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A New Method for Determining Root Canal Length using Estimation the Accuracy of Correlation between CBCT and CCT Measurements to Enhancing the Endodontic Diagnosis and Treatment

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Abstract

Background: Accurate root canal length determination in biomedical technology is critical to the success of endodontic treatment protocols, as inaccurate measurements may lead to complications such as treatment failure or unnecessary procedures.

Introduction: Conventional medical computed tomography (CCT) technique is widely used due to its effectiveness, simplicity and low cost, providing two-dimensional images, but it is not accurate. In contrast, cone-beam computed tomography (CBCT) technique provides 3D imaging, allowing detailed visualization of the root dimension and structures, which is particularly useful in cases involving complex root curvatures or anatomical variations. However, CBCT has been shown to have some serious limitations, particularly in cases of metal restorations and root fillings, which can cause unwanted image distortions. Moreover, since many hospitals and medical clinics still have only conventional radiology equipment, the authors came up with the idea of finding an empirical relationship, using a practical measurement comparison method that would enable dentists to maximize the use of conventional radiology equipment in implementing the treatment protocol with better accuracy while maintaining patient comfort, low cost and effective clinical applications.

Objective: This research aims to estimate the accuracy of correlation relationship between cone-beam tomography and conventional computed tomography techniques in integration with using Apex Locator, to provide a proposed accurate experimental method for determining root canal length in the diagnosis and treatment in dentistry. In addition to raising the awareness of dental students and increasing the concepts of newly graduated dentists.

Method: Clinical measurement results were obtained using CBCT and CCT techniques for a number of patients and were analyzed using statistical Pearson's correlation coefficient method.

Conclusion: Analysis of the results showed a new empirical correlation equation between the measurements of both techniques. The empirical relationship concluded may enable the dentists to rely on it in estimating the root canal length for diagnosis and treatment with a high accuracy of up to 98% while ensuring a balance between accuracy and effectiveness in terms of cost, time and patient comfort, which contributes to improving the quality of dental care. Valuable conclusions were also provided for making clinical decisions based on the specific needs of each case.

Keywords: Accuracy in dental treatment; Radiography; Diagnostic; CBCT and CCT techniques; Root canal length measurement

Abbreviations: CCT: Conventional medical computed tomography; CBCT: Cone-beam computed tomography

Introduction

Accurately determining the root length during root canal treatment in biomedical technology is one of the key factors contributing to the success and sustainability of the treatment. Inaccurate root length determination can lead to treatment failure, requiring re-treatment or even tooth loss in some cases. Therefore, modern imaging techniques are vital tools for enhancing diagnostic accuracy and making informed treatment decisions. X-ray techniques play a very important role in diagnosis and then treatment. The most common types of medical X-ray machines used are conventional computed tomography (CCT) radiography and cone-beam computed tomography (CBCT). Both CCT) and CBCT techniques stand out as primary tools in this regard. Conventional CT has been one of the most widely used tools in dental clinics for decades and still providing rapid images at a low cost. However, these images are two-dimensional (2D), making them less capable of providing the detailed information required in complex cases which needs more accuracy. In contrast, CBCT represents a significant advancement in imaging technology, offering three-dimensional images rich in detail, which allows dentists to evaluate teeth and roots more accurately and comprehensively, especially in complicated cases, as well as in the design and manufacture prosthetic organs [1-5]. When CBCT also has many limitations, especially in the cases of metal restorations and root fillings, which may cause unwanted image (produce undesirable) image resolution induced distortions [6-7]. In addition to imaging techniques, Apex Locator is an essential tool for accurately determining root length. This device relies on measuring the electrical resistance inside the root canal to reliably determine the apical foramen. It is used in all types of root canal treatments to ensure that the correct root length is achieved without damaging the surrounding tissues [8]. However, many hospitals and clinics still rely on conventional CT scanning to differentiate the diagnosis of cancers of the larynx, laryngeal cartilage, soft tissues and lung cancer [9-11]. This, of course, promotes the continued use of conventional CCT scanning and encourages its improvement in terms of both health safety and economic benefits.

Consequently, given the widespread availability of conventional CT techniques in a number of clinics and hospitals, there are also some significant limitations to the use of CBCT techniques. The important question remains: How can we improve the accuracy of conventional radiography measurements, in addition to being a simple, easy and economical tool for imaging procedures, besides being comfortable for patients? A large number of studies have been conducted that focused on the operation, accuracy and comparison of dental X-ray techniques [12-27]. Several previous studies have found no specific consistency in the results of evaluating the accuracy of linear measurements using CT in root canal length determination in Endodontic [28-29]. While correlation between the reference standard of CBCT technique has been presented in a little number of studies in the last ten years [30-35]. While there is no single study that provides a method to deduce an accurate experimental relationship between measurements using CCT and CBCT to maximize the benefit of traditional devices that are still operating efficiently in government clinics and hospitals.

Hence, this research is concerned with trying to find an appropriate answer to the above mentioned question, by presenting an innovative scientific method to improve the accuracy of medical CCT measurements. Thus, there is a need to determine the relationship between the two techniques in terms of accuracy of measurements. In a more professional sense, if a CBCT device is not available when performing diagnostic operations here the conventional device can be used with the use of the proposed method that is the subject of this study. Therefore, this research aims to present a new comprehensive empirical formula based on comparing the practical results between CBCT and CCT radiography in determining root length using Apex Locator in order to improve the accuracy of diagnosis and treatment. In addition, important technical aspects such as radiation dose, cost, time and patient comfort will be compared, with the aim of providing new recommendations regarding the optimal imaging technique for clinical dental practices.

Common Types of X-Ray radiography Techniques in Dentistry

The idea of X-ray computed tomography first appeared in the early 20th century, when Italian radiologist Alessandro Vallibona invented CT using a radiographic film to view a single slice of the body [26-38]. In the early 1930s, Dr. Bernard George Zedsis Des Plantes developed a practical method for applying this technique, known as focal plane computed tomography [39], which relies on the mechanical movement of the X-ray beam source and the capture film in unison to ensure that the desired plane remains in focus while blurring objects outside the plane being examined. In October 1963, William H. Oldendorf received a U.S. patent for his invention of a radiant energy device for investigating selected areas of internal objects obscured by dense materials [40]. The advent of computers led to scientific advances in the late 1960s and early 1970s that led to the development of the first practical CT scanners. The first clinical CT scan was performed in a London hospital in 1971 using a scanner invented by Mr. Godfrey Hounsfield [41]. Then, the first commercial CT technique was installed at Mayo Clinic, USA in 1973.

As is known, during the diagnostic process and before the treatment process, CBCT can be used to provide a three-dimensional image that clearly reveals the details of the root canals. If CBCT is not available, CCT is used to estimate the approximate length of the root canal. During the treatment process: Apex Locator is used to accurately measure the effective length using the electrical resistance inside the canal. After the treatment process: CBCT or CCT is used to ensure the success of the filling process. If the size of the area of interest to be irradiated is controlled by CCT, the radiation dose can be reduced, see Figure 1. In such control, it can be said that the radiation dose of the CBCT technique will be higher than that of the CCT in dentistry [15]. While without control, the radiation dose of the CCT technique is the largest [16]. Therefore, it will review the theory of work and use of each of them as follows:

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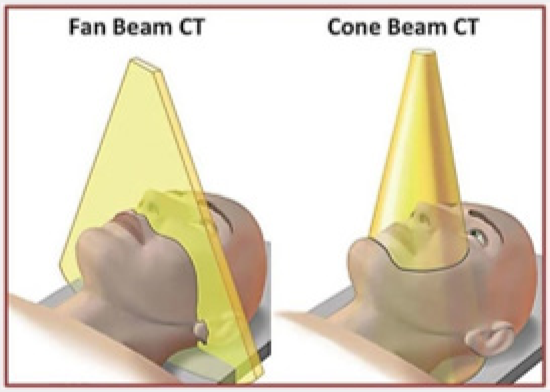
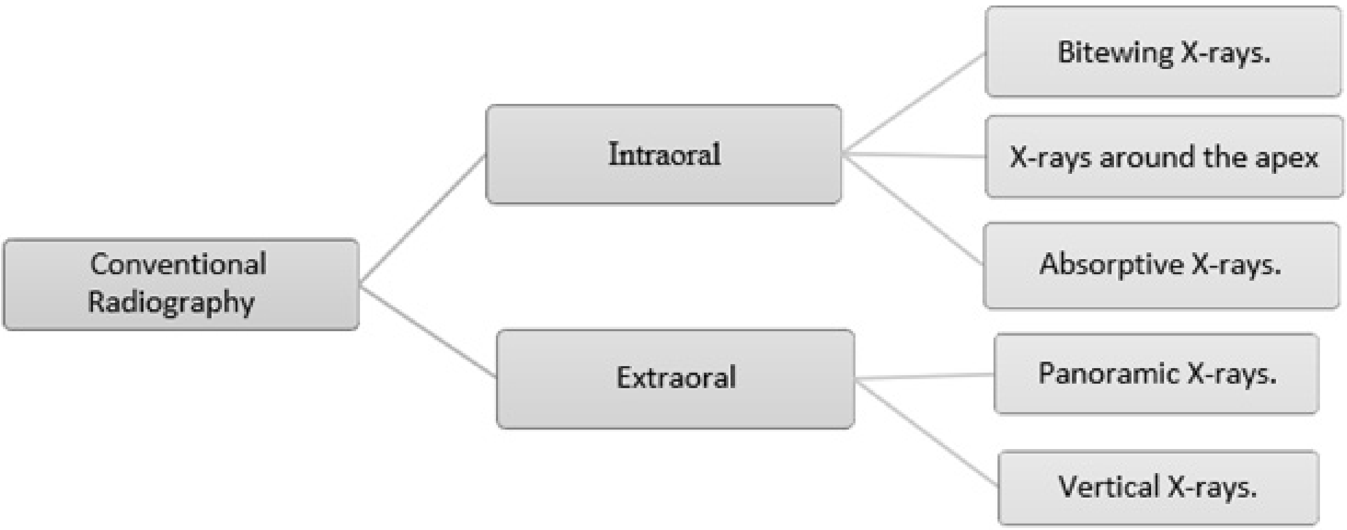


Figure 1: X-ray shape in both CBCT and CCT when controlling the size of the irradiated area.

CCT Technique

Since 1971, conventional medical computed tomography radiography technique has been one of the primary tools dentists rely on to detect problems that may not be visible during a conventional clinical examination [17]. Through this technique, internal structures of the mouth, such as teeth and jaws, can be imaged, contributing to appropriate diagnosis. Radiography utilizes electromagnetic radiation to capture detailed images that clearly show the teeth and bones. The differences between radiographic techniques lie in the materials and methods used: conventional radiography employs film to capture images, while digital radiography relies on digital sensors connected to computers, significantly reducing radiation exposure. Digital radiography is safer and more effective compared to conventional radiography. Among modern techniques, CBCT is one of the prominent methods that provide highly accurate three-dimensional images, improving diagnostic precision. This technique will be discussed in more detail in the following section. Conventional radiography is widely used in diagnosing interproximal caries and detecting bone loss in the jaw. It also helps determine the need for specific treatments, such as dental implants or orthodontics. During the imaging process, a lead apron is placed to protect the patient from excess radiation, in addition to a thyroid shield. The film is then placed in the patient's mouth, and the dentist presses the button to release the radiation. It is essential for the patient to remain still during the imaging to obtain an accurate picture. Radiography in dentistry plays a fundamental role in diagnosing and treating various oral health issues, enhancing the dentist's ability to provide the appropriate treatment to the patient [8]. Conventional X-rays are divided according to the position of the film on which they will be taken, as shown in Table 1. Figure 2 shows how the imaging process is performed.

Table 1 Types of Conventional Radiography in Dentistry.



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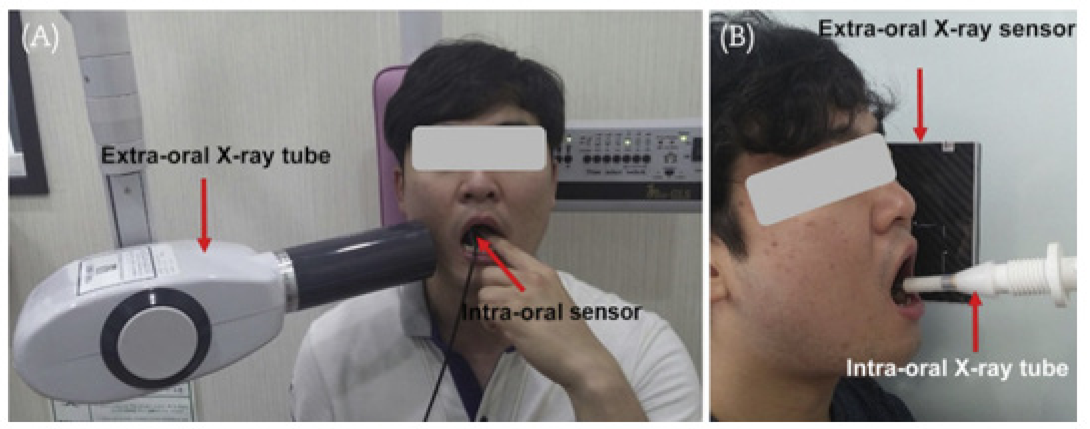

Figure 2: Operation process of CCT radiology technique [26]: (A) The device outside the mouth emits radiation and is accepted by the film inside the mouth; (B) The ready-made device is placed inside the mouth and the film is outside the mouth.

CBCT technique

CBCT was initially developed for angiography in 1982, subsequently applied to maxillofacial imaging. Only since late 1990s that it has been possible to produce clinical systems that is both inexpensive and small enough to be used in dental clinics. Emergence of cone beam Computed Tomography has expanded the field of oral and maxillofacial radiology [15]. CBCT is an advanced imaging technique used in situations where conventional dental or facial X-rays do not provide sufficient diagnostic information. This technology is distinguished by its ability to provide detailed 3D images of dental structures, soft tissues, nerve pathways, and bones in the craniofacial region in a single scan. Despite its high effectiveness, it is not used routinely due to the higher radiation exposure compared to conventional X-rays [19]. The absence of clinical reasons or symptoms that require this type of imaging is a justification for not resorting to it, as the decision to use it must be based on a careful evaluation between the desired benefits and possible risks [20]. This technique works by rotating a cone-shaped X-ray beam around the patient, generating a series of images that are then combined to create high-quality 3D images. It is more cost-effective and efficient than traditional methods, offering detailed images of bones and skeletal structures, which assist in the evaluation of jaw diseases, dental conditions, nasal cavity structures, and sinuses. However, it does not provide comprehensive information on soft tissues such as muscles and lymph nodes. Despite these limitations, its advantage lies in lower radiation exposure compared to traditional CT scans [21-30]. The CBCT device has been designed to be more compact and cost-effective, making it easier to implement in outpatient clinics. With these features, it has become an essential tool in the fields of dentistry and maxillofacial surgery, contributing to more precise treatment planning, see Figure 3 for the CBCT device [19].

Working mechanism and technical features of CBCT: The CBCT device operates by rotating a cone-shaped X-ray beam around the patient, capturing sequential images called "projections. These images are processed using advanced techniques to create a 3-D image that reveals fine details of the skeletal structures, teeth, nerves, and soft tissues in the oral and facial regions.

This technique is painless as it projects rays around the area to be imaged in the mouth and these rays are absorbed differently depending on the density of the tissues, resulting in a contrasting image. It only takes about 20-40 seconds to visualize the entire mouth through this technique [42]. This system allows the clinician to assess the health of the teeth and jaw comprehensively in a single scan, with reduced radiation exposure, thereby enhancing the ability of healthcare providers to make precise and informed treatment decisions. As shown in Figure 4, the main principles of CBCT are illustrated, demonstrating the sequence of technical processes that include generating X-rays, collecting the data, and converting it into detailed digital images [21].

Clinical applications and diagnostic benefits: CBCT is used in a wide range of clinical applications, including the evaluation and diagnosis of dental and jaw diseases, analysis of facial skeletal structures, and assessment of the nasal cavity and sinuses. CBCT is preferred for obtaining detailed, precise images of bones, nerves, blood vessels, and soft tissues such as glands and lymph nodes, which aids in more accurate treatment planning [21]. One of the key clinical applications of CBCT is its ability to precisely determine the Apex Location, a feature in which CBCT excels over traditional radiography. By providing detailed three-dimensional images, CBCT allows for the accurate determination of the root apex location, greatly aiding in the assessment of root-related issues such as infections or abnormalities. This also improves diagnostic accuracy in cases requiring surgical intervention, such as root canal treatments or dental implant procedures, by enabling the clinician to determine the relationship between the roots and the surrounding bone structures for precise and safe treatment planning.

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Figure 3: Basic operation process CBCT tomography technique.

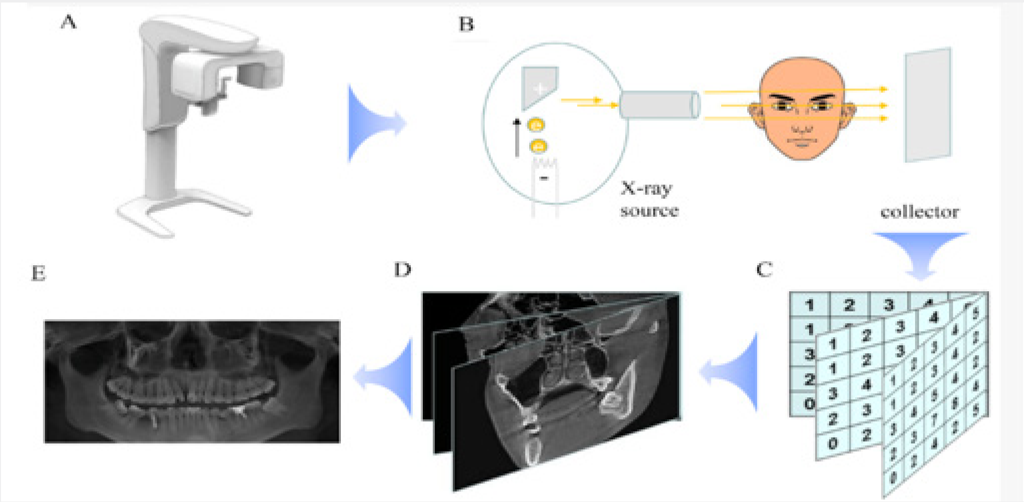

Figure 4: The main principles of CBCT: (A) The CBCT device consists of an X-ray source and a collector.(B) The X-ray source generates X-rays that penetrate the head and are collected by the collector.(C) The collector converts the X-rays into digital signals.(D) These signals are used to calculate the values of each point of the head using the Lambert-Beer Law and Radon transform.(E) Finally, the values are compiled and converted into detailed CBCT images [22].

Apex Locator

Apex Locator devices are crucial tools in endodontics, used to determine the exact location of the root canal's apex. These devices measure the distance between the coronal part of the tooth and its apex through an electrical impedance method, a process known as "conductance measurement." Accurate apex location is vital for successful root canal treatment, as it ensures proper root canal system cleaning, shaping, and filling. Choosing the most suitable device from the many available options is essential to obtain precise and effective results. How does an apex locator work? It works by passing an electrical circuit through the root canal to accurately locate the apex of the tooth. The circuit is completed when the device comes into contact with the gum tissue. Figure 5 shows the general layout and simplified diagram of how an apex locator works.

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It is important to understand how the device is used and operated to ensure correct comparison between imaging techniques such as CBCT and CCT radiography. This understanding enhances the accuracy of apex positioning, which helps improve diagnosis and treatment. It serves as an important reference in the comparison process, allowing for the evaluation of the accuracy of apex positioning by Apex Locator, its impact on dental treatment, and the effectiveness of each device in correctly identifying key points in treatment. Therefore, the benefits of conductivity measurement in root canal treatment can be summarized in the following points:

a) Determine the canal extensions where instruments can be inserted.

b) Ensure the accuracy of treatment results.

c) Reduce pain and discomfort for the patient.

Modern devices can provide some accuracy, but they may have some limitations, such as the shape of the canal or their ineffectiveness in immature teeth. It is also recommended to avoid their use in patients with pacemakers [23-24].

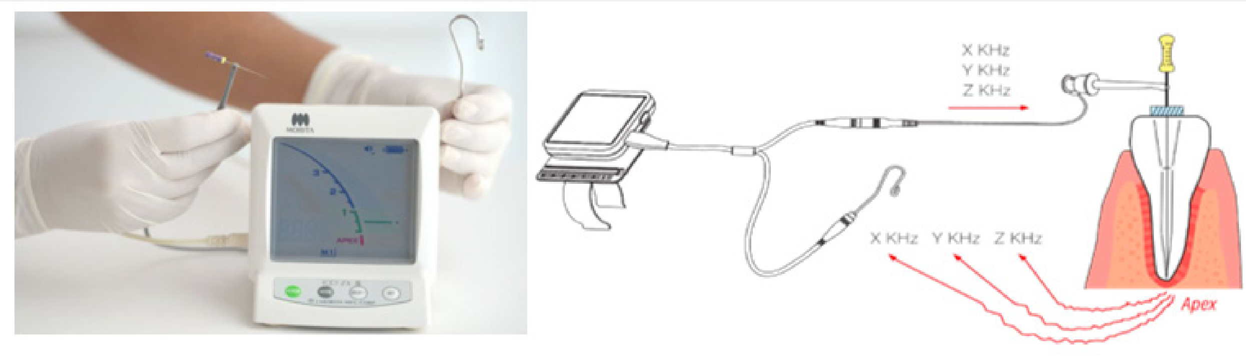

Figure 5: Apex Finder: (a) General configuration of the apex finder [23]; (b) Simplified explanation of the apex finder operation [25].

Advanced and Disadvantage of CBCT and CCT Techniques

For further clarification, during this section we will do a brief scheduled study that includes the advantages and disadvantages of each system as follows in Table1.

Correlation between CBCT and CCT Measurement Results

A group of researchers compared the accuracy of two techniques used to determine the actual length of curved root canals: the traditional Apex Locator and CBCT. Measurements were made using these techniques on 18 curved root canals in a group of patients, to examine the compatibility between the two methods in terms of accuracy and quality of measurement. Table 2 shows the results of the comparison [1] after removed the outlier value (number fifteen in the table) according to the statistical basic roles and international standard criteria [45]. Through the current study, the maximum and minimum values were identified and the average value of the measurements was calculated as shown in Table 3. Figure 6 was deduced to illustrate the relationship between the minimum, maximum and average values of the results measured using the two CCT and CBCT techniques in question.

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Table 2: Advantages and disadvantages of each CBCT and CCT technique.

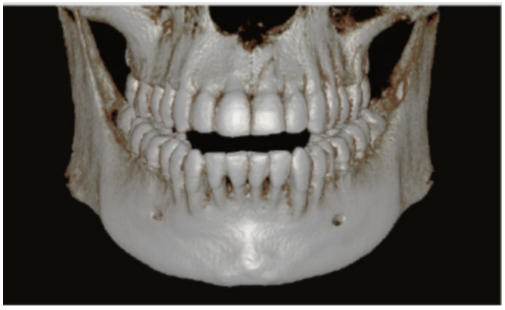
Techniques Criterions	CBCT	CCT
Accuracy	It offers very high-resolution thanks to 3D imaging, allowing a clear view of the fine details of the root canals, enhancing accurate root length determination	Limited accuracy with 2D imaging may make it difficult to identify fine details, especially in complex cases.
Radiation dose	Lower radiation dose [16]	Higher radiation dose [16], but the radiation dose can be reduced to the lowest, if the size of the area to be irradiated is controlled by directing the CCT to the area of interest [15], see Fig.1.
Cost	Higher cost due to advanced technology and the use of specialized equipment.	low cost compared to CBCT makes it more cost-effective for quick diagnostic cases and routine reviews
Patient comfort	May require the patient to remain still for a longer period during the check-up.	Very fast procedure with a short period.
Advanced clinical applications	Preferred for complex cases such as: (Endodontics, orthodontics (in cases where it is difficult for the dentist to visualize the location of the unremovable teeth using 2D images), TMJ disorders, bone diseases, and dental implants (because it determines the exact location of the canal) [43].	Primarily used for routine cases that do not require detailed imaging (e.g. regular root canal examination)
3D imaging capability	3D images provide a complete view of the tissue surrounding the canal, aiding in accurate diagnosis.	Is limited to 2D imaging restricting the ability to fully visualize the different dimensions of the tissue.
Detecting hidden issues	Hidden issues can be better detected with detailed imaging.	This technique may miss the hidden issues due to the lack of detail in the 2D image.
Examination speed	Time is needed.	A quick procedure with almost immediate results.
Impact on treatment decision	Aids in making precise treatment decisions	May lead to less accurate treatment decisions due to lack of 3D visualization of deeper issues.
Image results [44].		

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Table 3: Comparison of working length using CBCT and CCT techniques [1].

No. of Cases	CCT, mm	CBCT, mm
1	21	18.98
2	21	20.24
3	21	20.96
4	20	19.58
5	23	21.61
6	22	20.97
7	22	22.83
8	20	21.33
9	21	21.9
10	23	22.5
11	23	22.33
12	20	19.3
13	20	20.9
14	19	18.83
16	19	19.02
17	20	19.44
18	21	21.06

Equation 1 was extracted from the curve of Figure 6 using polynomial regression (second degree), where Y represents the CBCT measurement results and X represents the CCT measurement results. The relationship between the two measurement results using both CCT and CBCT techniques was analyzed using Pearson's correlation coefficient ($R^2 = 1$) via the CORREL function in Excel (2024 version), indicating a strong positive correlation between the measurements from both techniques as follows:

$$Y = 0.0200\ X^2 + 0.1592\ X + 8.5779 \text{ ....(1)}$$

From table no.3, the accuracy of the measurement results of the conventional CCT technique compared to CBCT can be estimated as follows:

$$CCT_{\text{Accuracy at min}} = 1-[(19-18.83)/19] = 0.9911 = 99.11\%,$$

$$CCT_{\text{Accuracy at max}} = 1-[(23-22.83)/23] = 0.9926 = 99.26\%; \text{............(2)}$$

$$CCT_{\text{Accuracy at average}} = 1-[(20.94-20.69)/20.94] = 0.9881 = 98.26\%$$

The mean relative error was estimated to be 100% - 98.26% = 1.74% (±0.87%), not more than 10%, which confirms the validity and efficiency of the proposed measurement method. On the other hand, the equation no.3 showed that the error range did not exceed the error limits of CBCT measurements referred to in the previous literatures [46-49]. This it can say that the relative error range that expresses the measurement accuracy of the proposed method was within the limits of ±0.87%, i.e. less than 10% and within the error limits of CBCT measurements which estimate confirms the high degree of confidence in the results and the validity and efficiency of the procedures followed in evaluating the proposed measurement method.

Result Analyses and Evaluation

The results showed that CBCT was more accurate in measuring the working length of root canals compared to conventional radiography (CCT), which provided acceptable but less precise measurements. Table 3 presents the important values of the measurement results, while Figure 6 illustrates the graphical representation, which helped derive the empirical relationship between the measurement results obtained from both techniques. The estimated equation no.1 represents the proposed empirical formula as follows:

$$\text{Proposed result} = 0.0200\ (CCT_{\text{result}})^2 + 0.1592\ (CCT_{\text{result}}) + 8.5779 \text{....... (3)}$$

From the nonlinear polynomial regression equation 3, the empirical formulas show that the proposed result has high sensitivity coefficients of 0.1592 to the measured result of CCT(X) within low sensitivity coefficients of 0.0200 to the square of the measured value of CCT(X) with potential measurement result of 8.5779 mm. Although the results showed a significant correlation, CBCT outperformed conventional radiography by less than 2% in accuracy, making it the preferred choice for cases requiring precise measurements. However, despite CBCT's superiority in accuracy, CCT remains an economically viable and easy-to-use option due to the availability of equipment, making it the best choice for less complex cases and clinics that require fast and cost-effective techniques. Nevertheless, the nonlinear variation in results may affect measurement accuracy, making the combined use of both methods beneficial in certain clinical cases to minimize errors and enhance precision. Thus, the following can be clearly observed and evaluated:

1. CBCT and CCT can be considered complementary tools, where the choice of the most appropriate technique depends on the complexity of the dental case, ultimately enhancing diagnostic accuracy and supporting more effective treatment decisions. Figure 6 presents the comparison analyses and conclusions reached, along with the advantages of each technique compared to the other in several aspects.

2. So, it can be said that the derived empirical equation is novel in its ability to determine the correlation between the measurements of the two techniques with a high accuracy of over 98%. This providing a new, easy, and accessible method for converting the measurements obtained using the CCT technique into higher-accuracy results comparable to those obtained using the CBCT technique with high accuracy. This may enable dentists who do not have CBCT technology and who do have CCT technology to rely on it to accurately estimate the length of the root canal for diagnosis and treatment.

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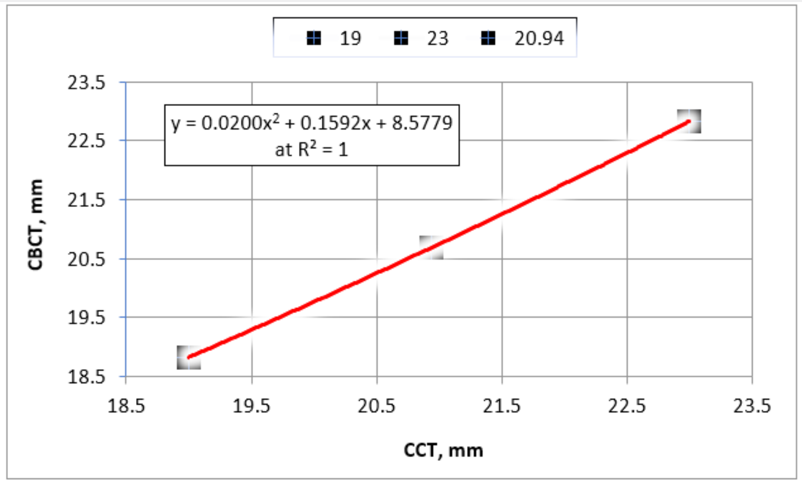

Figure 6: Illustration of relationship between the data of Table3.

Diagnostic and Treatment Procedures

a) During the diagnosis process: CBCT technology is used, if available, to obtain a three-dimensional image that clearly reveals the details of the root canals such as dimensions and curvatures. In the event that CBCT technology is not available, CCT which is characterized by simplicity and speed of use with patient comfort we can be used and with equation 3 can estimate the approximate length of the root canal, accurately.

b) During the treatment process: Apex Locator is used to accurately measure the effective length by determining the electrical resistance inside the canal, which reduces the need for repeated X-rays.

After the treatment process: CBCT or CCT technology is used to ensure the success of the filling process and the absence of gaps. The CBCT device is more accurate than conventional radiography (CCT), especially in difficult cases. The new: in the event that CBCT technology is not available, CCT technology is used to estimate the approximate length of the canal with the possibility of using the proposed method, which is based on use empirical formula (equation no. 2) under study to obtain accuracy comparable to CBCT technology while maintaining simplicity, speed of use and patient comfort. Here, the role of this paper becomes clear in presenting a new empirical formula that enables the dentist who has the traditional CCT technique to obtain highly accurate measurement results.

Conclusions

In this study, a comparative evaluation in biomedical technology was conducted between clinical measurements using both CBCT and CCT techniques, along with the use of Apex Locator, to determine the root canal length in dental treatments. Based on the comparative analysis using statistical Pearson's correlation coefficient method, the following conclusions could be drawn:

i. A new empirical equation (no.3) was deduced to determine the correlation between the measurements of the two techniques with an average accuracy exceeding 98%, which may enable dentists to rely on it to estimate the root canal length for diagnosis and treatment with great accuracy, if CBCT technology is not available.

ii. The possibility of using the proposed method, according to empirical equation (no.3), to improve measured results makes conventional X-ray CCT technique an effective option in terms of accuracy, in addition to its low cost, scanning speed, and patient comfort. It also excels in diagnosing other diseases such as cancers of the larynx, laryngeal cartilage and soft tissues, especially since CBCT requires specific and binding conditions, longer time in scanning operations, doses, and cost as mentioned above.

iii. The relative error range, which represents the accuracy of the measurement using the proposed method, was within ±0.87%, i.e., less than 10%, and within the error range of cone-beam computed tomography (CBCT) measurements. This estimate confirms the high degree of confidence in the results and the validity and efficiency of the procedures used to evaluate the proposed measurement method.

Eventually, CBCT remains the preferred choice for complex cases requiring high accuracy in root canal measurement, while conventional radiography remains suitable, as the chosen new strategy method (proposed empirical equation no.3) ensures the necessary balance between accuracy, cost-effectiveness, time and patient comfort, contributing to improved quality in dentistry and informed treatment decisions based on the specific nature of each case.

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