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Review Article

Advancing dental diagnostics: The significance of cone-beam computed tomography (CBCT) in modern dentistry

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ABSTRACT

Dental radiology has historically relied on 2-dimensional (2D) imaging, but recent advancements in Cone-Beam Computed Tomography (CBCT) have revolutionized maxillofacial imaging. This review explores the applications of CBCT, emphasizing its advantages in dental specialties such as implant dentistry, endodontics, orthodontics, and temporomandibular joint evaluation. CBCT offers unparalleled diagnostic accuracy while minimizing radiation exposure, making it a valuable tool in dental practice. The integration of artificial intelligence (AI) and machine learning into CBCT technology presents exciting possibilities for automated image analysis, pathology detection, treatment planning, radiation dose reduction, image enhancement, workflow optimization, predictive analytics, customized treatment plans, teledentistry, and dental education. AI's role in dentistry is poised to enhance diagnostic and treatment capabilities while optimizing CBCT scans, ultimately improving patient care.

1. Introduction

Since the advent of X-ray technology, dental radiology has played a pivotal role in the diagnosis, treatment planning, and prognosis assessment of dental conditions. Intraoral and conventional radiographic techniques have long been essential tools in dentistry, but they have inherent limitations associated with 2-dimensional (2D) imaging. These limitations include magnification, distortion, superimposition of structures, and the potential for misrepresentation.[1]

However, recent years have witnessed a significant transformation in dental imaging with the introduction of Cone-Beam Computed Tomography (CBCT). CBCT represents a distinct branch of computed tomography, setting itself apart from conventional CT scanners. Over the past half-decade, CBCT has gained widespread acceptance in dentistry for its ability to generate detailed three-dimensional (3D) data while minimizing radiation exposure and costs, all while providing a higher spatial resolution compared to traditional CT scans.[1]

The versatility of CBCT has revolutionized maxillofacial imaging, offering a wide range of applications across various dental specialties, from diagnosis to treatment planning. Nevertheless, there is a prevalent issue of inadequate education and awareness among dental professionals, often leading to unnecessary referrals for

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CBCT imaging.[2]

Early CBCT machines utilized image intensifiers with large fields of view (FOVs), potentially subjecting patients to higher radiation doses. Nonetheless, even in these early iterations, CBCT radiation doses remained lower than those associated with medical CT scans. Recent advancements in software and technology have enabled the optimization of CBCT scanners. These improvements include the incorporation of smaller FOVs, pulsed radiation exposure, and collimation, all of which contribute to reducing radiation exposure to patients.[3]

It is essential to underscore that CBCT exposure should always adhere to the principle of keeping radiation doses "as low as reasonably achievable (ALARA)," as endorsed by the American Dental Association. CBCT should not be seen as a wholesale replacement for conventional panoramic or projection radiography. Instead, it serves as a complementary imaging modality, best suited for specific applications where its unique advantages shine.[4]

This review seeks to highlight the diverse applications of CBCT in maxillofacial imaging. Furthermore, it explores the emerging possibilities for enhancing CBCT through the utilization of artificial intelligence and machine-based learning. Combining CBCT with optical imaging techniques is also discussed, showcasing its potential to facilitate improved diagnosis and treatment planning for complex dental conditions.

2. Discussion

2.1. Evolution of dental imaging: A paradigm shift

Traditionally, dental practitioners relied on conventional two-dimensional X-rays to diagnose oral health conditions. While these X-rays served as a valuable diagnostic tool, they possessed inherent limitations, often providing only a flattened and overlapping perspective of oral structures. In contrast, CBCT represents a paradigm shift in dental imaging. It delivers intricate three-dimensional images of the oral and maxillofacial regions, offering a depth and clarity of detail that were previously unimaginable.[5]

2.2. Unparalleled diagnostic accuracy

CBCT's greatest strength lies in its unparalleled diagnostic accuracy, which empowers dentists to visualize the oral and maxillofacial structures in three dimensions. This capability has wide-reaching implications across various dental specialties:

2.2.1. Implant dentistry: Precision beyond measure

In the realm of implant dentistry, CBCT is a game-changer. When planning dental implant procedures, accuracy is paramount. CBCT scans provide a comprehensive view of the patient's jawbone, enabling precise measurements of bone density, height, and width. Dentists can determine the optimal implant placement, ensuring a secure and long-lasting restoration. Moreover, CBCT helps identify potential challenges, such as inadequate bone volume, and necessitating bone grafting procedures.[6]

2.2.2. Endodontics: Navigating complex root canals

Endodontists also benefit significantly from CBCT technology. The 3D images allow them to uncover intricate root canal anatomy, including the presence of additional canals or unusual configurations. This information is invaluable for planning and executing root canal treatments with precision, reducing the likelihood of post-treatment complications.[7]

2.2.3. Orthodontics: Personalized treatment plans

Orthodontists use CBCT to evaluate the alignment of teeth and their relationship with adjacent bone structures. In complex cases, such as impacted teeth or surgical orthodontics, CBCT provides crucial insights for creating highly personalized treatment plans. The result is more efficient and effective orthodontic care.[8]

3. TMJ Evaluation and Airway Assessment

CBCT finds applications in evaluating temporomandibular joint (TMJ) disorders and assessing airway anatomy. For TMJ issues, CBCT aids in diagnosing joint problems and formulating tailored treatment options. In the context of airway assessment, CBCT helps identify obstructions or anomalies contributing to sleep-related breathing disorders like sleep apnea, guiding the development of targeted treatment strategies.[9]

3.1. Reduced radiation exposure: Prioritizing patient safety

Radiation exposure has long been a concern in dentistry. Traditional X-rays emit ionizing radiation, which, over time, can accumulate and pose potential health risks. CBCT addresses this concern by employing a cone-shaped X-ray beam and a precise detector, resulting in substantially lower radiation doses compared to conventional CT scans. This reduction in radiation exposure enhances patient safety, especially in cases requiring repeated or extensive imaging.[10]

4. Enhanced Treatment Planning and Patient Education[11]

Beyond diagnosis, CBCT enhances treatment planning and patient education in several ways:

4.1. Precise treatment visualization

CBCT scans can be integrated into advanced treatment planning software, allowing dentists to simulate the

outcomes of various treatment options. This aids in selecting the most appropriate and effective treatment plan tailored to each patient's unique needs.

4.2. Improved patient understanding

Visual aids play a pivotal role in patient education. Dentists can use the detailed 3D images from CBCT scans to explain oral health conditions and proposed treatment plans more comprehensively. Patients gain a clearer understanding of their dental issues, empowering them to actively participate in the decision-making process.

The integration of artificial intelligence (AI) and machine-based learning into Cone-Beam Computed Tomography (CBCT) technology represents an exciting frontier in dentistry. These emerging possibilities are poised to enhance the capabilities of CBCT in various ways: [12–15]

5. Automated Image Analysis

AI algorithms can be trained to perform automated image analysis on CBCT scans. This includes the identification and segmentation of specific structures, such as teeth, bone, and soft tissues. Automated analysis can significantly reduce the time required for interpretation and diagnosis, making the process more efficient and potentially more accurate.

6. Pathology Detection

AI can assist in the early detection of dental pathologies and anomalies by analyzing CBCT images. For example, AI algorithms can identify signs of dental caries, periodontal disease, or abnormalities in tooth development. This early detection can lead to timely intervention and better treatment outcomes.

7. Treatment Planning and Simulation

Machine learning can aid in treatment planning by simulating the potential outcomes of various interventions. Dentists can input patient data and treatment goals, and the AI system can generate simulations of how the patient's oral condition might change with different treatment options. This helps both dentists and patients make informed decisions about treatment approaches.

7.1. Radiation dose reduction

AI algorithms can optimize CBCT scans to further reduce radiation exposure. By analyzing the patient's anatomy and the clinical indication for the scan, AI can suggest scan settings that provide sufficient diagnostic information while minimizing radiation dose. This aligns with the ALARA principle, keeping doses "as low as reasonably achievable."

7.2. Image enhancement and noise reduction

AI can enhance CBCT images by reducing noise and artifacts, improving image quality and diagnostic accuracy. This is particularly valuable in cases where image quality may be compromised due to patient motion or other factors.

7.3. Workflow optimization

AI-driven tools can streamline the workflow in dental practices by automating tasks like image registration, data management, and report generation. This allows dental professionals to focus more on patient care and less on administrative tasks.

7.4. Predictive analytics

By analyzing large datasets of CBCT images and patient outcomes, machine learning models can develop predictive analytics for various dental conditions. For example, AI can predict the likelihood of implant success based on patient characteristics and CBCT data, helping dentists make informed decisions about treatment planning.

7.5. Customized treatment plans

Machine learning can assist in creating highly personalized treatment plans. By considering the patient's unique anatomy and treatment goals, AI can recommend the most suitable treatment options, implant sizes, or orthodontic strategies.

7.6. Teledentistry and remote consultations

In an era of telehealth and remote consultations, AI can facilitate the sharing and analysis of CBCT scans between dental professionals. This allows for collaborative treatment planning and second opinions, regardless of geographical distances.

8. Continuing Education and Training

AI-powered educational tools can assist dental students and practitioners in learning how to interpret CBCT images effectively. These tools can provide real-time feedback and guidance during the learning process.

Incorporating AI and machine-based learning into CBCT technology has the potential to revolutionize dental diagnostics and treatment planning. These tools can enhance accuracy, efficiency, and patient outcomes while optimizing the use of CBCT scans. As AI continues to advance, its role in dentistry is likely to become increasingly significant, providing valuable support to dental professionals and improving the overall quality of dental care.

9. Conclusion

In conclusion, the advent of Cone-Beam Computed Tomography (CBCT) has ushered in a new era of precision and diagnostic accuracy in dentistry. Its ability to provide detailed three-dimensional (3D) images while minimizing radiation exposure addresses longstanding concerns in the field. CBCT has found applications in various dental specialties, improving patient outcomes and treatment planning across the board.

Furthermore, the integration of artificial intelligence (AI) and machine learning into CBCT technology represents a promising frontier. These AI-driven tools have the potential to automate image analysis, enhance pathology detection, optimize radiation doses, improve image quality, streamline workflows, and facilitate predictive analytics. They can also support personalized treatment planning, teledentistry, and dental education.

As AI continues to advance, its synergy with CBCT is likely to transform dental practice, offering more efficient, accurate, and patient-centered care. Dentists and dental professionals should embrace these innovations, recognizing their potential to revolutionize diagnostics, treatment planning, and overall quality of dental care.

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11. Conflict of Interest

None.

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