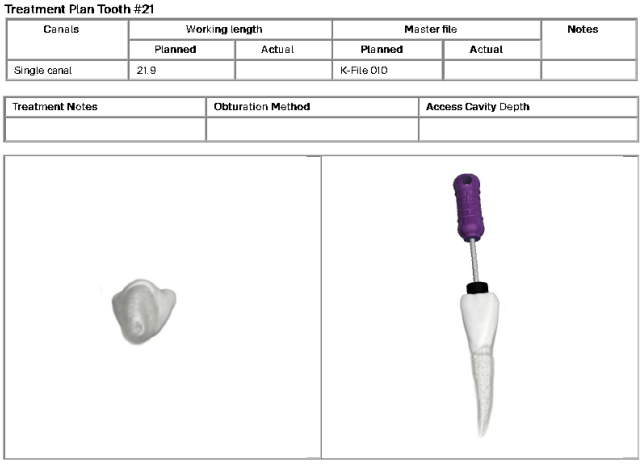


Figure 8: 3D endo measurements with rubber stop in position


Treatment Plan Tooth #21

Canals	Working length		Master file		Notes
	Planned	Actual	Planned	Actual	
Single canal	21.9		K-File 010		

Treatment Notes	Obturation Method	Access Cavity Depth

Figure 9: an automatic measurement of the working length generated by 3D endo

3.6.5. Physical Determination of Working Length using Access Cavity, Glide Path and Patency

An access cavity on each tooth was performed under a Carl Zeiss dental operating microscope (5.1 X) using a high speed hand-piece (Contra-angle Ti-MAX Z 95L, Japan) under coolant water. A number 4 round diamond bur (Dentsply, Maillefer) was used initially to gain access into the pulp chamber and thereafter an endo Z bur (Dentsply, Maillefer) was used to refine the pulp chamber's axial walls. Numbers 10K, 8K and/or 6K endodontic files (Dentsply, Maillefer) were used as required to secure the glide path of each canal and establish patency. RC prep, a chelating paste (Premier Dental Products Company, USA) was used as needed to facilitate glide path preparation.

RC Prep was introduced by Stewart et al in 1969. It consists of 15% ethylene diamine tetra acetic acid (EDTA), 10% urea peroxide (UP) and glycol in a water soluble base (Steinberg et al, 1999; Singh et al, 2009). The main use of RC Prep is canal lubrication which facilitates movement of the rotary instrument especially in the calcified canals (Steinberg et al, 1999) and therefore reduce the internal root stress as well as removal of the smear layer (Peters OA, 2005) (Adl et al, 2015).

3.6.6. Linear measurement using a hand file and digital callipers.

After the glide path was secured and patency established, a size 15K endodontic file (Dentsply, Maillefer) was inserted into each canal until the tip of the file flushes through the apical foramen. The file was then withdrawn until the tip was flush with the apical foramen from the tangential view. The silicone stop was adjusted at the same reference point that has been established in the 3-D endo software and the CBCT. The distance between the silicone stop and the tip of the file was measured using a digital calliper (brand name Digital Caliper 150mm6", unknown company, China).

The working length determined by the 3-D endo software was compared with the standard method (linear measurements using an endo ruler and a digital calliper), as well as the CBCT measurements. The differences were calculated to evaluate the reliability of the software.

CHAPTER 4. RESULTS

4.1. Test-retest reliability

Test-retest reliability between the first and second measurement for each of the measurement techniques using the Pearson Correlation Coefficient showed that there was a strong significant positive correlation as shown in Table 1.

Table 1: Test-retest reliability

	1st reading		**2nd reading**		**Pearson correlation coefficient**	
Measurement	**Mean**	**SD**	**Mean**	**SD**	**Correlation coefficient**	**p-value**
Linear	21.47	1.64	21.53	1.59	0.98	0.00
CBCT	21.38	1.57	21.37	1.56	0.91	0.00
3D-Endo	21.45	1.65	21.58	1.46	0.90	0.00

4.2.Test for normality

The average of the two readings was used for further analysis. The average of the two readings was tested for normality using the Shapiro-Wilk test as shown in Table 2.

Table 2: Test for normality using Shapiro-Wilk test

	Shapiro-Wilk		
Measurement	**Statistic**	**df**	**p-value**
Linear	0.96	30	0.33
CBCT	0.98	30	0.68
3D-Endo	0.94	30	0.12

The result showed that all three measurements were normally distributed, $p>0.05$ as shown in Table 2.

4.3. Tooth measurements

The average of the two readings for each of the methods is presented in Table 3 below:

Table 3: Average of the measurements

Measurement	N	Minimum	Maximum	Mean	Std. Deviation
Linear	30	17.72	25.30	21.50	1.61
CBCT	30	17.91	25.17	21.37	1.55
3D - Endo	30	18.60	25.28	21.51	1.51

The results showed that the mean measurement of linear, CBCT and 3D-Endo was 21.50±1.61, 21.37±1.55 and 21.51±1.51 respectively as shown in Table 3. Figure 10 below showed that the 3D-Endo had the highest score compared to the two other measurement methods however overall there are no statistical difference between the groups.

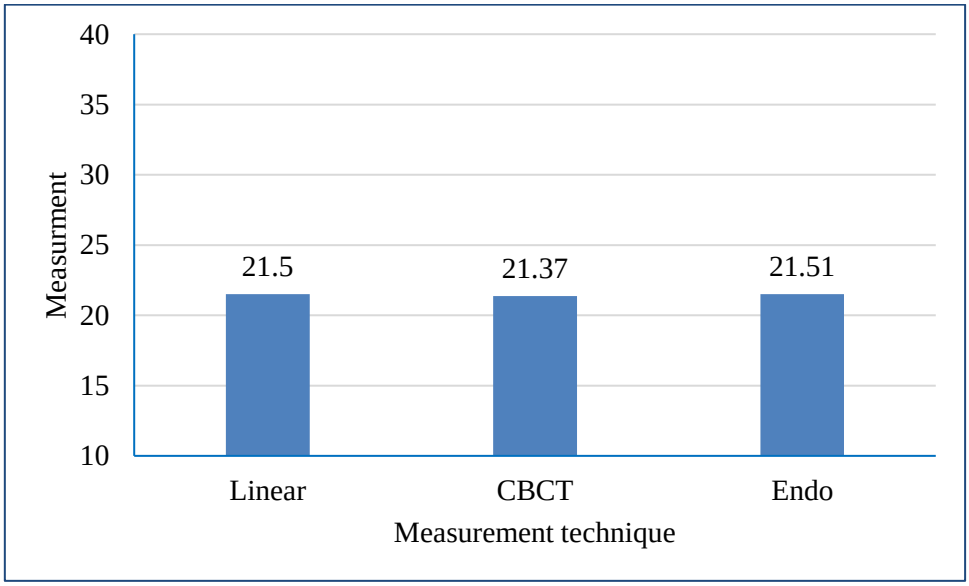


Figure 10: Average measurement value

4.4 Correlation between the linear measurement and CBCT

Pearson correlation was used to determine the linear relationship between the linear and the CBCT measurement as shown in Figure 11. There was a significant strong positive correlation between the linear and the CBCT measurement (rp=0.98; p-value=0.00).

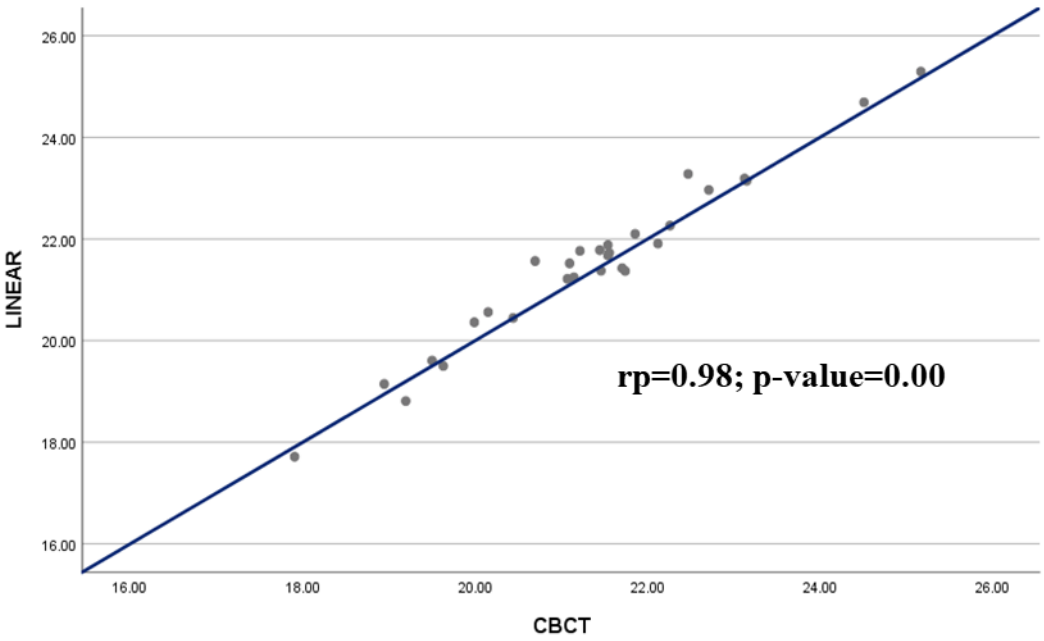


Figure 11: Correlation between linear and CBCT measurements

4.5 Correlation between linear measurement and 3D-Endo

Pearson correlation was used to determine the linear relationship between the linear and the CBCT measurement as shown in Figure 12. There was a significant strong positive correlation between the linear and the 3D-Endo measurement (rp=0.98; p-value=0.00).

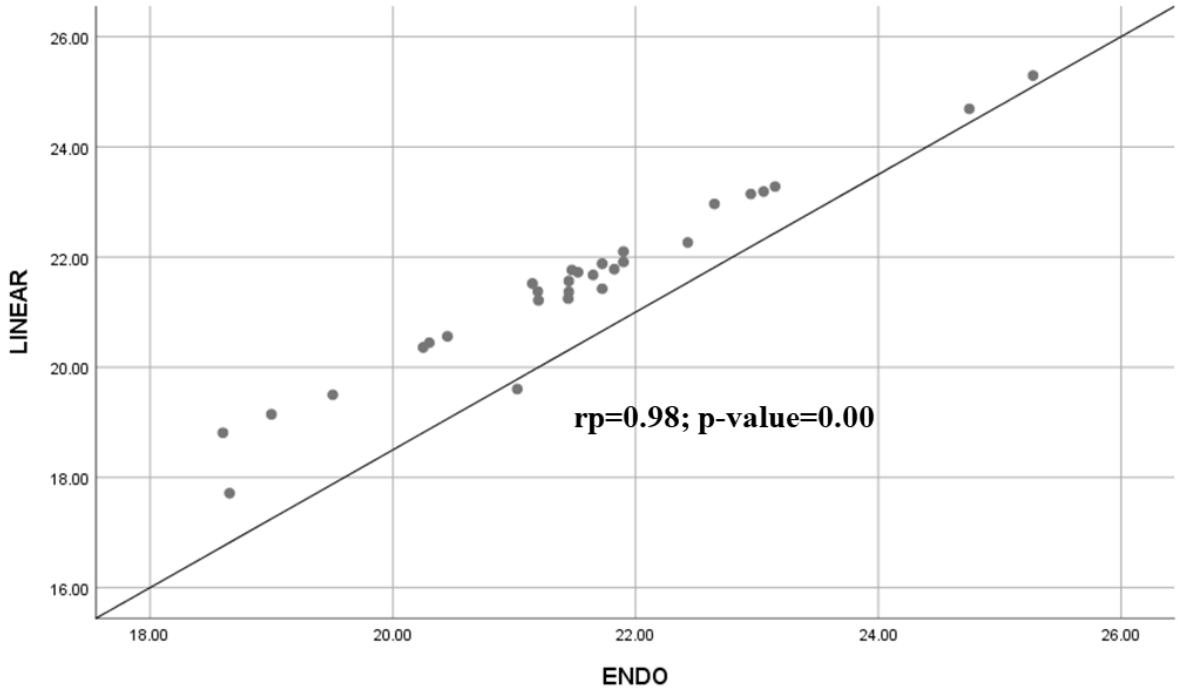


Figure 12: Correlation between linear and 3D-Endo measurements

4.6 Measure of agreement between linear and CBCT measurement

One sample T-test was used to measure the statistical significant difference in the mean difference between the linear and the CBCT measurements. The mean difference between the linear and the CBCT measurement is presented in Table 4 below.

Table 4: Mean difference and One sample T-test

Variable	**Difference**	**95% confidence interval**		**t**	**p-value**
	Mean ± SD	**Lower**	**Upper**		
Linear - CBCT	0.13±0.31	0.01	0.25	2.30	0.03

The result showed that there was a significant difference in the mean difference between linear and CBCT, p=0.03**.** Further analysis using Bland-Altman test was used to determine the proportion bias of the level of agreement as presented in Figure 13.

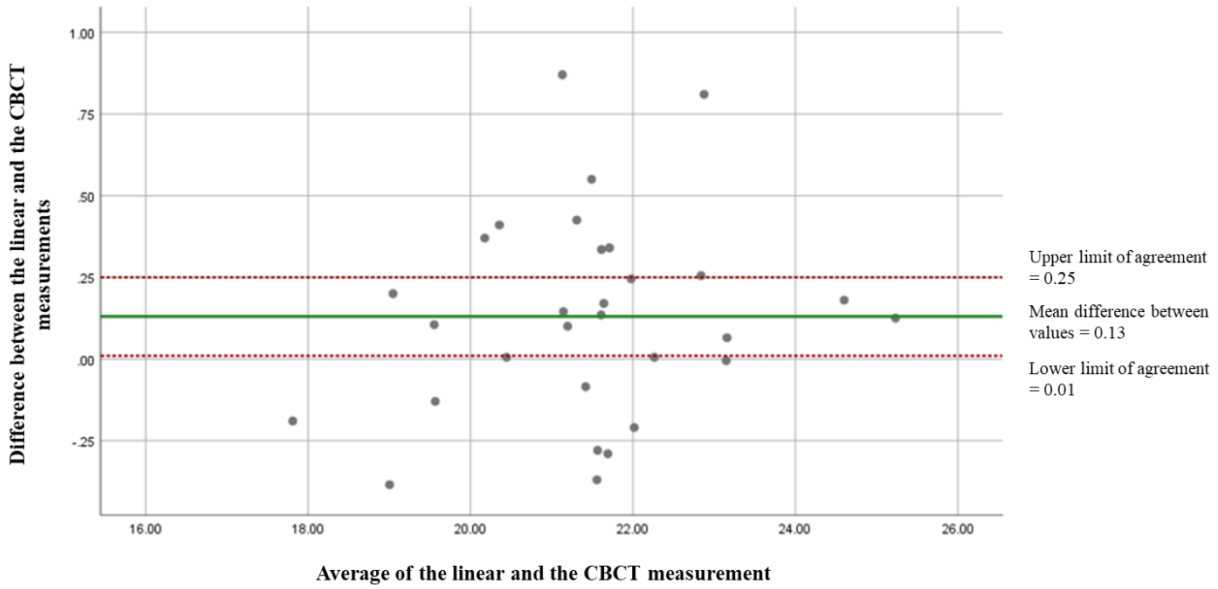


Figure 13: Bland-Altman test of linear and CBCT measurements.

As shown in Table 4, the mean difference between the linear and the CBCT measurement was 0.13, 95% confidence interval between 0.01 and 0.25. This implies that the CBCT reported a higher score by 0.13 and the difference could be as low as 0.01 and as high as 0.25 for 95% of the population.

Further analysis using linear regression was used to determine the agreement between the linear and the CBCT measurement (Table 5).

Table 5: Linear regression

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% CI	
	B	Std. Error	Beta			Lower	Upper
(Constant)	-0.66	0.79		-0.85	0.41	-2.27	0.94
Difference between Linear and CBCT	0.04	0.04	0.19	1.01	0.32	-0.04	0.11

The result showed that the unstandardized coefficient was 0.04 and the p-value was 0.32. This implies that the mean difference is close to zero and there was no significant difference between the two measurements.

4.7 Measurement of agreement between linear and 3D-Endo measurement

One sample T-test was used to measure the statistical significant difference in the mean difference between the linear and the 3D-Endo measurements. The mean difference between the linear and the CBCT measurement is presented in Table 6 below.

Table 6: Mean difference and One sample T-test

Variable	**Difference**	**95% confidence interval**		**t**	**p-value**
	Mean ± SD	**Lower**	**Upper**		
Linear – 3D-Endo	-0.01±0.35	-0.14	0.12	-0.15	0.88

The result showed that there was no significant difference in the mean difference between linear and 3D-Endo, p=0.88**.** Further analysis using Bland-Altman test was used to determine the proportion bias of the level of agreement as presented in Figure 14.

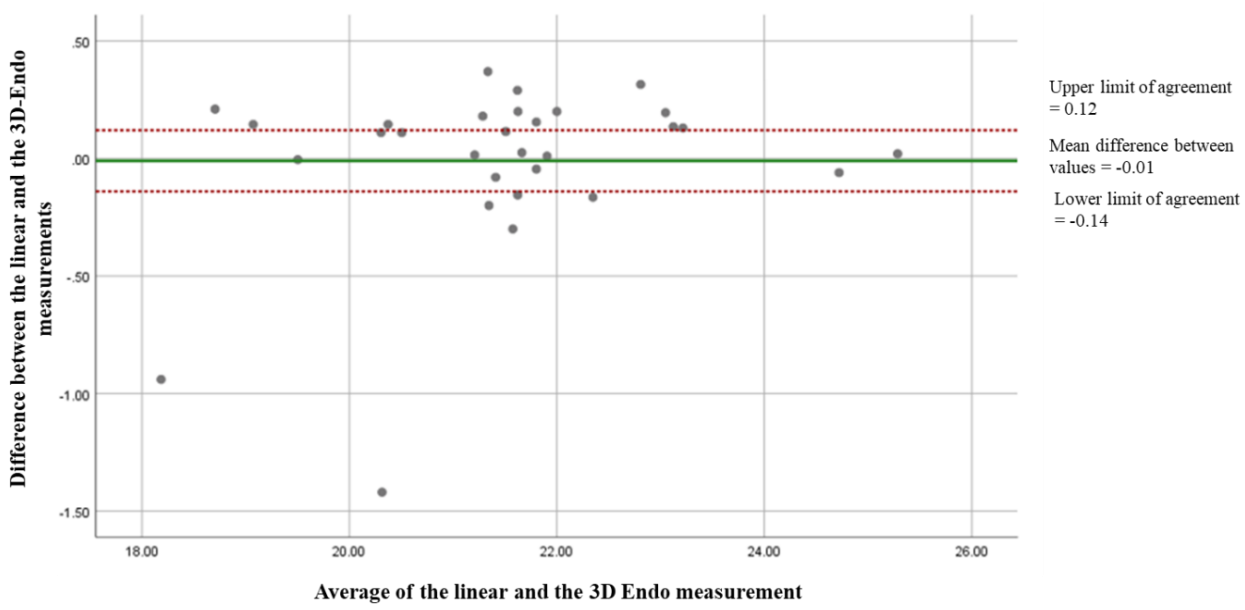


Figure 14: Bland-Altman test for linear and 3D-Endo measurements

Further analysis using linear regression was used to determine the agreement between the linear and the CBCT measurement (Table 7).

Table 7: Linear regression

	Unstandardized Coefficients		**Standardized Coefficients**	**t**	**Sig.**	**95% CI**	
	B	**Std. Error**	**Beta**			**Lower**	**Upper**
(Constant)	-1.39	0.91		-1.53	0.14	-3.25	0.47
Difference between Linear and 3D-Endo	0.06	0.04	0.28	1.52	0.14	-0.02	0.15

The result showed that the unstandardized coefficient was 0.06 and the p-value was 0.14. This implies that the mean difference is close to zero and there was no significant difference between the two measures.

4.8 Summary of Results

1. The results showed that the mean measurement of linear, CBCT and 3D-Endo was 21.50±1.61, 21.37±1.55 and 21.51±1.51 respectively.
2. The mean difference between the linear and the CBCT was 0.13±0.31
3. The mean difference between the linear and the 3D-Endo was -0.01±0.35
    a. The mean difference between the linear and the 3D-Endo was closer to zero.
4. The one sample T-test also corroborates the significant difference in the means of the difference between the linear and the CBCT. The result showed a statistically significant difference between the means of linear and CBCT measurements, and no statistically significant difference in those between linear and 3D-Endo.
5. The Bland Altman test was used to measure the limit of agreement and the results showed that:
    a. Linear and 3D-Endo average mean difference was -0.01, the upper limit of the agreement was -0.14 and the upper limit was 0.12, and this was true for 95% of the population.
    b. Linear and the CBCT average mean difference 0.13. The lower limit of agreement was 0.01 and the upper limit was 0.25, and this was true for 95% of the population.

CHAPTER 5. DISCUSSION

5.1 CBCT measurements

Two-dimensional periapical radiographs have been routinely utilised for preoperative assessments including working length estimation. This technique however presents with some limitations, one of which is that the apical foramen does not always coincide with the radiographic apex (Ricucci and Langeland, 1998; Piasecki et al, 2016).

CBCT has been approved to be used as a reliable diagnostic tool for oral and maxillofacial pathology. It has furthermore proven to be efficient in various stages of endodontic treatment i.e. in preoperative assessment of root canal anatomy, working length measurements and post-operative treatment assessment (Ziegler et al, 2002; Patel, 2009; Yılmaz et al, 2017). Compared to a conventional 3D imaging in the head and neck area such as CT, CBCT provides higher spatial resolution, at a significantly lower dose without affecting diagnostic accuracy.

The 3D Endodontic software is designed for endodontic treatment planning using a limited size CBCT (5 x 5.5CM). The software provides the operator with a 3D view of the canal anatomy and the ability to identify each canal using coloured codes to trace each canal from the coronal orifice to the apical foramen.

This study evaluated the reliability of the 3-D endo software in measuring the working length of a variety of root canals of both single and multi-rooted teeth. The software results were compared to those obtained through the conventional CBCT software, and the physically measured linear working length.

As this is a laboratory study, the outcomes obtained should not be directly applied to a clinical scenario. They should rather be used as a reference to understand the benefits and disadvantages of new software technologies.

In this study an artificial bone block (Solid Rigid Polyurethane Foam) was used to mimic the resolution obtained from patient scan. For endodontic use, a smaller FOV and voxel size are recommended, in order to decrease the exposure dosage, achieve an enhanced spatial resolution, and increase the measurements accuracy.

According to the literature, root canal measurements obtained with CBCT could be (0.02-0.59mm) shorter than the linear measurements (Liang et al 2013; Lucena et al, 2014; Michetti et al, 2015). The results obtained from this study showed that the mean length using the linear measurement was 21.50mm; while the measurements obtained from CBCT were 21.37mm. This means that the CBCT measurements were 0.13 mm shorter than the gold standard (linear measurement), and the mean values obtained were relatively similar to those obtained during several studies 0.46mm, ±0.50mm, 0.25mm (Liang et al 2013; Lucena et al, 2014; Segato et al, 2018) respectively.

A study by Liang et al (2013) showed that CBCT underestimated the length in 65% of the canals while overestimating it in 30%. The differences among the studies could be attributed to the different CBCT systems and the exposure parameters used such as fields of view, electric potential and current, as well as voxel size and resolution (Lofthag-Hansen et al, 2011; Panmekiate et al, 2012; Michetti et al, 2015; Aktan et al, 2016).

The discrepancies between studies may be due to the difference in the methods and capabilities of the softwares (Michetti et al, 2015; Yılmaz et al, 2017). The differences obtained in this study demonstrated that any method of measurement has capacity to create a degree of error.

Operator experience may have an influence on the accuracy of the measurements, for instance, obtaining measurements in a view displaying the coronal reference and the apical foramen at the same time might be challenging for an inexperienced operator. The main examiner in this particular study undertook training of the software by two experienced endodontists through a hands-on demonstration mini course. The results obtained from this particular study, however,

suggest that with the correct level of experience in using this system, the enhanced 3D view of the tooth generated by CBCT can make the measuring of working lengths easier and yield more accurate.

5.2. 3D endo measurements

The discrepancies between the mean measurements obtained by the 3D endo software and those obtained using linear measurements are 0.1mm, which is a relatively smaller difference compared to the outcome obtained by Segato et al., in 2018, which was 0.13mm. This might be related to the difference between the CBCT systems used, the exposure parameters considered, as the 3D endo is a CBCT based software.

The software provides the possibility for virtually determining the location of the endodontic access cavity. This, in turn, assists the operator in determining the file angulation and its relationship to the coronal reference point. The location of these relevant reference points renders the working length measurements obtained by 3D endo more accurate.

A morphologic study of the temporomandibular joint position by Zhang et al (2016) indicated that the measurements obtained by 3D method using a CBCT was more precise than linear measurements in the 2D view of CBCT images. 3D Endo also allows the operator to view the tooth embedded in a 3-D model with the ability of adjusting the apical distance and the coronal reference as well as the angulation of the file according to any view.

CHAPTER 6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion and recommendations

Within the limitations of this study, the outcomes of this study stated that there were no statistically significant differences between the two methods of measurement (CBCT and 3D endo) when compared with linear measurement. The results support the null hypothesis. This current study suggests that CBCT and the 3D-Endo software can be used as reliable methods for determining preoperative working length in endodontic treatment. The lower and upper limit of agreement for each of the measurement should be put into consideration in clinical terms. The highest value of the upper limit of agreement was that of the CBCT at 0.25mm when compared to the upper limit of the 3D-Endo which is 0.12mm. In clinical terms, these measurements both translate to 250 µm and 120 µm respectively. These values are far less than the critical value for the acceptable margin of error when a canal working length measurement and obturation extent are established, which is ≤ 2mm from the radiographic apex. They are therefore clinically insignificant. Both methods can therefore be used as reliable tools for preoperative working length measurement. The study further suggests that both methods can be used for a variety of teeth, including multirooted teeth.

Obturation of canals done using measurements from this tool would not exceed the critical margin of error, which is obturation completed ≤2 mm short of the radiographic apex. The clinical interpretation of these results should however be interpreted with caution as this study is not representative of the variety of root canal anatomical variations that can possibly present in the clinical setting.

6.2 Limitations

The limitations of this study that can be highlighted is the level of operator experience which may have yielded some margin of error in the exact determination of the apical foramen on the softwares; difficulties in determining the root curvature on the CBCT software; and the ability to view the entire canal with a coronal reference and apical foramen simultaneously. Similar studies can be conducted in the future with an additional operator to assess the impact of operator experience.

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APPENDIX A: Ethical clearance

UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

R14/49 Dr A Abdualhafid

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
CLEARANCE CERTIFICATE NO. M191074

NAME: (Principal Investigator)	Dr A Abdualhafid
DEPARTMENT:	School of Oral Health Sciences Department of Oral Rehabilitation Dental School University
PROJECT TITLE:	Comparison of reliability of an endodontic three dimensional and CBCT softwares to measure working length of root canals
DATE CONSIDERED:	Ad hoc
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Drs TI Mmutlana and M Thokoane
APPROVED BY:	Dr CB Penny, Chairperson, HREC (Medical)
DATE OF APPROVAL:	2019/10/28

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary on the 3rd Floor, Phillip Tobias Building, Parktown, University of the Witwatersrand, Johannesburg.
I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to submit details to the Committee. I **agree to submit a yearly progress report**. When a funder requires annual re-certification, the application date will be one year after the date when the study was initially reviewed. In this case, the study was initially reviewed in **October** and will therefore reports and re-certification will be due early in the month of **October** each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature _____ Date _____

PLEASE QUOTE THE CLEARANCE CERTIFICATE NUMBER IN ALL ENQUIRIES