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Accuracy of Cone-beam Computed Tomography in diagnosing root canal configuration: a literature review

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ABSTRACT

Objectives: This review article aims to describe the accuracy of cone-beam computed tomography (CBCT) in diagnosing root canal configuration.

Review: This study is a literature review consisting of English articles about the accuracy of cone-beam computed tomography in diagnosing root canal configuration, published in 2013 – 2023. The article search databases used were Pubmed and Science Direct with the keyword "(cone-beam computed tomography[MeSH Terms]) AND (configuration, root canal[MeSH Terms])." The selected articles were screened by checking the publication year, duplicating articles, reading the titles and abstracts, and the entire article's contents. The total search results for articles based on keywords obtained were 205 and only seven were included. In order to successfully perform root canal treatment, thorough knowledge of the root canal configuration is essential. Cone-beam computed tomography (CBCT) can improve our understanding of root canal configuration. The development of CBCT has brought to light the disadvantages of conventional radiography, which include the compression of three-dimensional anatomy, geometric distortion, and anatomical noise.

Conclusion: Radiology is essential in treatment planning, disease monitoring, and assessmen t of treatment outcomes. The development of cone-beam computed tomography (CBCT) offers three-dimensional accuracy with a reasonable cost, no geometric distortion and anatomical noise, and the ability to create cross-sectional images, revolutionizing the imaging of dentomaxillofacial structures. This imaging system has been shown to overcome some of the limitations of conventional radiography.

Keywords: *Cone-beam computed tomography, root canal configuration, radiograph*
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INTRODUCTION

Success in endodontic treatment requires understanding root canal morphology, which is fundamental for cleaning, shaping, and obturating root canals.[1,2] Therefore, a thorough understanding of their anatomic differences may help clinicians perceive those deviations during root canal therapy, enhancing the chance for successful treatment.[3]

Periapical radiography is a two-dimensional radiographic method widely used for evaluating root canal morphology. However, the disadvantages of periapical radiography are the superimposition of anatomical structures and image distortion.[1] Anatomical variations exist with each type of tooth.[4] The root canals aligned in the buccolingual plane, complex root canal systems, or calcified root canals may not be identified in periapical radiography.[1] The two-dimensional nature of radiographs means that they do not always reveal the actual number of canals present in teeth. This may lead to the inability to identify all the root canals present and lead to a poorer outcome of the root canal treatment.[4]

Limitations of conventional 2D imaging techniques describe the amount of information gained from conventional film and digitally captured intraoral and panoramic imaging is limited by the fact that they are two-dimensional (2D) representations of three-dimensional (3D) objects. The objects are visualized in the mesial-distal and apical-coronal lanes; however, the buccolingual plane is not possible to assess. Anatomical structures surrounding the teeth may superimpose, causing anatomical noise and leading to difficulty in interpreting periapical radiographs. 2-D radiographs show less severe bone destruction than is actually present, and soft-tissue-to-hard-tissue relationships are not revealed.[5] In case periapical radiography shows some doubtful extra canals or a complex morphology, CBCT should be used for further clarification.[6]

Cone-Beam Computed Tomography (CBCT) is an

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extraoral imaging system specifically designed for three-dimensional imaging of the oral and maxillofacial structures. Most of the limitations of conventional radiography, such as the compression of three-dimensional objects into a two-dimensional image, image distortion, and anatomic superimposition, are overcome with cone-beam computed tomography (CBCT). CBCT produces clear, higher-resolution images with reduced radiation and at a lower cost when compared to medical CT. It is a faster, compact, and safer version of medical CT. The time it takes for a full scan is usually under a minute, and the radiation dose is several times lower than the CT scanner.[7] The appropriate use of CBCT helps determine an accurate diagnosis, which helps in treatment planning.[8]

Based on that, a literature study on the accuracy of using CBCT is important in optimizing the results of radiographic images in dental practice to determine the right diagnosis and treatment plan. This research is a literature review consisting of English articles published in 2013-2023. The sample used was restricted to free-full text and open-access articles written in the English language and published, with inclusion criteria discussing the accuracy of cone-beam computed tomography in diagnosing root canal configuration. Articles were obtained by searching through PubMed and Science Direct. Articles searches were carried out using a Boolean Operator Strategy to get specific and structured results with the main keyword "(cone beam computed tomography[MeSH Terms]) AND (configuration, root canal[MeSH Terms])." The selected articles were screened by checking the publication year, duplicating articles, reading the titles and abstracts, and the entire article's contents. Inclusion criteria were developed using the PICOS framework (Population: root-canal configuration, Intervention: cone-beam computed tomography examination, Comparison: not available, Objective: accuracy cone-beam computed tomography in evaluating and diagnosing root canal configuration which includes the compression of three-dimensional anatomy, geometric distortion, and anatomical noise at the quality of the radiographic image, Study design: descriptive observational). The search for literature related to the research topic about the accuracy of CBCT in diagnosing root canal configuration was carried out. Then a filter was applied in the database search engine based on the year (2013 – 2023), and the availability of free full-text articles and open-access articles. The identified articles were screened by checking for duplicates, reading the titles and abstracts, and reading the entire articles. From 2 databases, 205 articles were found: 143 articles from Pubmed, and 62 articles from Science Direct. Then, a duplication check was carried out, the remaining 103 journals were obtained. The screening was done by reading the title and abstract, 96 articles were excluded for not being relevant to a topic. The final result was obtained only seven articles were included.

REVIEW

ROOT CANAL CONFIGURATION CLASSIFICATION SYSTEMS

Weine's Classification. Root canal configuration was classified by Weine et al. from type I to type IV as follows (Figure 1. A): Type I: a single canal from the pulp chamber to the root apex. Type II: two

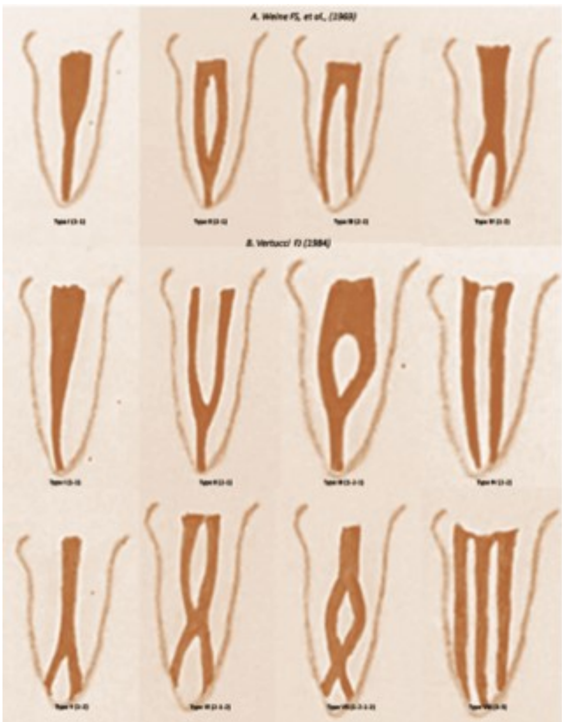

Figure 1. The root canal configurations from the pulp chamber to ther root apex according to Weine FS et al. (A/upper part) and Vertucci FJ (B/lower part)[10]

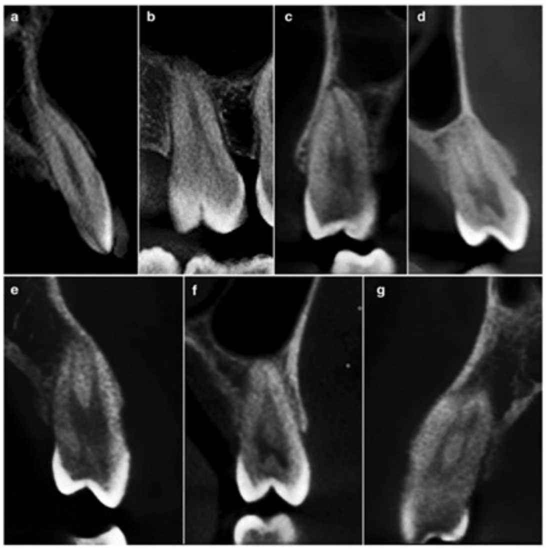

Figure 2. CBCT images of maxillary teeth in custom planes (reconstructed based on axial, sagittal, and coronal planes) based on Vertucci's classification. (a) Type I – right maxillary central incisor; (b) Type II – right maxillary first molar; (c) Type III – right maxillary second premolar; (d) Type IV – left maxillary first Premolar; (e) Type V – left maxillary first premolar; (f) Type VI – left maxillary second premolar; (g) Type VII – right maxillary first premolar[12]

separate canals start from the pulp chamber and then, during their course, unite into one. Type III: two separate canals from the pulp chamber to the root apex. Type IV: a single canal starting from the pulp chamber and dividing into two canals near the root apex.[9,10,11]

Vertucci's Classification and Its Supplemental Configurations. Vertucci classified root canal morphology into eight types described as follows (Figure 1. B), CBCT images shown in Figures 2 and 3.[12] Type I: a single main canal is present, starting from the pulp chamber to the root apex. Type II: two separate canals leave the pulp chamber but join to form one canal to the apex. Type III: one canal leaves the pulp chamber and divides into two smaller canals that merge again to exit through one canal. Type IV: two separate canals run from the pulp chamber to the root apex. Type V: A single canal exiting the pulp chamber divides into two canals with separate apical foramina. Type VI: two separate canals join at the middle of the root to form one canal, which extends to the apex, just short of the apex, and again divides into two. Type VII: the canal starts as a single until the middle third of the root, then divides into two separate canals that rejoin after some distance and then, near the apex, divides into two again. Type VIII: the pulp chamber near the coronal portion divides into three separate canals extending to the apex.[9,10,11]

By clearing technique, Sert S and Bayirli GS evaluated root canal configurations in a Turkish population in 2800 mandibular and maxillary permanent teeth. They also added fourteen new root canal configurations to Vertucci's classification. They numbered them from Type IX to Type XXIII, described as follows (Figure 4): Type IX: a single canal starts from the pulp chamber and, during its course, divides into three. Type X: a single canal starts from the pulp chamber and divides into two, out of which one canal further divides into two with two foramina. Type XI: a single canal starts from the pulp chamber and divides into two, out of which one further subdivides into two and runs as three canals and ends with four foramina. Type XII: two separate canals start from the pulp chamber, out of which one further subdivides into two and, later, all three join to form one canal with one foramen. Type XIII: a single canal starts from the pulp chamber and divides into two canals that rejoin as one and divide into three canals with three

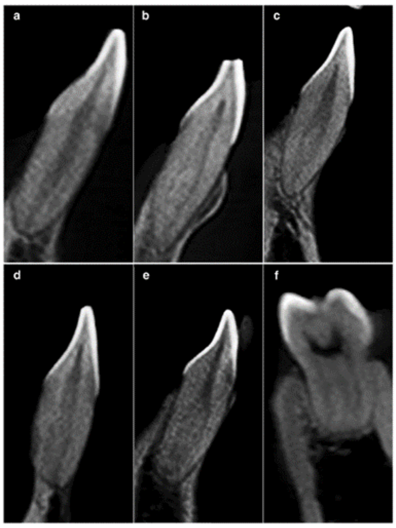

Figure 3. CBCT images of mandibular teeth in custom planes (reconstructed based on axial, sagittal and coronal planes) based on Vertucci's classification. (a) Type I – left mandibular central incisor; (b) Type II – right mandibular central incisor; (c) Type III – left mandibular lateral incisor; (d) Type IV – left mandibular central incisor; (e) Type V – right mandibular left lateral incisor; (f) Type VIII – left mandibular first molar[12]

foramina. Type XIV: four canals start from the pulp chamber; two of each will later join and end with two foramina. Type XV: three canals start from the pulp chamber, out of which two join to form one canal and end with two foramina. Type XVI: two canals start from the pulp chamber, out of which one further subdivides into two and ends with three foramina. Type XVII: a single canal starts from the pulp chamber and divides into three canals which again rejoin to form a single canal with a single foramen. Type XVIII: three canals start from the pulp chamber and rejoin to form a single canal with a single foramen. Type XIX: two canals start from the pulp chamber and join as a single canal, further divide into two, and rejoin as one canal with a single foramen. Type XX: four canals start from the pulp chamber and end with four foramina. Type XXI: four canals start from the pulp chamber and join as a single canal with a single foramen. Type XXII: five canals start from the pulp chamber, one joins with another and ends as four canals with four foramina. Type XXIII: three canals start from the pulp chamber, out of which one further divides into two and ends with four canals with four foramina.[9,10,11]

Kartal N et al. reported two new root canal configurations (Figure 5. A) in mandibular anterior teeth. Type I: Root canal configuration (1-2-1-3), One canal starts from the pulp chamber and divides into two in the middle third. These two canals join again into one canal and divide into three canals before exiting from the root apex. Type II: Root canal configuration (2-3-1), Two separate canals that extend from the pulp chamber to mid-root where the lingual canal divides into two; all three canals then join in the apical third and exit as one canal. Kartal N et al. divided Vertucci's Type II into two subgroups Type IIa: Two separate canals merge into one canal before reaching the apex; Type IIb: Two separate canals joining within the apical foramen and then exiting one apical foramen.[9,10,11]

Gulabivala K et al. examined mandibular molars in a Burmese population and added seven additional configurations (Figure 5. B) to Vertucci's Type I to Type VII classification. These configurations classified 4 or 5 canals extending from the orifice also. These additional configurations were as follows: Type I (3-1): The pulp space separates into three and joins in its course into one. Type II (3-2): The pulp space separates into three, and two of them join into one during its course to exit as two root canals. Type III (2-3): The pulp space separates into two canals in the coronal portion, and then one canal further divides into two and exits as three canals from the apex. Type IV (2-1-2-1): The pulp space separates into two canals and joins into one during its course and then further divides into two canals and at the apex join into one and exit as one canal. Type V (4-2): The pulp space in the coronal portion separates into four then during its course two canals join together and exit as two canals at the apex. Type VI (4-4): The pulp chamber near the coronal portion divides into four separate root canals extending to the apex of the root. Type VII (5-4): The pulp chamber near the coronal portion divides into five separate canals, and during its course, one canal joins with another canal and exits as four canals.[9,10,11]

The New Classification by Ahmed et al. Ahmed et al.'s classification system provides a single code for the tooth number, the number of roots (considering any division of roots as two or more roots), and the canal configuration, giving a logical and accurate classification. One important facet of the new system is that teeth with the same canal configuration and separate roots are described as single code, accurately reflecting their anatomy. It can also describe the previous non-classifiable root

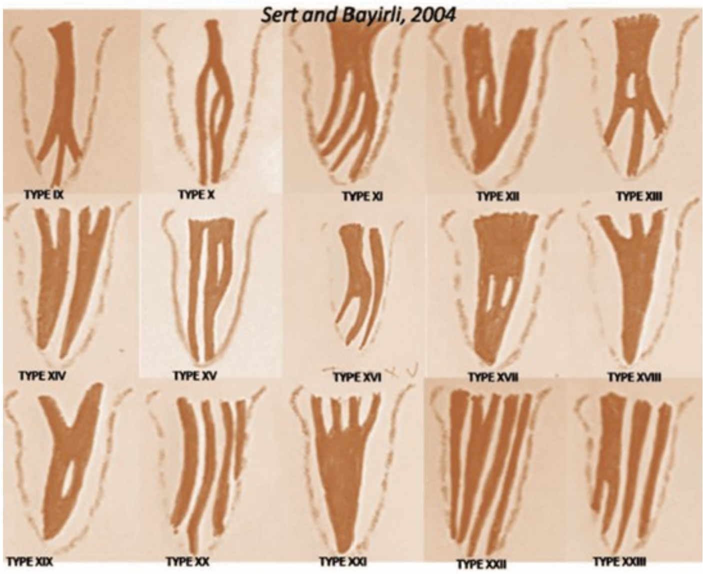

Figure 4. Root canal configurations from the pulp chamber to the root apex, according to Sert and Bayirli[10]

Figure 5. Root canal configurations from the pulp chamber to the root apex according to Karta N et al. (A/left part) and Gulabivala K et al. (B/right part) Bayirli[10]

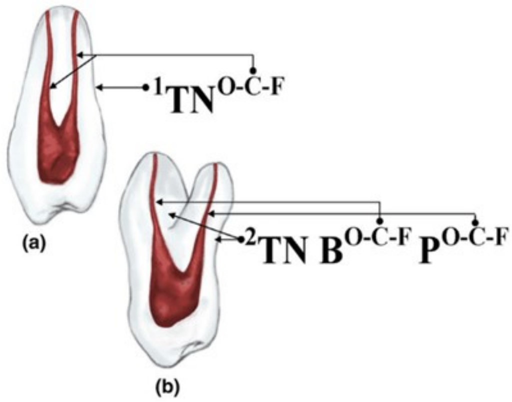

Figure 6. Diagram describing the new classification system for the description of root and canal anatomy as proposed by Ahmed et al. in 2017. TN, tooth number; O, orifice; C, canal; F, foramen. The left superscript number represents the number of roots (left of TN). Root canal configurations are described per root (B, buccal; P, palatal)[13]

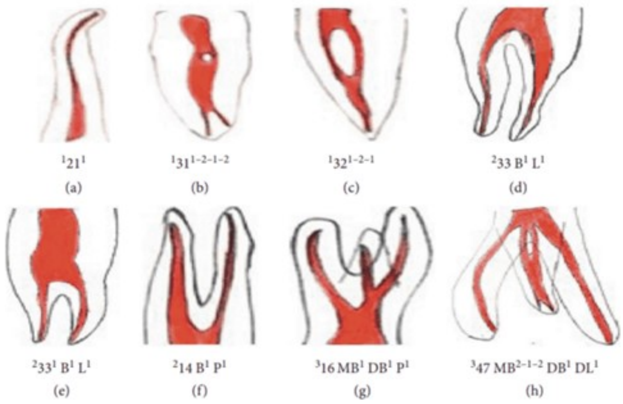

Figure 7. Examples of classification of root canal configuration by Ahmed et al.[9]

canal morphologies with a simple single code giving exact anatomy. Furthermore, it overcomes the confusion of how to define complex intercanal communications.[9]

ACCURACY OF CONE-BEAM COMPUTED TOMOGRAPHY

Radiographic examination is essential for diagnosis and throughout the endodontic treatment. However, two-dimensional conventional in-traoral techniques and the resulting superimpo-sition of structures and geometric distortion of anatomical structures are significant problems due to potential morphological masking. This can lead to diagnostic or therapeutic complications. CBCT obtains three-dimensional images that allow us to explore the area in the sagittal and coronal planes. This provides accurate information on root and canal morphology, and its use is recommended for root and canal morphology variations. The use of CBCT has already been suggested in cases of aberrant root morphology.[15]

Cone-Beam Computed Tomography is a relatively new diagnostic method that may be beneficial when conventional radiographs provide narrow information while more details are desired. CBCT imaging has advantages such as lower size and price (compared to conventional CT), fast acquisition, submillimeter resolution, relatively low patient radiation dose (compared to conventional CT), and interactive analysis. The most important advantage of CBCT as a non-invasive technique over

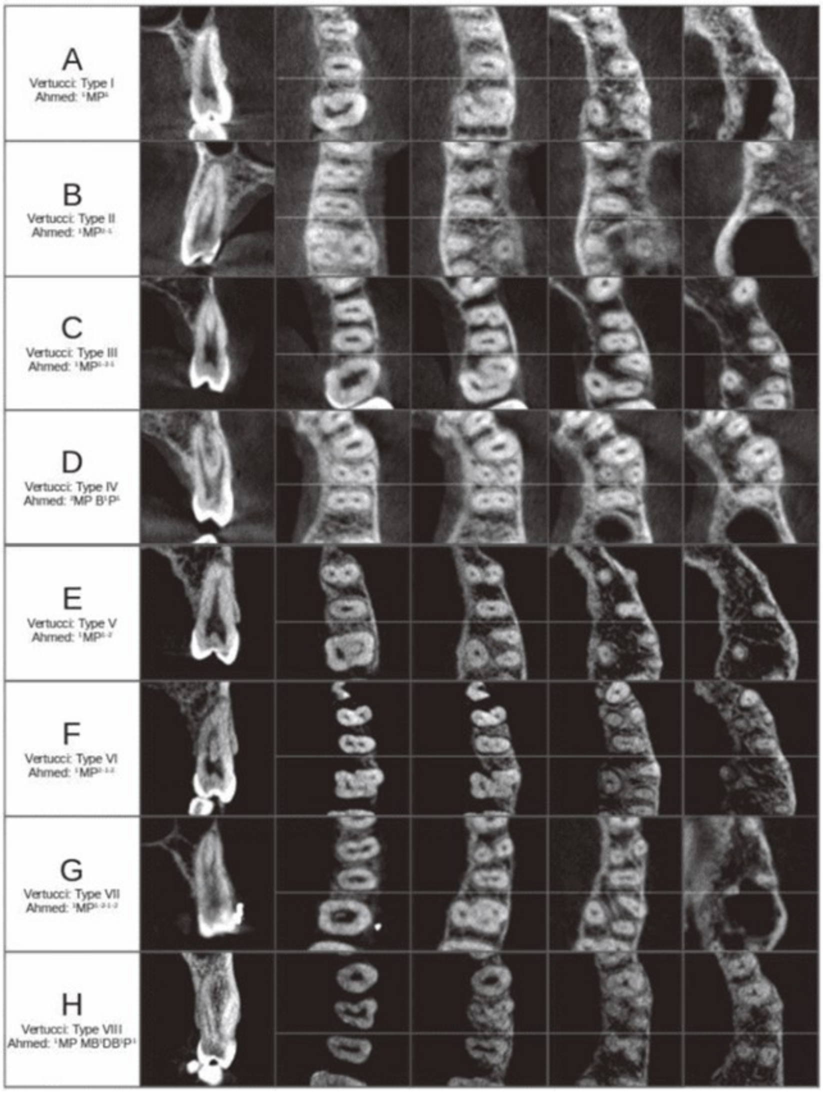

Figure 8. Several common canal configurations are demonstrated using coronal and axial sections of CBCT scans. All Vertucci types are represented, and the corresponding Ahmed et al. classifications are included below[13]

other conventional radiography techniques, such as intraoral and panoramic radiographs, is that it exhibits anatomical features in high-quality 3D images without superimposing structures. In addition, the CBCT enables dentists to examine the anatomy of structures in sagittal, coronal, and axial sections. Given the pervasive use of CBCT in dentistry and the significance of knowing the number of root canals in root canal treatment.[16]

CBCT technology in clinical dental practice provides many advantages for maxillofacial imaging. This modality is very compact equipment with higher resolution resulting in sharper images and better diagnosis. Produces a 3D rendition of a 2D image and provides geometrically accurate images. Increased specificity for caries, periodontal and periapical lesions when compared to conventional CT and periapical radiographs. Small FOV – hence possible to have images of only the area of interest. Fewer metal devices. Less exposure time and lower radiation dose when compared to medical CT. Patient comfort increases when compared to traditional intra-oral radiographs as there is no placement of intra-oral film or sensors. Also, for most equipment, the patient is in a sitting position and not lying down, further increasing the comfort and acceptance of the patients. Good soft tissue rendition when compared to traditional 2D imaging.[5,17]

The principle of “as low as reasonably achievable,” regarding exposing patients to ionizing radiation, was strictly adhered to during image acquisition.[9] If the objective of the examination is hard tissue only, using a CBCT would not be a problem; however, CBCT is not sufficient for soft tissue evaluation. A significant issue affecting the image quality and diagnostic accuracy of CBCT images is the scatter and beam hardening artifacts caused by high-density adjacent structures, such as enamel and radiopaque materials, such as metal posts, restorations, and root filling materials. Additional artifacts that may obscure radiographic findings are patient movement during the scan and volume reconstruction. Despite the provision of the third dimension, the spatial resolution of CBCT images (0.4mm to 0.076mm or equivalent to 1.25 to 6.5 line pairs per mm−1 (lp.mm−1)) is inferior to conventional film-based (approx. 20 lp.mm−1) or

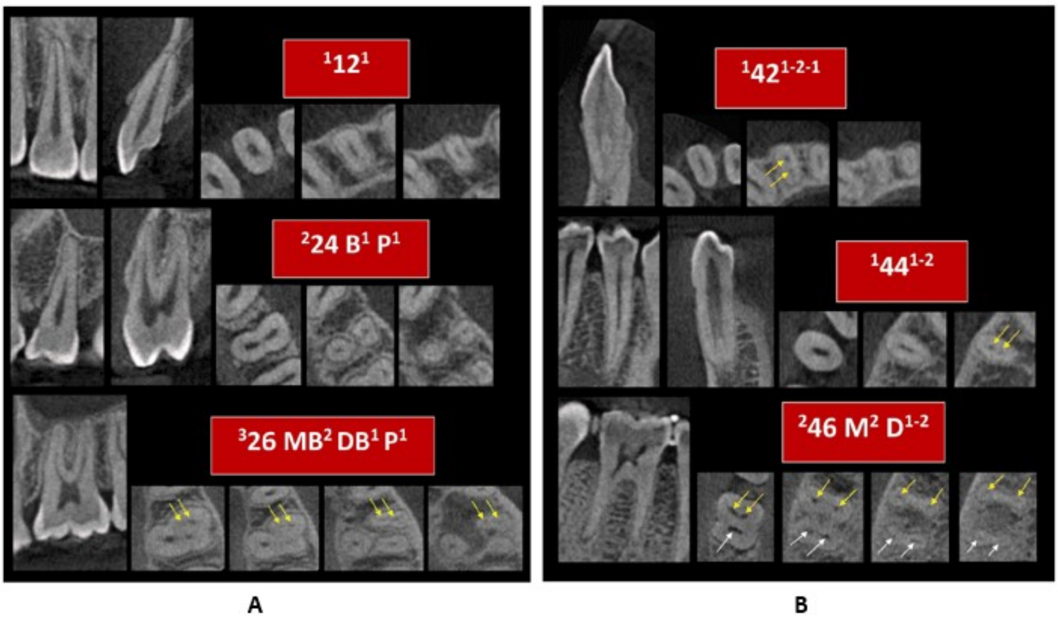

Figure 9. Examples of Ahmed et al. classifications in maxillary teeth (A) and mandibular teeth (B) in CBCT scans[14]

digital (ranging from 8–20 lp.mm−1) intraoral radiography.[5,17]

CBCT provides three-dimensional visibility of the region and accurate detail and resolution of the dental and alveolar anatomy. This improves the diagnosis of various pulpal and periapical malformations and pathologies. However, CBCT has known limitations, including potentially overexposing patients to radiation. Although the effective dose of CBCT is lower than that of a regular CT, it is much higher than that of conventional periapical intraoral radiographs.[15,18,19,20]

DISCUSSION

The articles found that CBCT is reliable as a precise diagnostic device to detect root canals. All articles considered for the study are shown in Table 1. In their article, Kajan et al. (2018) showed that CBCT provides accurate information about root canal morphology. Application of this technique could result in more successful endodontic treatment. Mohsen et al. (2021) showed that CBCT is a safe and non-invasive tool that can detect root canals if other low-dose radiation imaging techniques do not provide acceptable results. Khalifa et al. (2023) state in their article that CBCT is a non-invasive imaging modality that can be used to accurately detect root canal morphology when other intra-oral low-dose imaging techniques do not provide conclusive results.[16,21,22]

In another article by Arslan et al. (2014) showed that CBCT may be recommended as an effective diagnostic device for identifying complex root canal configurations. The prevalence of complex root canal configuration was higher in males than in females. Asgary et al. (2015), in their article, showed that CBCT has acceptable diagnostic accuracy for the measurement of canal wall thickness. Aung et al. (2021) state in their articles that CBCT is informative for detecting the second canal. Clinicians should remember that the accuracy can vary in different types of teeth, with the prevalence of second canal across different populations and with the spectrum of second canal anatomy, despite the reviewers having postulated overestimation of the findings. In an article written by Pathak et al. (2015), cone beam computed tomography is an invaluable endodontic tool for use before, during, and after treatment CBCT scanning drives diagnostic accuracy, which positively impacts clinical decisions, increases the speed of treatment and improves productivity and patient outcomes. In short, it has provided the greatest advancement in digital imaging over the past decade.[23,24,25,26]

Knowledge of root canal configuration with their variation is important for successful nonsurgical root canal treatment. This is followed by negotiation, cleaning, shaping, and obturation of the entire canal system in three dimensions. Various root canal configurations have been evaluated in different studies. The earliest clinical classifications of more than one canal system in a single root were given by Weine and Vertucci. These classifications were further elaborated by Gulabivala et al., who studied the root canal morphology of mandibular molars and identified seven additional canal types. In addition to Vertucci's classification, a new classification was given by Sert and Bayirli, explaining 14 new canal types (Type IX–Type XXIII). Ahmed et al.'s classification system provides a single code for the tooth number and number of roots considering the further division of roots as two or more roots, including the canal configuration; hence, it is considered a more logical and accurate classification.[9,27]

Advanced imaging technique such as CBCT has proved to be an additional diagnostic tool in revealing the internal and external anatomy of

Table 1. Articles included in this study

AUTHORS (YEAR)	TITLE	OBJECTIVE	FINDINGS AND CONCLUSION
Zahra Dalili Kajan, Mehran Taramsari, Negar Khosravi Fard, Mohsen Kanani (2018)	Accuracy of Cone-Beam Computed Tomography in Comparison with Standard Method in Evaluating Root Canal Morphology: An In Vitro Study	The goal of the present study was to compare the accuracy of CBCT in revealing the number and form of the root canals of different maxillary and mandibular teeth with clearing and staining method.	CBCT provides accurate information about root canal morphology. Application of this technique could result in more successful endodontic treatment.
Masoumeh Mohsen pourian, Azin Alasvand Javadi, Mohammad Yazdizadeh (2021)	The accuracy of cone-beam computed tomography in the detection of the number of root canals: An in vitro study	The aim of this study was to examine the accuracy of cone-beam computed tomography (CBCT) as a diagnostic tool to detect the root canals of maxillary first premolars in a selected Iranian population.	It seems that CBCT is a safe and non-invasive tool that can be used to detect root canals if other low-dose radiation imaging techniques do not provide acceptable results.
Shrouk Fathy Khalifa, Wael Selim Amer, Asmaa Youssry Abdullah (2023)	Accuracy of cone beam computed tomography with standard resolution for detection of mesiobuccal root canal anatomical variations in maxillary molars	To determine the accuracy of standard resolution cone-beam computed tomography (CBCT) in detection of the Mesiobuccal root canal morphology of maxillary molars.	CBCT is a non-invasive imaging modality that can be used to accurately detect root canal morphology when other intra-oral low-dose imaging techniques do not provide conclusive results.
Hakan Arslan, Huseyin Ertas, Elif Tarim Ertas, Fahrettin Kalabalık, Gokhan Saygılı, Ismail Davut Capar (2014)	Evaluating root canal configuration of mandibular incisors with cone-beam computed tomography in a Turkish population	The aim of this retrospective study was to analyze the morphology of root canal systems of mandibular incisors using cone-beam computed tomographic (CBCT) images.	The CBCT may be recommended as an effective diagnostic device for identifying complex root canal configurations. The prevalence of complex root canal configuration was higher in males than in females.
Saeed Asgary, Sima Nikneshan, Alireza Akbarzadeh-Bagheban, Naghmeh Emadi (2015)	Evaluation of diagnostic accuracy and dimensional measurements by using CBCT in mandibular first molars	This study aimed to assess the diagnostic accuracy of cone beam computed tomography (CBCT) and quantitatively evaluate the morphology of mandibular first molars using CBCT.	CBCT has acceptable diagnostic accuracy for measurement of canal wall thickness. Cleaning and shaping of the canals should be performed based on the unique anatomy of the respective canal; which necessitates the use of advanced imaging techniques for thorough assessment of root canal anatomy in a clinical setting.
Nyan M. Aung and Kyaw K. Myint (2021)	Diagnostic Accuracy of CBCT for Detection of Second Canal of Permanent Teeth: A Systematic Review and Meta-Analysis	The aim of this systematic review was to find the diagnostic accuracy of CBCT for detection of the second canal of the root canal system of permanent teeth.	CBCT is informative for detecting the second canal. Clinicians should keep in mind that the accuracy can vary in different types of teeth, with the prevalence of second canal across different populations, and with the spectrum of second canal anatomy in spite of the reviewers having postulated overestimation of the findings.
Seema Dhananjay Pathak, Pradnya Vilas Bansode, Shraddha Pradeep Gite, Jaishri Sanjay Pagare, Manthara Baburao Wavadhane, Shrish Bhimrao Khedgikar (2015)	Cone Beam Computed Tomography: A New Boon and a Ray of Hope to the Endodontist—A Series of Cases	This article aims to provide comprehensive information related to the cone beam computed tomography (CBCT) as a diagnostic aid and its potential applications in dentistry.	Cone beam computed tomography is an invaluable endodontic tool for use before, during, and after treatment CBCT scanning drives diagnostic accuracy, which positively impacts clinical decisions, increases speed of treatment, and improves productivity and patient outcomes. In short, it has provided the greatest advancement in digital imaging over the past decade.

teeth. Other uses of CBCT scans in endodontics include diagnosis and management of endodontic treatment complications, dentoalveolar trauma, identification of external and internal resorption, pathology of non-endodontic origin, and presurgical case planning. In addition, conservative access can be prepared to the root canals when the operator has prior knowledge of its anatomy with the help of CBCT.[27]

CBCT can be used to determine root morphology to measure the number of roots, canals, and accessory canals. Root morphology can be visualized in 3-D, as can the number of root canals and whether they converge or diverge from each other. Unidentified and untreated root canals may be identified using axial slices, which may not be readily identifiable with periapical radiographs. In contrast, with increasing resolution of CBCT, the second mesiobuccal canal (MB2) detection rate of maxillary first molar enhanced from 60% to 93.3%. CBCT has also been shown to be a reliable tool to accurately assess the degree of curvatures associated with the roots of teeth. It also easily identifies C shaped root canal system.[5]

Scientific literature indicates that CBCT is more accurate than radiography in dentofacial anatomical and pathological imaging structures. Studies have shown CBCT to be accurate and reliable in detecting apical periodontitis, vertical root fractures, and resorptive defects. CBCT also provides a better view of the anatomy of the root canal and pulp when compared to radiography. For example, there is a buccolingual curvature of the root is most often missed by radiography, but it can be easy to detect on CBCT images. Most often radiography gives little, or there is no information about the presence of additional channels, their shape, and curvature. However, CBCT imaging will reveal the same findings with high accuracy.[28]

CONCLUSION

Radiology is essential in treatment planning, disease monitoring, and assessment of treatment outcomes. The development of cone-beam computed tomography (CBCT) offers three-dimensional accuracy with a reasonable cost, no geometric distortion and anatomical noise, and the ability to create cross-sectional images, revolutionizing the imaging of dentomaxillofacial structures. This imaging system has been shown to overcome some of the limitations of conventional radiography.

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None.

FOOTNOTES

All authors have no potential conflict of interest to declare for this article.

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