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Magnetic resonance revelations: transforming endodontics with MRI: A literature review

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Abstract
This review article discusses the applications of Magnetic Resonance Imaging (MRI) in endodontics, highlighting its potential in visualizing soft tissues, detecting periapical lesions, and evaluating pulp vitality. The article emphasizes the advantages of MRI over traditional radiographic imaging modalities, including its non-invasive nature and lack of ionizing radiation. Recent advances in MRI technology, such as high-resolution dental MRI and diffusion-weighted imaging, are also explored. The article concludes by discussing the challenges and limitations of MRI in endodontics, including high acquisition costs, long scan times, and motion artifacts. Future directions and research opportunities are also highlighted, including the integration of artificial intelligence and the development of dedicated MRI protocols for endodontic applications. Overall, the article demonstrates the potential of MRI to revolutionize endodontic diagnosis and treatment planning.

Keywords: Magnetic Resonance Imaging (MRI), endodontics, dental imaging, soft tissue imaging, pulp vitality, periapical lesions, root canal treatment, dental materials, Temporomandibular Joint (TMJ), Radiation-Free Imaging

Introduction
Radiographic imaging stands as a cornerstone in both primary and advanced dental diagnostics and treatment planning. At the foundational level, it facilitates an initial appraisal by delivering intricate images of the teeth, osseous structures, and adjacent tissues. This enables the precise identification of pathological conditions such as carious lesions, fractures, and osteolysis. At a more sophisticated level, radiographic imaging underpins meticulous evaluations and the formulation of comprehensive treatment plans. This encompasses the examination of root canal systems, the assessment of impacted dentition, and the analysis of dental and maxillofacial alignment. The deployment of this imaging technology is paramount for the attainment of accurate diagnoses, the orchestration of effective treatment strategies, and the longitudinal surveillance of dental health [1].

Magnetic Resonance Imaging (MRI) has long been a pivotal modality in the realm of dental diagnostics, notably in the assessment of temporomandibular disorders (TMD), owing to its superior capacity to render soft tissue histology with unparalleled clarity [2]. Although MRI is well-entrenched within the guidelines for TMJ imaging, its application across other dental specializations remains in a dynamic state of evolution [3]. The absence of ionizing radiation in MRI renders it particularly advantageous for repetitive use, notably within the domain of pediatric dentistry, where patient safety is paramount [4].

Principles of MRI
The MRI technique (fig.1) [5] is predicated upon the creation of a magnetic field by an MRI scanner, within which the patient is situated. Images are produced by capturing the “signals” emitted by protons, particularly hydrogen atoms, that are excited by the magnetic field. This imaging modality employs a potent and uniform static magnetic field in conjunction with radiofrequency pulses to generate images. When substances are exposed to a magnetic field, they become magnetized to an extent dictated by their magnetic susceptibility.

Unfortunately, variations in magnetic field strength at the juncture between dental materials and adjacent tissues can induce spatial distortions and signal loss, thereby producing artifacts in the images. Beyond artifact generation, MRI may incite other deleterious effects such as radiofrequency interference, physical phenomena like heating, and magnetically induced displacement of dental materials [6].
MRI, a venerable imaging technique within various medical disciplines, has become indispensable for the non-invasive diagnosis of soft tissue pathologies due to its salient advantage of eschewing ionizing radiation. This circumvents the biological detriments associated with other three dimensional imaging modalities such as CT and CBCT. In terms of spatial resolution and the capability to visualize data in transverse and panoramic planes familiar to dental professionals, MRI is almost commensurate with the latter [7].
However, MRI is encumbered by several contraindications, primarily owing to its utilization of intense magnetic fields. High acquisition costs and protracted scan durations are notable drawbacks of this technique. Claustrophobia in patients and the presence of biomedical devices such as pacemakers, cochlear implants, neurostimulators, or infusion pumps are significant contraindications, as these devices may malfunction or inflict harm due to the magnetic field. Nevertheless, fixed metal prostheses and aneurysm clips are generally no longer deemed contraindications [1].

Fig 1: Magnetic Resonance Imaging (MRI) [7]

MRI Techniques relevant to endodontics

Conventional MRI methodologies are predominantly adept at imaging soft tissues, including the pulp and attached periodontal membrane, yet they are often encumbered by protracted scanning durations, rendering them less suitable for clinical applications [8]. High-resolution dental MRI (dMRI) emerges as a promising radiation-free imaging modality. While its efficacy in measuring endodontic working length (fig.2) is commendable, its current accuracy remains insufficiently refined [9].

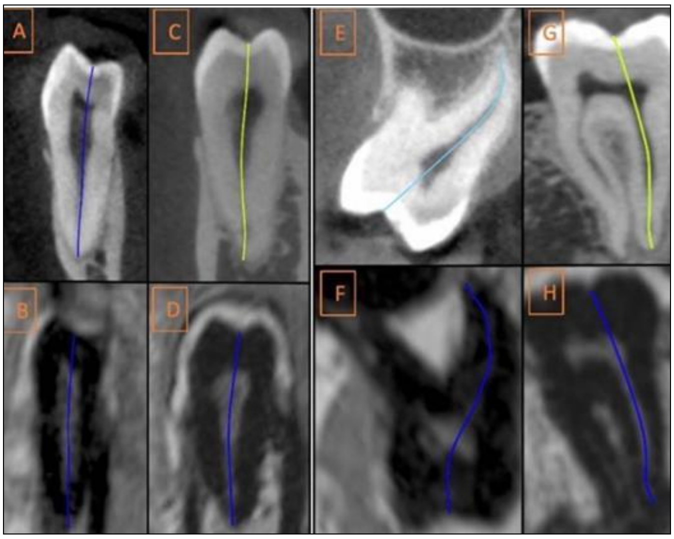

Fig 2: Measurements of the working length in cone-beam computed tomography (CBCT) and dental magnetic resonance imaging (dMRI) for premolars and molars exhibit meticulous precision. For premolars, the data encompasses the first left lower premolar (A, B) and the first right lower premolar (C, D). In the realm of molars, the focus extends to the second left upper molar (E, F) and the second left lower molar (G, H) [9].

Advanced MRI sequences play a crucial role in the nuanced identification of benign soft tissue growths (BSG), facilitating the early detection of tumor progression and informing subsequent biopsy and surgical interventions [10]. Techniques such as diffusion-weighted imaging (DWI), apparent diffusion coefficient (ADC) mapping, and maximum intensity projection (MIP) are instrumental in the characterization and differentiation of normal and pathological entities within the oral and maxillofacial regions. DWI elucidates the movement of water molecules within tissues, enabling the identification of areas with restricted diffusion often indicative of malignancy. ADC maps provide a quantifiable measure of diffusion, allowing for precise differentiation between benign and malignant lesions based on cellular density and structural integrity. Conversely, MIP generates a three-dimensional visualization by projecting the highest intensity values within a dataset, thereby enhancing the depiction of vascular structures and augmenting lesion detection. The integrative application of these imaging techniques significantly bolsters diagnostic precision and informs the development of targeted treatment strategies [11].
In the realm of dentistry, the paramount objective is to conserve natural tissue and reconstruct lost structures utilizing biomaterials. Nuclear Magnetic Resonance (NMR) spectroscopy proves indispensable for examining the chemical interactions and impacts of these biomaterials on natural tissues. It has been extensively employed in the investigation of glass ionomer cement (GIC), resin composites, dental bone cements, and periodontal membrane materials [12].

Application of MRI in endodontics

MRI excels in the visualization of soft tissues and vascular structures, with high signal intensity (SI) producing bright images and low SI yielding darker images. Bone and air manifest as dark due to their low SI, whereas fat and soft tissues exhibit bright signals. The use of contrast agents can further amplify the MRI signal, enhancing image clarity [13]. A recent pilot study has illustrated that dental MRI can delineate six critical characteristics that distinguish periapical cysts from granulomas, thus holding promise for augmenting diagnostic accuracy and minimizing unnecessary surgical interventions for patients afflicted with apical periodontitis [14].

The 9.4T Ultra-Short Echo Time (UTE)-MRI affords exceptional spatial resolution, which is pivotal for visualizing intricate root canal anatomy, assessing root canal preparation and obturation, and serves as a versatile instrument for research into dental materials within the field of endodontics [15]. MRI has demonstrated comparable sensitivity and specificity to limited field-of-view cone beam computed tomography (CBCT) for the detection of dental cracks and fractures. Although MRI technology for dental imaging is nascent and ripe for further optimization, it harbors the potential to evolve into a valuable diagnostic tool for clinical identification of dental fractures and cracks [16].

Moreover, MRI has proven effective in monitoring changes in pulp vascularization. In the assessment of vascularization in diseased teeth, healthy vital teeth typically exhibit a slightly hyperintense signal with a threadlike or punctate appearance, encircled by a hypointense (black) area representing dental hard tissues. In contrast, the MRI signals of the pulp in areas of inflammation or infection display distinct variations in both shape and intensity compared to healthy control teeth [17].

MRI in Pulp Vitality Assessment

The investigation elucidates that 3T MRI constitutes a formidable modality for assessing dental pulp vitality in pediatric cases of traumatic dental injury (TDI). The deployment of 3T MRI sequences proves to be a reliable method for visualizing reperfusion and determining tooth vitality, thereby indicating that root canal treatment (RCT) may not be requisite for every TDI case. This technique holds the potential to avert unnecessary RCTs and their concomitant treatments in children. The study's findings, corroborated through meticulous clinical examinations, underscore the need for expansive research to substantiate these results and advocate for the integration of 3T MRI into standard clinical protocols for the management of dental trauma [18].

Comparative Analysis with Other Imaging Modalities

X-rays, utilizing ionizing radiation, are predominantly employed to elucidate bone structures, whereas MRIs, favored for their superior depiction of soft tissues, eschew the use of ionizing radiation. MRI has demonstrated superior diagnostic performance and greater inter reader reliability in identifying structural lesions compared to conventional radiography [19]. The review reveals that the synergistic use of Cone Beam Computed Tomography (CBCT) and Magnetic Resonance Imaging (MRI) substantially enhances diagnostic accuracy for intricate periapical pathoses. MRI's principal advantage is its ability to image soft tissues devoid of ionizing radiation, whereas the principal limitation of CBCT lies in its propensity for overdiagnosis [20].

Furthermore, a systematic review and meta-analysis have ascertained that ultrasonography offers satisfactory diagnostic precision for detecting disc displacement within the temporomandibular joint, thereby improving the efficacy of treatment for temporomandibular disorders. Nonetheless, the technique requires additional training to mitigate the learning curve and achieve its integration into routine dental diagnostics. The standardization of evidence and further research are imperative to reinforce these findings [21].

Challenges and Limitations of MRI in Endodontics

The visualization of hard tissues, such as enamel and dentin, remains a significant technical challenge for MRI due to their minimal proton content, which results in negligible MRI signals. This limitation hinders the widespread adoption of MRI as a routine diagnostic tool in dentistry. Additionally, motion artifacts pose a substantial issue in MR imaging, stemming from the protracted examination durations relative to CT or CBCT, which can compromise image fidelity. High acquisition costs and extended scan times further exacerbate the drawbacks of MRI. Further complications include the risk of patient claustrophobia and contraindications for individuals with certain biomedical devices, such as pacemakers, cochlear implants, neurostimulators, or infusion pumps. Nevertheless, fixed metal prostheses and aneurysm clips are no longer considered contraindications. In the context of fixed orthodontic treatment, NiTi arch wires and stainless-steel brackets can perturb local magnetic fields, inducing significant artifacts that complicate image interpretation [1].

Recent Advances and Innovations in MRI for Endodontics: Recent advancements in MRI technology, such as SWeep Imaging with Fourier Transform, have significantly enhanced the resolution of both hard and soft dental tissues, thereby improving the diagnostic capabilities for carious lesions and assessing pulpal health. MRI has demonstrated reliability in diagnosing sialodochitis and sialectasia, proving itself an invaluable first-line investigation for facial swelling attributed to salivary gland disorders. Furthermore, MRI excels in the precise digitization of tooth surfaces for dental restorations, detection of root resorption in orthodontic cases, and the detailed characterization of inflammation and healing within periodontal tissues [22].

MRI in Endodontic Research

MRI holds potential for becoming a widely utilized diagnostic modality in both research and clinical endodontics, owing to its capability to assess the extent of dental decay, evaluate pulp vitality and vascularization, identify residual soft tissue, locate missing canals, detect cracks and fractures, and meticulously monitor periapical lesions, all without the use of ionizing radiation [1]. In animal model studies, cerebral blood volume (CBV)-based imaging utilizing superparamagnetic iron oxide particles presents a viable alternative to blood-oxygen-level-dependent (BOLD) functional magnetic resonance imaging (fMRI). This technique, employed in a range of animal species, offers superior specificity to cortical layers and orientation columns and boasts a markedly higher contrast-to-noise ratio (CNR) compared to BOLD fMRI at low and intermediate magnetic fields. Nevertheless, its application is constrained to animal research due to the lack of availability of ultrahigh field magnets and concerns regarding potential toxicity in human subjects [23].

Future Perspectives and Research Directions

Future advancements in the imaging of periapical lesions underscore the critical need for rigorous clinician training and calibration. Emerging developments include refined volume calculation methodologies and the integration of artificial intelligence (AI) for the detection of periapical radiolucencies, with AI systems demonstrating encouraging levels of accuracy. Enhanced comprehension of lesion characteristics can be attained through ultrasonography (US) (fig.3) and MRI, both of which present lower biological risks compared to conventional imaging modalities. Despite these advancements, challenges persist, including the high cost, limited accessibility, and the requisite learning curve associated with MRI and US. Prospective innovations such as specialized US probes, wireless coils, and abbreviated MRI scan durations hold the potential to establish a comprehensive multimodal diagnostic framework [24].

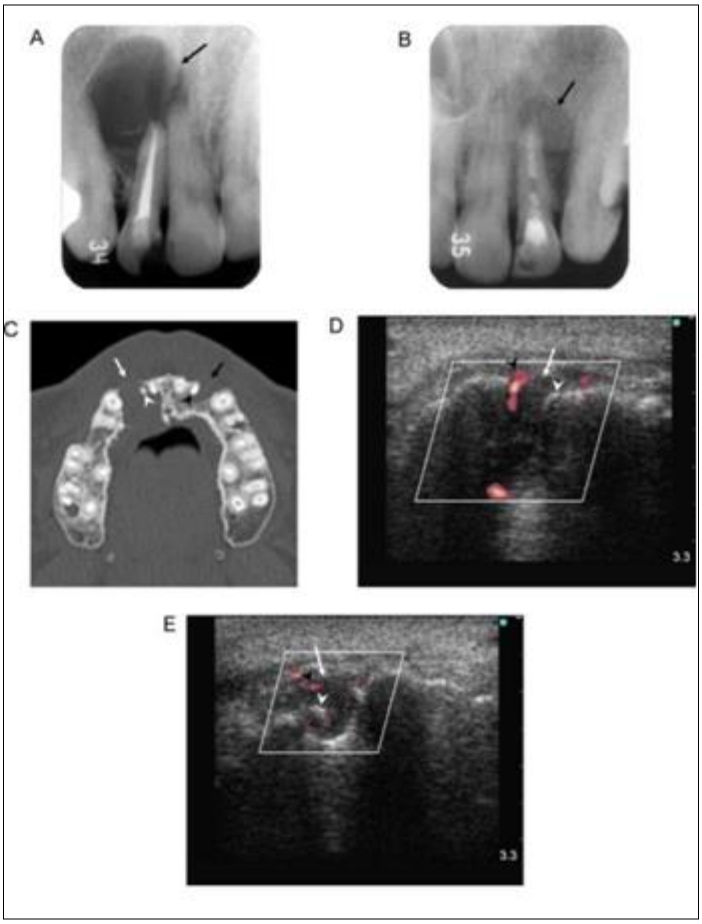

Fig 3: A 50-year-old male presents with a primary complaint of gingival swelling in the right upper incisor region.

A. The intraoral X-ray of the upper right incisor-canine region reveals a well-demarcated radiolucent lesion with a clearly defined margin at the apex of the right upper lateral incisor (indicated by the arrow).
B. The intraoral X-ray of the upper left incisor-canine region displays a well-demarcated
C. radiolucent lesion with an ill-defined margin at the apex of the left upper lateral incisor. - C: A transverse CT scan at the apex level of the upper incisors in a bone display window shows a well- demarcated lesion with significant cortical bone resorption around the root apex of the right upper lateral incisor (white arrowhead). The labial and lingual cortex of the lesion is thinned and expanded, with disrupted bone density (white arrow). Similarly, a well-demarcated lesion with bone resorption is observed around the root apex of the left upper lateral incisor (black arrowhead), with thinning and expansion of the labial cortex and focal interruption of bone density (black arrow).
D. Power Doppler ultrasonography of the upper right incisor-canine region reveals a well demarcated hypoechoic lesion (white arrow) with significant labio-lingual expansion around the root apex of the right upper lateral incisor (white arrowhead). The cortical bone's surface echo is focally interrupted by the lesion, with peripheral vascularity noted around the labial and lingual margins of the lesion (black arrowhead).
E. Power Doppler ultrasonography of the upper left incisor-canine region shows a well demarcated hypoechoic lesion (white arrow) with slight labial expansion around the root apex of the left upper lateral incisor (white arrowhead). The cortical bone's surface echo is focally interrupted by the lesion, with scattered vascularity within the lesion (black arrowhead) [27].

Clinical Implications and Recommendations

To optimize MRI image quality, it is advisable to remove removable dentures and orthodontic wires prior to scanning the head and neck region. Metallic orthodontic appliances can induce image distortion, thereby diminishing diagnostic efficacy, whereas non-metallic aesthetic brackets do not present such issues. Additionally, deferring the placement of fixed appliances until after imaging studies can be beneficial. While titanium implants are widely regarded as the standard in dental implantology, zirconia implants tend to produce fewer artifacts in MRI scans. Ferromagnetic components should be ideally removed, with their fixation meticulously inspected before and after MRI procedures. Given the limited comprehensive knowledge regarding the MRI compatibility of various dental materials, it is imperative for consultations with dental professionals and thorough literature reviews to be conducted, as manufacturers often do not provide exhaustive information. Consequently, radiologists must judiciously assess each patient and adjust the magnetic field strength as required. Furthermore, there should be a mandate for manufacturers to disclose the magnetic properties of dental materials to improve MRI compatibility [25].

Ethical and Legal Considerations

The ethical framework governing medical research must be rigorously adhered to in dental MRI studies involving human subjects. This framework encompasses principles such as respect for persons, beneficence, and justice. In scenarios involving critically ill or comatose patients, particularly in intensive care and functional MRI research, obtaining informed consent poses significant challenges due to the patients' incapacity, necessitating the involvement of surrogate decisionmakers whose legal authority may be contentious. The vulnerability of critically ill patients necessitates heightened safeguards to mitigate research risks. Ethical considerations must address the assurance of patient safety during intra-hospital transport, the management of uncertainty related to MRI findings and prognostic implications, and the potential influence on decisions regarding life-sustaining treatments. Researchers and ethics committees must meticulously address these ethical dimensions to ensure the integrity and protection of participants in dental MRI research [26].

Conclusion

This literature review highlights the potential of Magnetic Resonance Imaging (MRI) in endodontics, particularly in the diagnosis and treatment of periapical lesions, pulp vitality assessment, and root canal anatomy visualization. While MRI offers several advantages over traditional radiographic imaging modalities, including the absence of ionizing radiation and high spatial resolution, there are still challenges and limitations to its widespread adoption in dentistry. These include high acquisition costs, long scan times, and motion artifacts.Future directions in MRI for endodontics include the integration of artificial intelligence, volume calculation methods, and the development of dedicated MRI probes and wireless coils. Additionally, researchers and clinicians must address ethical considerations, such as informed consent and patient safety, particularly in vulnerable populations.Overall, MRI has the potential to revolutionize endodontic diagnosis and treatment, but further research and innovation are needed to overcome the existing challenges and fully realize its benefits. As the technology continues to evolve, it is essential to prioritize patient-centered research and address the ethical implications of MRI in endodontics.

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Author's Contribution

Not available

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