Narrative Review

Micro-Computed Tomography as a Transformative Tool in Endodontics: A Narrative Review

Microcomputed Tomography in Endodontics

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ABSTRACT

Objective: This review article focuses on Micro-CT's role in endodontics. It provides a comprehensive understanding of Micro-CT technology, explores its applications in diagnosis and treatment planning, acknowledges challenges like radiation exposure and cost, and considers future prospects, including AI integration.

Study Design: comprehensive Literature Search

Place and Duration of Study: This study was conducted at the Department of Restorative Dentistry, College of Dentistry in Ar-Rass, Qassim University, KSA from 2020 to 2022.

Methods: A comprehensive literature search identified articles from electronic databases, focusing on Micro-CT's role in endodontics. Selection criteria included studies published in English within the last ten years, offering substantial insights into Micro-CT technology and applications.

Results: Micro-CT serves as a pivotal tool in endodontics, enabling in-depth analysis of root canal anatomy, instrumentation techniques, obturation quality, and the detection of fractures. Its non-destructive nature and sub-micrometre resolution enhance diagnostic accuracy and treatment planning. Sample preparation, scanning protocols, and image acquisition and reconstruction techniques play vital roles in Micro-CT's success. However, limitations, including radiation exposure and sample size constraints, must be acknowledged.

Conclusion: Micro-CT has significantly impacted endodontics, improving diagnosis and treatment planning. Future developments are expected to solidify its role in routine practice, enhancing patient care and advancing endodontic knowledge.

Key Words: Micro-Computed Tomography (Micro-CT), Endodontics, Imaging, Radiography

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INTRODUCTION

Micro-Computed Tomography (Micro-CT) has revolutionised the landscape of endodontics, offering non-invasive, high-resolution 3D imaging of dental structures. Developed in the early 1980s, Micro-CT employs X-rays to provide detailed insights into tooth anatomy and root canal morphology. This review explores the applications and challenges associated with Micro-CT in endodontics.

Micro-Computed Tomography (Micro-CT) has emerged as a pivotal technological tool in the field of dentistry. This technique, invented in the early 1980s, functions as non-intrusive and non-destructive imaging in two and three dimensions.[1]

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It operates by converging multiple X-rays onto the sample, captured by a sensor, and converted into digital images. Micro-CT offers volumetric pixels (voxels) ranging from 5-50 μm, with smaller voxels producing higher-resolution images. Software can be used to calculate the distance between axial scanning steps, which effects exposure time and the resolution of the image.[2] However, closer scanning steps require longer X-ray exposure and demand substantial computer memory for storing multiple images. The time needed for scanning can also vary based on the material being examined.[3]

Micro-CT offers several advantages over alternative methods, such as scanning electron microscopy, stereomicroscopy, and confocal laser microscopy. Unlike these techniques, micro-CT enables multiple tests on the same sample without destruction, an essential characteristic for assessing the volume before and after instrumentation, the integrity of root canal obturation, or the elimination of materials following retreatment. Additional benefits include the potential for multiple scans and modifying of images using specialist software.[4] However, it has limitations, including unsuitability for in vivo studies due to exposure to radiation and restrictions on specimen size for certain analyses. In such cases, cone beam

computed tomography (CBCT) with lower resolution might be more applicable.

Micro-CT finds diverse applications in endodontic research, including analysis of internal structure of tooth, root canal instrumentation, evaluation of root canal fillings, retreatment, and the study of material properties, both physical and biological.[5] Endodontic therapy hinges on the accurate identification of every root canal in order for a comprehensive cleansing. Examining the internal structure of the root canal system is essential for comprehending its intricate nature and devising a treatment strategy. The objective of evaluating instrumentation methods is to enhance the elimination of contamination from root canals, while root canal filling techniques and sealing agents need to be adjusted accordingly to the canal walls. A significant amount of research has been conducted on the level of quality of obturations.[6] Since microorganisms are the prime reason for chronic apical periodontitis, retreatment is required in specific circumstances to eliminate the presence of these microorganisms from the root canal system. This review article focuses on Micro-CT's role in endodontics. It provides a comprehensive understanding of Micro-CT technology, explores its applications in diagnosis and treatment planning, acknowledges challenges like radiation exposure and cost, and considers future prospects, including AI integration.

METHODS

The methodology of this review article involved a comprehensive literature search to gather relevant research papers and articles pertaining to the role of Micro-Computed Tomography (Micro-CT) in endodontics. The search was conducted using electronic databases, including PubMed, Google Scholar, Scopus and Web of science (Figure 1). The search terms used included variations of "Micro-CT," "endodontics," "dental imaging," and "root canal morphology." Boolean operators such as "AND" and "OR" were employed to refine the search results.

The inclusion criteria for selecting articles encompassed studies and reviews published in peer-reviewed journals, conference papers, and authoritative textbooks related to Micro-CT's applications in endodontics. Articles published in English from the past ten years were prioritised to ensure the inclusion of recent developments and technologies. In addition, articles that offered substantial insights into Micro-CT technology, its applications in endodontics, and its impact on clinical practice and research were considered. Exclusion criteria involved articles in languages other than English, studies older than ten years, those lacking relevance to Micro-CT in endodontics, and sources with insufficient scholarly rigor or those that were not peer-reviewed.

To identify potentially relevant publications, a basic evaluation of titles and summaries is part of the selection procedure. Subsequently, the full-text publications were meticulously examined to evaluate their compliance with the specified eligibility and exclusion requirements. Any inconsistencies or discrepancies encountered throughout this procedure were settled by reaching an agreement that lie within the review panel. The final selection yielded a collection of articles that form the foundation of this review article. These chosen articles provided the basis for the comprehensive exploration and evaluation of Micro-CT's significance and applications in the field of endodontics.

Micro-CT in Endodontics

Definition and Principles of Micro-CT: Micro-CT, which stands for micro-computed tomography, is a non-destructive imaging technique that uses X-rays to produce high-resolution, three-dimensional images of the internal structure of objects at a micrometre scale. It operates on the same principles as medical CT scans but at a much higher resolution. Micro-CT is widely used in various fields, including biomedical research, materials science, and geology, to visualise and analyse the internal structure of samples without dissecting or damaging them. The technique involves rotating the sample 360 degrees while capturing X-ray images from different angles. These images are then reconstructed using algorithms to produce a 3D volume of the sample, which can be analysed and visualised in detail. Key principles of Micro-CT include its ability to provide sub-micrometre resolution, its non-destructive nature, and its suitability for visualising both hard and soft tissues within teeth.[7] (Table 1).

Table No.1: Findings on Micro CT in Endodontics from different studies

Author	Year	Publication	Findings
Marina Angélica Marciano	2012	Current Microscopy Contributions to Advances in Science and Technology	Micro-CT Represent the ideal advice for laboratory researches. In comparison with microscopic methods of analysis, three-dimensional images provided by micro-CT are superior for laboratory analysis. The limitation of not allows the use in patients; do not limit its use in endodontic research.
Mehrsima Ghavami-Lahiji	2021	Imaging Sci Dent.	Micro-CT is a high-resolution, non-destructive 3D imaging tool widely used in dental research, offering the ability to examine internal structures and material

			adaptations without sample preparation, but it comes with drawbacks like high costs, time-consuming scanning, need for computer expertise, and handling large data volumes.
Buket Acar	2015	Imaging Sci Dent.	Although micro-CT is not suitable for clinical use, it provides more detailed information about minor anatomical structures. However, CBCT is convenient for clinical use but may not be capable of adequately analyzing the internal anatomy of primary teeth.
Mana Mirfendereski	2012	Endodontic Radiology	The data offered by micro-CT technology can lead to clinical applications such as development of new techniques, comparative analysis of existing approaches in endodontic treatment, and enhancement of dental education in preclinical and clinical stages.
Marco A. Versiani	2019	Braz dent Journal	This technology allows for the three-dimensional study of the root canal system and the evaluation of its influence on different procedures. Applications of micro-CT for experimental endodontology are now becoming extensive and integrated into dental education.
Begüm Erpaçal	2019	International dental research	The high resolution of the 3D μCT imaging method allows the examination of small details. In many studies, the results obtained with μCT imaging have been compared with histological methods, and the results have been similar. The reliability of this method has been confirmed many times with research studies.

Applications of Micro-CT in Endodontics:

i. **Root Canal Morphology and Anatomy**: Micro-CT serves as a pivotal tool in endodontics for delving deep into the complexities of root canal systems. It not only visualises the intricate pathways but also discerns minute anatomical variations within teeth. By offering insights into the exact number, curvature, and dimensions of root canals, Micro-CT equips endodontists with the knowledge to tailor their treatment strategies, thereby enhancing the likelihood of successful root canal therapies.[8]

ii. **Evaluation of Instrumentation Techniques**: The realm of Endodontics is replete with diverse instrumentation techniques. Micro-CT stands as a benchmark for assessing the precision and efficacy of these techniques, be it rotary systems or reciprocating methodologies. By providing a detailed view of the post-instrumentation canal shape, it ensures that the shaping process achieves the desired outcome, paving the way for effective canal obturation.[9]

iii. **Assessment of Root Canal Fillings and Sealers**: The integrity of root canal fillings and sealers is paramount for a successful endodontic procedure. Micro-CT acts as a quality control tool, assessing the thoroughness of obturation materials, ensuring they extend to the canal's apex and are densely packed, thereby minimising the potential for future infections.[10]

iv. **Detection of Root Fractures and Perforations**: While traditional radiographic techniques may overlook nuanced root fractures or perforations, Micro-CT does not share this limitation. Owing to its superior sensitivity, Micro-CT adeptly identifies even the most inconspicuous fractures, allowing endodontists to take timely and precise corrective actions, thereby optimising both prognosis and therapeutic results.[11]

v. **Evaluation of Apical Periodontitis and Healing**: Apical periodontitis, a common endodontic concern, can be meticulously quantified using Micro-CT. It not only gauges the severity of periapical lesions but also tracks their healing trajectory over time. Such detailed insights empower endodontists to make informed decisions about treatment modalities and follow-up schedules.[12]

vi. **Three-Dimensional Analysis of Dental Tissues**: Micro-CT offers a comprehensive three-dimensional analysis of dental tissues, including enamel, dentin, and pulp. This is valuable for studying dental development, tooth anomalies, and the effects of dental materials on these tissues.[8]

Methodological Considerations

Sample Preparation and Scanning Protocols: For Micro-CT scanning, meticulous sample preparation is paramount to ensure high-quality imaging. Typically, samples are first fixed, often using solutions like formalin, to preserve their structure. Depending on the nature of the sample, it might undergo dehydration and staining processes to enhance contrast. Once prepared, the sample is mounted on a suitable holder, ensuring

stability during the scanning process. The scanning protocol is then chosen based on the sample's size, density, and the desired resolution. It's crucial to optimise parameters such as voltage, current, and exposure time to obtain clear and detailed images. Post-scanning, the acquired data undergoes reconstruction to produce a three-dimensional representation of the sample's internal structure.[13]

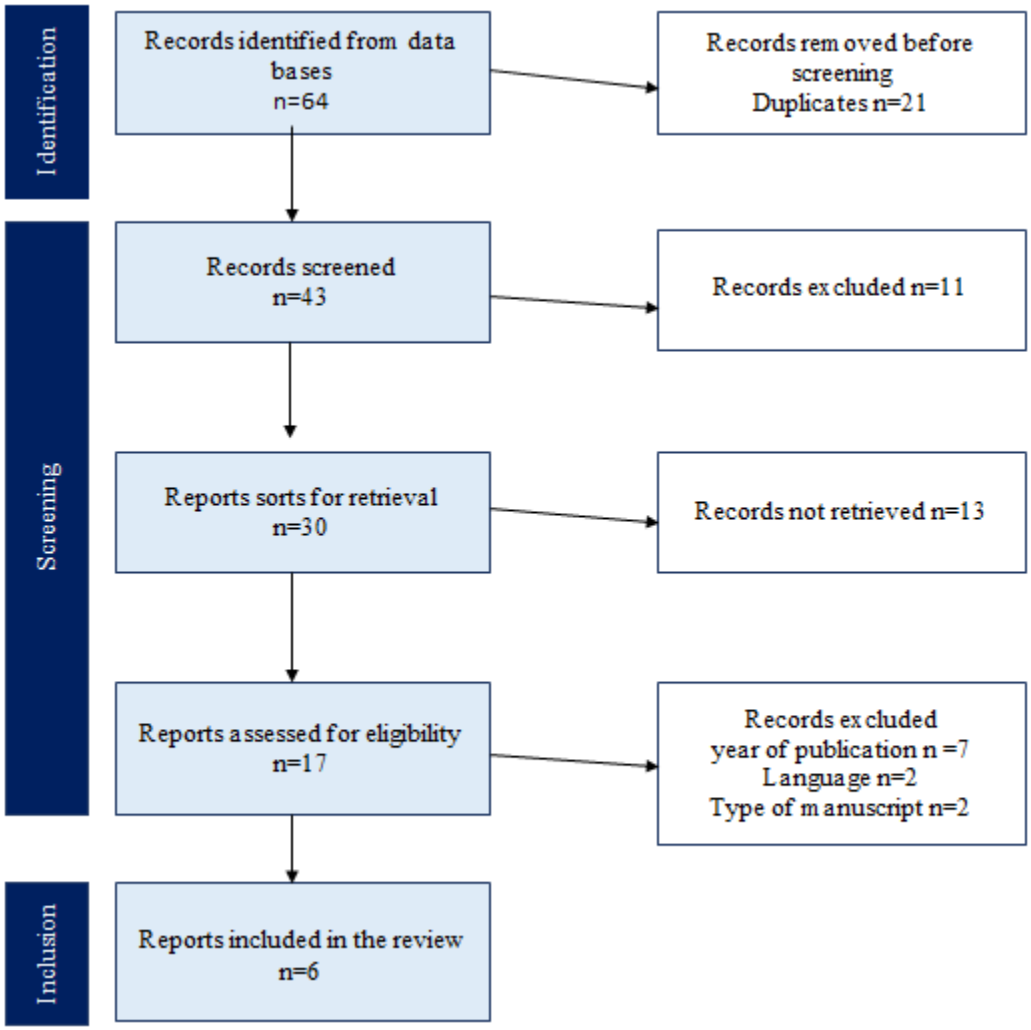

Figure No.1: Identification of studies via databases and registers

Image Acquisition and Reconstruction Techniques: Micro-CT image acquisition involves capturing a series of 2D X-ray projections as the specimen is rotated. The selection of an appropriate scanning protocol is essential to achieve the desired image quality while minimising radiation exposure. The acquired 2D projections are then processed through reconstruction algorithms to create the final 3D image. Common reconstruction techniques include filtered back projection and iterative reconstruction methods, each with its advantages and limitations. Post-processing techniques, such as noise reduction, beam-hardening correction, and 3D visualisation, are essential for improving the quality and interpretability of Micro-CT images. These techniques help enhance the clarity of root canal systems, dentin, and other dental structures, contributing to more accurate analyses and diagnoses.[14]

Limitations and Challenges of Micro-CT in Endodontics: Despite its significant advantages, Micro-CT in endodontics is not without limitations and challenges.[15] Some key considerations include:

i. Radiation Exposure: Micro-CT uses X-rays, albeit at lower doses than conventional CT scans. However, minimising radiation exposure is crucial, particularly when imaging teeth in clinical practice, and adherence to the ALARA (As Low As Reasonably Achievable) principle is essential.

ii. Sample Size: Micro-CT is primarily suited for small specimens, limiting its applicability for whole-tooth imaging. This may necessitate

sectioning or scanning specific regions of interest within teeth.

iii. Cost and Accessibility: The equipment and expertise required for Micro-CT can be costly and may not be readily available in all dental settings. This can pose challenges for its widespread adoption.

iv. Image Artifacts: Beam hardening, scatter, and metal artifacts can affect image quality, potentially obscuring fine details in dental structures.

v. Limited Soft Tissue Contrast: While Micro-CT excels at visualising hard tissues, it has limitations in distinguishing soft tissues within teeth, such as nerves and blood vessels.

vi. Ethical Considerations: When using extracted human teeth for research purposes, ethical considerations regarding informed consent and patient privacy must be addressed.

Clinical Implications and Future Perspectives

Impact of Micro-CT on Endodontic Diagnosis and Treatment Planning: The integration of Micro-Computed Tomography (Micro-CT) into endodontics has had a profound impact on clinical practice. Its role in diagnosis and treatment planning cannot be overstated. Micro-CT provides clinicians with an unprecedented level of detail regarding tooth anatomy, root canal morphology, and periapical conditions. This heightened diagnostic accuracy enables more precise and personalised treatment plans. Clinicians can confidently identify intricate root canal systems, detect fractures, and assess the extent of infections, which is particularly crucial in cases with complex anatomies or atypical pathologies. Furthermore, Micro-CT allows for virtual treatment simulations, helping endodontists strategies and optimise procedures before they are executed. This results in more effective treatments, reduced chairside time, and enhanced patient comfort.[16]

Advancements and Potential Future Developments: The future of Micro-CT in endodontics holds promising advancements. An area of significant progress involves the incorporation of artificial intelligence (AI) and machine learning techniques. AI can automate the analysis of Micro-CT images, expediting diagnoses and treatment planning. Moreover, AI-driven tools may aid in the detection of minute anatomical variations and anomalies that might otherwise be challenging to identify. Another potential advancement lies in the refinement of Micro-CT hardware and software. Improved scanning protocols, faster image reconstruction algorithms, and enhanced image quality will make Micro-CT even more user-friendly and accessible. Furthermore, the development of portable or chairside Micro-CT units could revolutionise the way endodontic procedures are performed, offering real-time imaging during treatments.[17]

Integration of Micro-CT in Routine Endodontic Practice

i. **Chairside Micro CT units**: As Micro-CT technology continues to evolve and become more accessible, its integration into routine endodontic practice is a foreseeable trend. Dental practices may incorporate chairside Micro-CT units for immediate diagnostic and treatment planning purposes. This would enhance the efficiency and precision of root canal procedures, benefiting both patients and practitioners.

ii. **Education and Awareness:** Additionally, ongoing education and training in Micro-CT interpretation will be essential for endodontists and dental professionals. Ensuring that clinicians are proficient in harnessing the full potential of this technology will be integral to its successful integration into everyday practice.

In conclusion, Micro-CT has already had a substantial impact on endodontics, improving diagnosis and treatment planning. Looking ahead, advancements in AI, hardware, and software, as well as increased accessibility, are expected to further solidify Micro-CT's role in routine endodontic practice. Its potential to enhance patient care and streamline procedures highlights the importance of embracing this technology within the field of endodontics.

CONCLUSION

In essence, Micro-CT has profoundly reshaped endodontic practice and research. Its clinical and research applications have not only refined diagnostic and treatment methodologies but also hold immense promise for future advancements. As technology evolves, the embrace of Micro-CT will undeniably further the progression of endodontic care and knowledge.

Author's Contribution:

Concept & Design of Study:	Muhammad Atif Saleem Agwan
Drafting:	Muhammad Atif Saleem Agwan
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