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Transforming Conservative Dentistry and Endodontics with Advanced Imaging Technologies: A Narrative Review

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Abstract

Diagnostic imaging plays a critical role in conservative dentistry and endodontics, influencing early disease detection, treatment planning, and clinical outcomes. Conventional two-dimensional radiographic techniques are limited by anatomical superimposition, geometric distortion, and reduced sensitivity for early or subtle pathological changes. Recent advances in imaging technologies have expanded the diagnostic armamentarium by enabling three-dimensional visualization, enhanced structural resolution, and, in certain modalities, functional and biological tissue assessment. This narrative review explores contemporary and emerging imaging modalities, including magnetic resonance–based techniques, cone beam and micro-computed tomography, ultrasound, infrared thermography, near- and short-wave infrared imaging, optical coherence tomography, and photothermal radiometric methods. The principles, clinical applications in conservative dentistry and endodontics, and inherent

limitations of each modality are discussed. Collectively, these advanced imaging technologies facilitate earlier diagnosis, improved visualization of complex dental structures, and more precise, minimally invasive clinical decision-making. Although no single modality is universally applicable, their judicious, case-specific integration supports a shift toward precision-based, biologically driven, and patient-centered dental care.

Categories: Dentistry

Keywords: Advanced imaging technologies, Conservative dentistry, Endodontics, CBCT, Optical coherence tomography, Near-infrared imaging

Introduction

Diagnostic imaging plays a pivotal role in conservative dentistry and endodontics, guiding clinicians from disease detection to treatment planning and outcome evaluation. Conventional intraoral radiography, despite being the cornerstone of dental diagnostics, is inherently limited by its two-dimensional nature, geometric distortion, and inability to depict early or subtle pathological changes. Superimposition of anatomical structures often masks carious lesions, root fractures, accessory canals, and early periapical disease, leading to delayed diagnosis and compromised treatment outcomes[1].

Advances in imaging science have introduced a wide array of non-conventional imaging modalities that overcome these limitations by providing three-dimensional visualization, enhanced contrast resolution, functional tissue assessment, and, in some cases, radiation-free imaging[2]. These technologies have enabled a paradigm shift from symptom-based and reparative approaches to biologically driven, minimally invasive, and precision-oriented dental care[3].

This narrative review comprehensively discusses contemporary and emerging advanced imaging technologies that are transforming conservative dentistry and endodontics. Each modality is described with respect to its fundamental imaging principles, specific clinical applications in conservative dentistry and endodontics, and inherent limitations. A consolidated comparative table (Table 1) provides a structured overview of the clinical indications, diagnostic advantages, and practical constraints of each imaging technology, facilitating informed, evidence-based selection in clinical practice[3].

Magnetic Resonance Imaging (MRI)

Magnetic resonance imaging is based on the interaction of hydrogen nuclei with strong magnetic fields and radiofrequency pulses, generating images with exceptional soft-tissue contrast without the use of ionizing radiation Although traditionally used in medical diagnostics, recent advances have expanded its application in dentistry [4].

In conservative dentistry, MRI allows non-invasive visualization of the dentin–pulp complex. Its ability to detect changes in tissue hydration and blood perfusion makes it valuable for assessing pulp vitality and differentiating reversible from irreversible pulpitis. MRI has also demonstrated utility in detecting internal resorption and pulpal inflammation before gross structural changes become radiographically evident [4].

In endodontics, MRI facilitates three-dimensional visualization of root canal anatomy without beam-hardening artifacts caused by metallic restorations. It has shown promise in differentiating periapical cysts from granulomas based on tissue composition and fluid content, thereby aiding in treatment planning and prognosis assessment [5].

MRI is particularly advantageous in cases requiring repeated imaging, such as follow-up of healing, due to the absence of radiation exposure. However, widespread clinical adoption of MRI in dentistry is limited by high cost, long acquisition times, motion sensitivity, and relatively low spatial resolution for highly mineralized tissues such as enamel [6].

Micro-Magnetic Resonance Imaging (Micro-MRI)

Micro-MRI is an ultra-high-resolution variant of MRI primarily employed in experimental and laboratory settings. It provides detailed visualization of dental tissues at a microscopic scale, enabling precise assessment of internal structural and compositional changes [12].

In conservative dentistry, micro-MRI has been extensively used to study early enamel and dentin demineralization, resin infiltration, and adhesive interface integrity. It enables longitudinal evaluation of remineralization strategies without destroying the specimen [3].

In endodontics, micro-MRI has been used to investigate dentinal tubule orientation, hydration dynamics of dentin, and diffusion of irrigants and sealers within the root canal system [4]. These insights are particularly valuable for understanding material–tissue interactions and improving endodontic materials.

Despite its advantages, micro-MRI is limited to in vitro research due to restricted field of view, long scanning times, and specialized equipment requirements.

Cone Beam Computed Tomography (CBCT)

Cone beam computed tomography has emerged as one of the most influential imaging advancements in dentistry. CBCT provides high-resolution, three-dimensional images of dental and maxillofacial structures with lower radiation doses compared to conventional medical CT [7].

In conservative dentistry, CBCT aids in detecting occult carious lesions, evaluating tooth fractures, and assessing the extent of structural loss beneath existing restorations. It is particularly useful in cases where clinical findings and conventional radiographs are inconclusive [1].

In endodontics, CBCT has transformed diagnostic accuracy by enabling reliable identification of periapical pathology, missed canals, complex root canal morphology, external and internal resorption, and vertical root fractures. CBCT is indispensable in pre-surgical planning for endodontic microsurgery and in evaluating persistent post-treatment disease [2].

Limitations of CBCT include higher radiation exposure compared with intraoral radiographs, limited soft-tissue contrast, and susceptibility to artifacts from metallic restorations. Judicious use following established guidelines is therefore essential [8].

Conventional Computed Tomography (CT)

Conventional computed tomography uses fan-shaped X-ray beams and multiple detectors to generate cross-sectional images. Although largely replaced by CBCT in dental practice, CT has played a historical role in maxillofacial diagnostics [9].

In conservative dentistry, CT has been used for evaluating extensive osseous defects and complex craniofacial relationships. In endodontics, it was previously employed for assessing large periapical lesions and complex anatomical structures [2].

The high radiation dose, high cost, and inferior spatial resolution for dental hard tissues compared with CBCT have limited its current dental applications.

Micro-Computed Tomography (Micro-CT)

Micro-CT is considered the gold standard for three-dimensional assessment of dental microstructures in research. It provides isotropic, high-resolution images that allow precise quantitative analysis [2].

In conservative dentistry, micro-CT is widely used to evaluate microleakage, polymerization shrinkage, internal adaptation of restorative materials, and integrity of tooth restoration interfaces [2].

In endodontics, micro-CT enables detailed assessment of root canal morphology, canal preparation efficacy, remaining debris, obturation quality, and sealer penetration. Its non-destructive nature allows repeated evaluation of the same specimen at different treatment stages [2].

The major limitations of micro-CT are high radiation dose, limited field of view, high cost, and restriction to in vitro studies.

Tuned Aperture Computed Tomography (TACT)

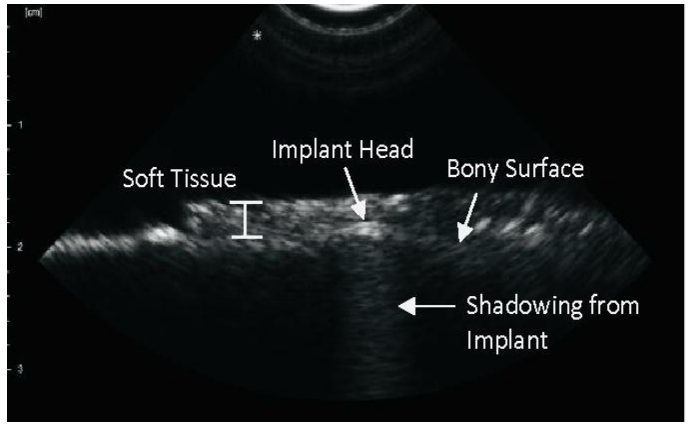
TACT reconstructs three-dimensional images from a series of limited-angle radiographic projections using computational algorithms [10].

In conservative dentistry, TACT improves detection of proximal and recurrent caries by reducing anatomical noise and superimposition.

In endodontics, it aids in identifying periapical lesions and root fractures[11]. Despite its diagnostic potential, limited availability, technique sensitivity, and lack of widespread commercial systems have restricted its clinical adoption.

Ultrasound Imaging

Ultrasound imaging utilizes high-frequency sound waves to generate images based on tissue echogenicity [2].



In conservative dentistry, ultrasound has been explored for evaluating soft-tissue lesions adjacent to teeth and assessing vascularity using Doppler techniques. In endodontics, ultrasound has shown promise in differentiating cystic and granulomatous periapical lesions and in monitoring healing following endodontic therapy [12].

Its clinical use is limited by poor penetration through mineralized tissues and operator dependency.

Infrared Thermography

Infrared thermography detects surface temperature variations resulting from underlying physiological or pathological processes [8].

In conservative dentistry, thermography has been used to detect cracks, assess microleakage, and evaluate pulp vitality by analyzing thermal responses to stimuli. In endodontics, it assists in monitoring temperature changes during instrumentation and obturation procedures [9].

Environmental sensitivity and limited depth penetration remain major limitations.

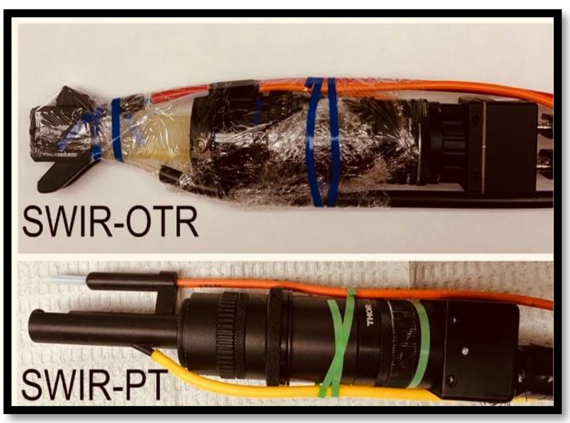
Near-Infrared Light Transillumination (NIR-LT)

NIR-LT employs near-infrared light to visualize demineralized tooth structure with high contrast.

In conservative dentistry, it is highly effective for early detection of enamel and dentinal caries, particularly proximal lesions, without radiation exposure. In endodontics, NIR-LT aids in identifying cracks and assessing coronal structural integrity however, it cannot visualize periapical tissues or deep structures [13].

SWIR OTR and SWIR PT Imaging

Short-wave infrared occlusal transillumination and reflectance (SWIR-OTR) and short-wave infrared photothermal imaging (SWIR-PT) are emerging optical technologies [14].



In conservative dentistry, these modalities enable early detection of occlusal caries beneath intact enamel and quantitative monitoring of remineralization. In endodontics, they assist in identifying crack propagation and subsurface structural defects [15].

These techniques are currently confined to research settings due to limited clinical availability.

Cross-Polarization Optical Coherence Tomography (CP-OCT)

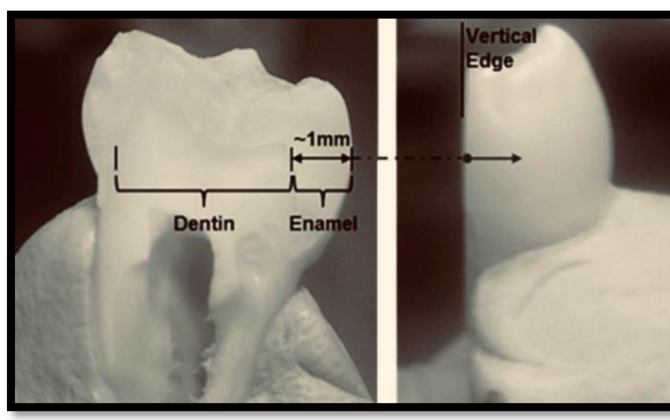
CP-OCT provides high-resolution cross-sectional images of dental tissues using near-infrared light.

In conservative dentistry, CP-OCT enables detection of early enamel caries, evaluation of adhesive interfaces, and assessment of restoration integrity. In endodontics, it assists in identifying crack depth and dentinal defects [16].

Limited penetration depth restricts visualization of deeper structures.

Photothermal Radiometry and Modulated Luminescence (PTR-LUM)

PTR-LUM combines thermal and luminescent signals to detect subsurface structural changes.



In conservative dentistry, PTR-LUM allows quantitative detection of early carious lesions and monitoring of lesion progression or remineralization. In endodontics, it assists in assessing thermal and structural changes in dentin [17,18].

Its use is limited by specialized equipment requirements and limited clinical availability.

Table 1: Advanced Imaging Modalities in Conservative Dentistry and Endodontics

Imaging Modality	Uses in Conservative Dentistry	Uses in Endodontics	Limitations
MRI	Pulp vitality, internal resorption	Periapical lesion differentiation, canal anatomy	Cost, long scan time
Micro-MRI	Demineralization, adhesive interface	Dentin hydration, sealer diffusion	Experimental only
CBCT	Occult caries, fractures	Missed canals, resorption, surgery	Radiation, artifacts
CT	Osseous defects	Large lesions	High radiation
Micro-CT	Microleakage, interfaces	Canal morphology, obturation	In vitro only
TACT	Proximal caries	Root fractures	Limited availability
Ultrasound	Soft tissue evaluation	Cyst vs granuloma	Poor hard-tissue penetration
Thermography	Cracks, vitality	Thermal monitoring	Environmental sensitivity
NIR-LT	Early caries, cracks	Coronal integrity	No periapical imaging
SWIR-OTR	Occlusal caries	Crack detection	Experimental
SWIR-PT	Lesion activity	Subsurface defects	Research-based
CP-OCT	Enamel caries, interfaces	Crack depth	Limited penetration
PTR-LUM	Early caries	Dentin changes	Limited availability

Conclusion

Advanced imaging technologies have fundamentally transformed diagnostic and therapeutic approaches in conservative dentistry and endodontics by overcoming the inherent limitations of conventional two-dimensional radiography. These modalities enable three-dimensional visualization, enhanced structural resolution, and, in certain techniques, functional and biological tissue assessment, thereby facilitating earlier diagnosis and more precise treatment planning. Tomographic systems such as cone beam computed tomography and micro-computed tomography have significantly improved the understanding of complex root canal anatomy and periapical pathology, while magnetic resonance–based imaging offers radiation-free evaluation of the dentin pulp complex. Optical and infrared imaging technologies further support minimally invasive dentistry by enabling early detection of demineralization, cracks, and restorative defects.

Despite their proven advantages, no single imaging modality is universally applicable, as each technique presents inherent limitations related to cost, accessibility, radiation exposure, or penetration depth. Consequently, a multimodal, case-specific imaging approach is essential to maximize diagnostic accuracy. Continued technological refinement, standardization of protocols, and robust clinical validation are expected to further integrate advanced imaging into routine practice. Overall, these technologies collectively support a shift toward precision-based, minimally invasive, and patient-centered dental care.

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