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Review Article

Cone-Beam Computed Tomography and Magnetic Resonance Imaging in Maxillofacial Diagnostics: A Structured Narrative Review of Complementary Imaging and Image Fusion Applications

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Abstract

Introduction: Accurate imaging is essential for diagnosing and managing maxillofacial disorders. Cone-beam computed tomography (CBCT) provides high-resolution assessment of osseous structures, whereas magnetic resonance imaging (MRI) offers superior soft tissue characterization. Accordingly, this structured narrative review critically evaluated the complementary applications of CBCT and MRI and examined the emerging role of CBCT-MRI image fusion in maxillofacial diagnostics.

Methods: A structured literature search was conducted in PubMed, Scopus, and Web of Science databases for studies published between January 2008 and May 2025. Relevant studies investigating complementary CBCT-MRI imaging or image fusion applications in oral and maxillofacial radiology were included in the review. Then, two reviewers independently screened eligible studies, and disagreements were resolved through discussion and final consensus with a senior author. Ultimately, the findings were narratively synthesized due to methodological heterogeneity.

Results: Overall, evidence suggested that the complementary use of CBCT and MRI may improve diagnostic assessment in temporomandibular joint disorders, tumors, trauma, and surgical planning. It was found that CBCT-MRI fusion enables simultaneous visualization of osseous and soft tissue structures and may enhance diagnostic interpretation in selected clinical scenarios. However, the available evidence remains limited by heterogeneous methodologies, small sample sizes, and insufficient multicenter validation.

Conclusion: CBCT and MRI provide complementary diagnostic information in maxillofacial imaging. In addition, CBCT-MRI fusion represents a promising multimodal imaging approach. Nonetheless, further standardized clinical studies are required before recommending routine clinical implementation.

Keywords: Maxillofacial imaging, MRI, Image fusion, CBCT, Complementary imaging

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Introduction

Accurate imaging plays a critical role in the diagnosis and management of a diverse range of disorders that affect the oral and maxillofacial region (1). In addition, the ability to delineate the detailed anatomical structures of this complex region is crucial for effective clinical decision-making. Multiple imaging modalities have traditionally been employed in oral and maxillofacial diagnostics, each with distinct advantages and limitations. Cone-beam computed tomography (CBCT) has emerged as a widely adopted imaging modality because of its high spatial resolution and relatively low radiation dose compared with conventional CT (2). Moreover, the transition from two-dimensional (2D) to 3D imaging has substantially improved anatomical visualization and diagnostic precision in maxillofacial assessment (3). By enabling detailed 3D visualization of maxillofacial anatomy, CBCT surpasses the limitations of 2D imaging (e.g., magnification and superimposition), leading to enhanced diagnostic accuracy and more effective treatment planning (4). Additionally, CBCT is characterized by high spatial resolution and efficacy in the diagnosis of bone abnormalities within the temporomandibular joint

(TMJ). Nonetheless, its application is restricted in the assessment of soft tissue due to poor differentiation of low-density structures, commonly necessitating complementary imaging for comprehensive assessment (5). Magnetic resonance imaging (MRI) is frequently implemented in these clinical contexts, due to its capacity to provide high-contrast images of soft tissues without the use of ionizing radiation (6). Although CBCT provides excellent visualization of osseous abnormalities in TMJ disorders, its limited soft tissue contrast commonly necessitates complementary MRI evaluation for assessing the articular disc and associated soft tissue structures. Furthermore, the diagnostic process for TMJ disorders often requires the integration of CBCT for bone evaluation with MRI for soft tissue evaluation, highlighting their complementary roles in comprehensive diagnosis (7). Consequently, combined CBCT and MRI interpretation has become increasingly important in complex maxillofacial conditions that require simultaneous evaluation of hard and soft tissues. Despite growing interest in multimodal maxillofacial imaging, the current literature remains fragmented, and a comprehensive critical evaluation of complementary CBCT-MRI applications and image fusion techniques is still lacking. Therefore, this structured narrative review aims to critically evaluate the complementary diagnostic roles of CBCT and MRI in order to examine the current evidence regarding CBCT-MRI image fusion in oral and maxillofacial imaging.

Introduction to Cone-Beam Computed Tomography

The CBCT method involves the utilization of a rotating cone-beam X-ray projection to acquire volumetric information in a single acquisition, which is then reconstructed to generate high-resolution 3D images of the maxillofacial area (8). Due to its capacity for providing detailed views of hard tissues and delivering a lower radiation dose compared with conventional CT, CBCT is widely used in oral and maxillofacial surgeries (2, 9, 10). It is noteworthy that CBCT surpasses several limitations of 2D imaging, notably distortion and superimposition, by providing accurate, multi-planar views that are vital for diagnosis and treatment planning (4, 11). Moreover, CBCT has demonstrated high diagnostic utility in the evaluation of fractures, foreign bodies, osseous lesions, and implant planning because of its ability to provide detailed 3D visualization of craniofacial structures (12). In addition, its ability to provide detailed 3D reconstructions has made it a valuable tool in emergency and trauma settings (13). Likewise, CBCT is valuable for assessing osseous tumor extension and supporting preoperative surgical planning in selected maxillofacial neoplasms (14). However, limited contrast resolution reduces its effectiveness for soft tissue evaluation, making it difficult to distinguish lesions, such as cysts, granulomas, or abscesses, regardless of clear bone visualization (5, 15). Despite these benefits, CBCT's limited soft-tissue contrast often requires complementary imaging, such as MRI.

Introduction to Magnetic Resonance Imaging

MRI is a non-ionizing imaging modality that provides superior soft tissue contrast and multiplanar visualization, making it particularly valuable for evaluating soft tissue pathology in the maxillofacial region (6, 16). It has an important role in the evaluation of oral and maxillofacial soft tissues, including nerves, dental pulp, and gingiva. Additionally MRI iss employed in orthodontic planning and diagnosing pulpitis, periapical, and periodontal lesions (17). Despite its strengths, MRI has several limitations, including lower bone resolution than CBCT, longer scan times, higher cost, and susceptibility to motion and metal artifacts. While CBCT better visualizes bony structures, MRI is preferred for assessing the articular disc and soft tissues of the TMJ, enabling more comprehensive diagnosis (18). Consequently, MRI is frequently used as a complementary modality to CBCT in complex maxillofacial conditions requiring simultaneous evaluation of hard and soft tissues.

Technological Developments in Cone-Beam Computed Tomography and Magnetic Resonance Imaging

Both CBCT and MRI are continually advancing, further enhancing their capabilities in maxillofacial diagnostics (19). Recent developments in the scope of CBCT include improvements in image quality and resolution, faster scan times, and further reductions in radiation dose, making it an even safer and more efficient imaging option (20). Furthermore, the ability to control the field of view and voxel size allows for the optimization of the radiation dose delivered to the patient, adhering to the principle of "As Low As Reasonably Achievable". Further, advancements encompass the development of smaller field-of-view imaging studies, broader dynamic ranges through the use of flat-panel image receptors, and improved interactive software programs. Similarly, MRI technology continues to evolve with the development of higher field strength magnets, advanced imaging sequences, and specialized coils that provide improved image quality and faster acquisition times (21, 22). Table 1 summarizes their main technical characteristics, clinical applications, advantages, and limitations of CBCT and MRI in maxillofacial imaging. This comparison provides a practical overview of the situations in which each modality may be most effectively utilized.

Key parameters, including spatial resolution, tissue contrast, radiation exposure, scan duration, cost, accessibility, and primary clinical indications, were compared to illustrate the complementary strengths and limitations of each modality. The findings revealed that CBCT provides high-resolution visualization of osseous structures with rapid image acquisition and broad clinical availability, whereas MRI offers better soft-tissue contrast without ionizing radiation and is particularly valuable for the assessment of TMJ disorders, neural structures, and soft-tissue lesions. The comparisons are based on the evidence synthesized from the studies included in this narrative review and are intended to provide a general

Table 1. Clinical and Technical Comparison of CBCT and MRI in Maxillofacial Diagnostics

Features	CBCT	MRI
Spatial resolution (bone)	High	Lower compared to CBCT
Spatial resolution (soft tissue)	Poor	High
Soft tissue contrast	Poor	Excellent
Bone contrast	Excellent	Good, but lower than CBCT
Radiation dose	Lower than conventional CT but higher than 2D radiographs	None
Cost	Generally lower than CT and MRI	Generally higher than CBCT
Scan time	Short	Longer
Accessibility	High and often in-office	Lower and may require referral to specialized centers
Primary applications	Osseous abnormalities, implant planning, and trauma (bone)	Soft tissue lesions, TMJ disc, nerve imaging, and tumors (soft tissue)

Note. CBCT: Cone-beam computed tomography; MRI: Magnetic resonance imaging; TMJ: Temporomandibular joint; 2D: Two dimensional; CT: Computed tomography

overview rather than quantitative performance metrics. It is noteworthy that the terms "high," "good," "excellent," and "poor" represent qualitative assessments reported in the reviewed literature and should not be interpreted as standardized quantitative measures.

The Concept of Cone-Beam Computed Tomography-Magnetic Resonance Imaging Fusion

Considering that CBCT and MRI provide complementary diagnostic information, integration of these modalities through image fusion has emerged as a potentially valuable approach in maxillofacial imaging. This process, known as image fusion or multimodal imaging, combines information from multiple imaging modalities in order to produce a more accurate and comprehensive composite image for clinical diagnosis and treatment planning. It should be noted that image fusion should be regarded as an advanced extension of complementary imaging rather than a routine replacement for individual imaging modalities. Through the registration and combination of CBCT and MRI data, clinicians can simultaneously visualize both hard and soft tissues in one image, which may help overcome the selected inherent limitations of using each imaging technique independently (23). This capability is particularly valuable in complex maxillofacial conditions, such as TMJ disorders (TMD), where an accurate and precise evaluation of the spatial relationship between osseous structures and soft tissues (e.g., the articular disc) is crucial. In addition to individual application in TMJ imaging, integration of CBCT and MRI has shown clinical efficacy in diagnosing tumors affecting the jaw and in planning orthodontic and orthognathic treatments, thus underscoring the wider applicability of these two modalities (24).

Methods

Review Design

This structured narrative review was conducted to critically evaluate the complementary application of CBCT and MRI, as well as the emerging role of CBCT-MRI image fusion in oral and maxillofacial diagnostics.

It should be noted that no formal risk-of-bias assessment tool was applied because this study was designed as a structured narrative review and included heterogeneous study designs. Instead, studies were critically appraised based on methodological transparency, imaging methodology, clinical applicability, and relevance to the review objectives.

Search Strategy

A structured literature search was performed in PubMed, Scopus, and Web of Science databases for studies that were published between January 2008 and May 2025. The search strategy combined medical subject headings terms and free-text keywords related to CBCT, MRI, image fusion, multimodal imaging, TMD, oral radiology, and maxillofacial diagnostics. The representative search strategy was as follows:

("CBCT" OR "cone beam computed tomography") AND ("MRI" OR "magnetic resonance imaging") AND ("image fusion" OR "multimodal imaging" OR "image registration") AND ("maxillofacial" OR "temporomandibular joint" OR "oral radiology").

Study Selection

Two reviewers independently screened titles, abstracts, and full-text articles for eligibility. In addition, disagreements regarding study inclusion were resolved through discussion and final consensus with a senior author.

Inclusion and Exclusion Criteria

Eligible studies included human clinical investigations, diagnostic imaging studies, observational studies, methodological imaging studies, and relevant review articles addressing complementary CBCT-MRI imaging or CBCT-MRI fusion applications in maxillofacial imaging.

Nonetheless, the exclusion criteria were animal studies, phantom studies, conference abstracts, editorials, non-peer-reviewed publications, articles lacking adequate imaging methodology, and studies published in languages other than English.

Data Synthesis

Following screening the titles, abstracts, and full-text, 79 studies meeting the predefined eligibility criteria were included in the final narrative synthesis. No formal risk-of-bias assessment and quantitative meta-analysis were performed given the heterogeneity of study designs and the narrative nature of this review. Instead, studies were qualitatively evaluated according to methodological clarity, imaging protocol description, diagnostic applicability, and clinical relevance. Moreover, particular attention was given to study design, sample characteristics, image registration methodology, fusion validation techniques, and reported diagnostic outcomes.

The findings were narratively synthesized and categorized based on imaging principles, clinical applications, technical considerations, and future directions in multimodal maxillofacial imaging.

Literature Synthesis

The included studies demonstrated substantial heterogeneity in study design, imaging protocols, and clinical applicability. For narrative synthesis, the available evidence was categorized into (1) complementary imaging studies, (2) feasibility or pilot fusion studies, and (3) clinically validated fusion applications.

Principles and Techniques of Cone-Beam Computed Tomography-Magnetic Resonance Imaging Fusion

Image Registration

Image registration is a fundamental step in CBCT-MRI fusion, as accurate spatial alignment is essential for reliable multimodal interpretation (25). Most CBCT-MRI fusion workflows involve an initial manual pre-registration step followed by automated alignment algorithms (26). Additionally, normalized mutual information (NMI) is among the most frequently used similarity metrics for multimodal CBCT-MRI registration because of its robustness to variations in image contrast and overlap. NMI evaluates the statistical correlation between the intensity values of corresponding voxels in the two images. This similarity measure is well-suited for multi-modal registration since it exhibits lower sensitivity to variations in image contrast and the degree of overlap between modalities (27). CBCT primarily visualizes osseous structures, whereas MRI provides soft tissue contrast. Thus, advanced similarity metrics are required to compensate for the non-linear intensity relationship between modalities. It is noteworthy that most currently available fusion protocols rely on rigid transformation models that compensate for translational and rotational differences between datasets. This model addresses translational and rotational differences between the two image sets, based on the assumption that there has been no significant deformation of the patient's tissues between the acquisition of the CBCT and MRI scans. Although fiducial marker-based approaches have been proposed, intensity-based automatic registration generally demonstrates superior accuracy in maxillofacial CBCT-MRI fusion (28).

Image Fusion

Following image registration, CBCT and MRI datasets are integrated to generate a fused image that simultaneously displays complementary hard and soft tissue information (29). It should be noted that the visualization strategy used during fusion is critical for effective clinical interpretation. Color-coded overlays are commonly employed to distinguish CBCT-derived osseous structures from MRI-derived soft tissue anatomy. This visual separation allows clinicians to simultaneously assess both the bony and soft tissue components of the TMJ in a single view. Likewise, effective fusion techniques improve anatomical correlation and may enhance diagnostic interpretation in selected maxillofacial conditions (23). Similarly, automatic and point-based fusion approaches have demonstrated higher registration accuracy than manual fusion techniques in multimodal maxillofacial imaging (30).

Figure 1 illustrates the main steps involved in CBCT-MRI image fusion, including image acquisition, registration of the two datasets, fusion processing, and generation of the final fused image. CBCT provides detailed visualization of osseous structures, while MRI offers superior visualization of the articular disc and surrounding soft tissues. By combining information from these two modalities, the fused image allows simultaneous assessment of hard and soft tissue structures in a single view. The example demonstrates the anterior disc displacement of the TMJ and highlights the additional anatomical information that can be obtained through image fusion.

Advantages of Cone-Beam Computed Tomography-Magnetic Resonance Imaging Fusion in Maxillofacial Diagnostics

Simultaneous Visualization of Hard and Soft Tissues

CBCT-MRI fusion enables simultaneous visualization of osseous and soft tissue structures by combining the complementary strengths of both imaging modalities. Several studies have reported improved visualization of TMJ

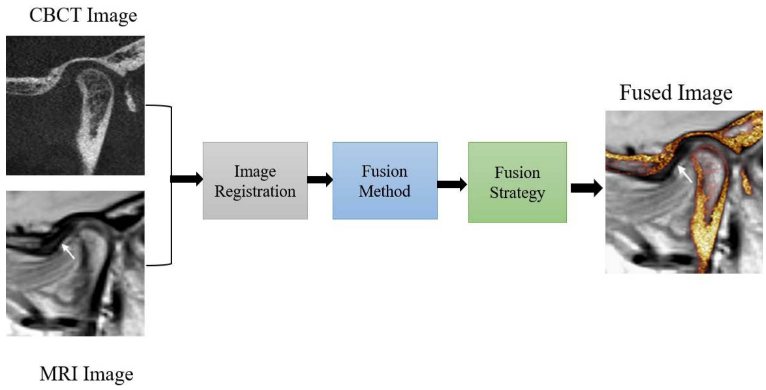

Figure 1. Workflow of CBCT-MRI Image Fusion for Temporomandibular Joint Evaluation
Note. CBCT: Cone-beam computed tomography; MRI: Magnetic resonance imaging

disc calcifications and surrounding anatomical structures using fused CBCT-MRI datasets (31, 32). Additionally, fusion imaging appears particularly useful in disorders involving simultaneous hard and soft tissue abnormalities, including TMJ internal derangement and disc displacement (33). Therefore, the integration of multimodal information may improve lesion characterization and support preoperative planning in selected clinical scenarios (32). Furthermore, potential applications have been proposed for third molar assessment and surgical risk evaluation involving the inferior alveolar nerve (34).

Improved Diagnostic Accuracy and Reliability

Several studies have suggested that CBCT-MRI fusion may improve diagnostic accuracy and observer reliability in maxillofacial imaging compared with the independent interpretation of each modality (35). In TMJ imaging, fused CBCT-MRI datasets demonstrated higher diagnostic performance for detecting articular disc calcification in comparison with CBCT or MRI alone (31). In addition, higher intra-observer and inter-observer agreement has been reported with fusion imaging approaches. Further, improved diagnostic agreement has been achieved in the assessment of TMJ internal derangement and osseous abnormalities when CBCT information is integrated with MRI findings (36). Moreover, fusion-based imaging may improve diagnostic confidence and facilitate more comprehensive interpretation in complex maxillofacial conditions (37).

Enhanced Assessment for Complex Cases

CBCT-MRI fusion may be particularly beneficial in complex diagnostic situations where isolated CBCT or MRI interpretation remains inconclusive (38). Several studies have highlighted the value of fusion imaging for distinguishing TMJ disc calcifications from intra-articular loose bodies (31). It has been shown that the integration of complementary hard and soft tissue information may reduce diagnostic ambiguity while improving interpretive reliability in selected TMJ disorders (23).

Improved Visualization of Anatomical Relationships

Fusion imaging may improve the visualization of anatomical relationships involving fractures, foreign bodies, and adjacent soft tissue structures, thereby supporting surgical planning (12).

Applications of Cone-Beam Computed Tomography-Magnetic Resonance Imaging Fusion

Temporomandibular Joint Disorders

TMDs represent the most extensively investigated clinical application of CBCT-MRI fusion. Table 2 summarizes the principal applications and reported diagnostic benefits of CBCT-MRI fusion in TMD assessment.

Articular Disc Displacement

The evaluation of TMJ articular disc displacement is one of the primary applications of CBCT-MRI fusion (32, 39). Several studies have investigated the diagnostic performance of fused datasets for evaluating disc position relative to adjacent osseous structures. Simultaneous visualization of soft tissue and osseous anatomy represents a major advantage of fusion imaging over separate modality interpretation. Previous studies have also reported improved diagnostic agreement and observer confidence when fusion imaging is used for disc displacement assessment (23). In addition, MRI-CBCT fusion has demonstrated higher examiner reliability than MRI alone in evaluating disc position (40). Additionally, current evidence supports CBCT-MRI fusion as an adjunctive imaging approach rather than a replacement for standalone CBCT or MRI examinations.

Articular Disc Calcification and Loose Bodies

CBCT-MRI fusion has also been investigated for differentiating TMJ disc calcifications from intra-articular loose bodies (31). Fusion imaging combines the calcification sensitivity of CBCT with the soft tissue contrast of MRI, thereby improving lesion localization and diagnostic interpretation. The findings of one study revealed significantly higher diagnostic accuracy for fused images compared with individual imaging modalities (31).

Bone Changes and Degenerative Joint Diseases

Some studies have employed CBCT-MRI fusion for the assessment of osseous abnormalities associated with degenerative TMJ disorders, including erosions, osteophytes, and subchondral changes (36, 39, 40). While CBCT provides high-resolution evaluation of osseous structures (5), MRI contributes additional information regarding disc morphology, joint effusion, and surrounding soft tissue alterations. A couple of studies have reported higher diagnostic performance for fused CBCT-MRI

Table 2. Reported clinical applications and diagnostic contributions of CBCT–MRI complementary imaging and fusion in maxillofacial diagnostics.

Application	Key Findings	References
TMJ evaluation	Improved visualization of disc and bone structures and higher diagnostic accuracy	(31, 32)
Third molar surgery	Enhanced assessment of the IAN-MTM relationship and superior soft tissue imaging	(34)
3D cephalometric analysis	High reliability and agreement with CBCT measurements and radiation-free alternative	(49)
Facial trauma	Potential complementary assessment of osseous and soft tissue injuries in complex trauma cases	(13)
Tumor surgery	Precise tumor delimitation and improved surgical planning and monitoring	(14)

Note. CBCT: Cone-beam computed tomography; MRI: Magnetic resonance imaging; IAN: Inferior alveolar nerve; MTM: Mandibular third molar; TMJ: Temporomandibular joint; 2D: Two-dimensional datasets in comparison with MRI alone in the evaluation of TMJ osseous abnormalities (23, 32). The simultaneous assessment of hard and soft tissue changes may facilitate more comprehensive evaluation of degenerative joint disease progression (41).

Internal Derangement Assessment

MRI-CBCT fusion has demonstrated promising reliability in the evaluation of TMJ internal derangement (23). Previous research confirmed improved intra-examiner and inter-examiner agreement with fused datasets compared with MRI-only assessment (33).

Orofacial Tumors

Both CBCT and MRI have shown diagnostic utility in the evaluation of mandibular invasion by oral malignancies (42). However, evidence regarding the routine clinical implementation of CBCT-MRI fusion in tumor imaging remains limited. Fusion imaging may improve the visualization of tumor extension by integrating CBCT-derived osseous detail with MRI-based soft tissue contrast (23, 43). Several studies have explored CT/CBCT-MRI fusion for the visualization and surgical planning of jaw tumors (23, 43). It is noteworthy that the simultaneous assessment of bone invasion and adjacent soft tissue involvement may support preoperative staging and surgical planning. MRI remains advantageous for evaluating soft tissue extension and neurovascular involvement, whereas CBCT provides a detailed assessment of osseous destruction (44). Accordingly, combining these datasets may improve anatomical delineation in selected oncologic cases. Comparative studies have reported relatively similar diagnostic performance among CBCT, MRI, and conventional CT for detecting osseous invasion in oral squamous cell carcinoma (44). Thus, further studies are required to determine whether CBCT-MRI fusion provides clinically significant advantages over standalone imaging modalities in oncologic applications (45). However, the currently available evidence is primarily derived from feasibility studies and small case series. Therefore, the true incremental diagnostic value of CBCT-MRI fusion over conventional complementary imaging remains insufficiently established.

Maxillofacial Trauma

The application of CBCT-MRI fusion in maxillofacial trauma remains largely investigational. As mentioned earlier, CBCT is highly effective for fracture detection and osseous assessment, while MRI provides superior evaluation of adjacent soft tissue structures (46). Hence, fusion imaging may allow simultaneous assessment of fractures and associated soft tissue injuries in complex trauma cases (23, 47, 48). Nonetheless, evidence supporting routine clinical implementation remains insufficient. Moreover, no prospective comparative studies have yet demonstrated a clear diagnostic advantage of CBCT-MRI fusion over the separate interpretation of CBCT and MRI datasets in maxillofacial trauma.

Three-Dimensional Cephalometric Analysis

CBCT-MRI fusion has also been investigated for 3D cephalometric analysis, representing acceptable agreement with conventional CBCT-based measurements (49).

Dental Implant Planning

Accurate 3D imaging is essential for contemporary dental implant planning (50). CBCT is extensively used for implant planning because of its high spatial resolution and accurate visualization of osseous anatomy and adjacent anatomical structures (51-54). Likewise, MRI has been investigated as a radiation-free alternative for evaluating soft tissue anatomy and inferior alveolar nerve localization during implant planning (55-57). Several studies have explored MRI-based virtual implant planning workflows and their integration with CBCT datasets (58, 59). Although MRI-based planning has shown promising feasibility, CBCT currently demonstrates greater reproducibility and clinical practicality (60). Accordingly, CBCT-MRI fusion may improve simultaneous visualization of osseous structures and neurovascular anatomy during implant planning. Although not directly involving MRI-CBCT fusion, some previous studies have reported the feasibility of integrating CBCT with other 3D datasets for implant planning (61, 62). Similarly, combined CBCT/CT and MRI volumetric visualization has been proposed for comprehensive implant assessment (63). At present, evidence supporting routine CBCT-MRI fusion for implant planning is scarce, and its clinical benefits over established CBCT-based workflows require further validation.

Table 2 provides the main clinical applications of CBCT-MRI complementary imaging and fusion techniques in oral and maxillofacial diagnostics. The investigated studies demonstrated how combining the strengths of CBCT for hard-tissue assessment and MRI for soft-tissue visualization can improve diagnostic evaluation in a range of clinical scenarios, including TMJ disorders, third molar surgery, facial trauma, cephalometric analysis, and tumor assessment. Overall, our findings suggest that multimodal imaging may enhance anatomical visualization, diagnostic confidence, and treatment planning when compared with the use of either modality alone.

Limitations and Challenges

Registration Accuracy and Potential Errors

Accurate registration between CBCT and MRI datasets remains technically challenging because of differences in image contrast, spatial resolution, anatomical representation, and field of view (25). Potential sources of registration errors include MRI geometric distortion, patient motion, variations in facial expression, and differences in patient positioning during image acquisition. Moreover, the non-linear intensity relationship between CBCT and MRI complicates automatic multimodal registration (64). In addition, minor spatial mismatches may persist despite advanced registration algorithms and can potentially affect diagnostic interpretation (65). Regardless of the frequent use of manual pre-registration followed by automatic registration utilizing similarity metrics, such as NMI (66), the non-linear association of intensity values between CBCT and MRI underscores the need for a careful selection and optimization of registration parameters (64). Both fiducial marker-based and intensity-based registration techniques have been investigated for maxillofacial image fusion (67). It should be noted that registration inaccuracies may distort anatomical relationships and reduce the reliability of fused datasets (68). Current research focused on improving registration robustness while reducing operator dependency in multimodal fusion workflows (24).

Spatial Resolution Alignment

The mismatch in spatial resolution between modalities is considered a key challenge in CBCT-MRI fusion for maxillofacial imaging. CBCT offers high-resolution imaging (voxel size ~0.1–0.4 mm), ideal for osseous structures (69, 70), while MRI provides superior soft tissue contrast but lower resolution (voxel size ~0.5–1.5 mm) (71). This discrepancy complicates image registration, particularly in anatomically complex areas, such as the TMJ (72). Resolution harmonization techniques may require interpolation or down-sampling processes that can potentially reduce image quality (24). Although artificial intelligence (AI)-assisted registration and mutual information-based algorithms have shown promising results (73), standardized fusion protocols are still lacking, and operator interaction often remains necessary (74).

Workflow Integration

Clinical implementation of CBCT-MRI fusion requires coordination between imaging modalities, dedicated software platforms, and trained personnel familiar with multimodal image processing (75). Furthermore, post-processing time and workflow complexity may limit routine clinical adoption. Efficient workflow integration requires standardized acquisition protocols and user-friendly fusion software. While digital dentistry and multimodal imaging advance maxillofacial workflows (76), further technological refinement is essential before CBCT-MRI fusion can become perfectly integrated into routine maxillofacial imaging workflows.

Comparison of Cone-Beam Computed Tomography-Magnetic Resonance Imaging Fusion With Individual Modalities

The comparative diagnostic value of CBCT-MRI fusion remains dependent on the specific clinical application and currently available evidence.

Diagnostic Accuracy for Temporomandibular Joint Disorders

Several studies have compared CBCT-MRI fusion with standalone CBCT or MRI for TMJ disorder assessment (23, 31, 32). Overall, fusion imaging has demonstrated improved diagnostic agreement and observer reliability in selected TMD applications. It has also shown higher reliability than MRI alone for evaluating disc displacement and osseous abnormalities of the TMJ (40). Additionally, improved diagnostic accuracy has been reported for differentiating disc calcifications from intra-articular loose bodies. The addition of CBCT-derived osseous information appears to improve the interpretation of degenerative TMJ changes when combined with MRI findings (23, 32).

Diagnostic Accuracy for Orofacial Tumors

Evidence evaluating the diagnostic accuracy of CBCT-MRI fusion in orofacial tumors remains limited (23, 44). CBCT provides superior osseous detail, whereas MRI is preferable for soft tissue characterization and neurovascular assessment. Although preliminary studies have shown promising visualization capabilities, additional clinical validation is required before drawing definitive conclusions (23, 43).

Diagnostic Accuracy for Maxillofacial Trauma

Current evidence supports the use of CBCT for detailed evaluation of facial fractures and osseous injuries, while MRI remains superior for the assessment of associated soft tissue injuries (46). However, there is limited comparative evidence regarding the diagnostic superiority of CBCT-MRI fusion over standalone imaging modalities in maxillofacial trauma. It is noteworthy that fusion imaging may provide additional value in complex trauma cases involving simultaneous osseous and soft tissue injuries (38). Nevertheless, further clinical studies are required to confirm its practical benefits.

Reduced Radiation Exposure

Compared with conventional CT, CBCT generally involves lower radiation exposure, while MRI provides imaging without ionizing radiation. Consequently, complementary CBCT-MRI protocols may help reduce overall radiation burden in selected clinical scenarios (77, 78).

Future Directions

Future developments in CBCT-MRI integration are expected to improve image quality, registration accuracy, workflow efficiency, and clinical applicability in maxillofacial diagnostics. In addition, advances in CBCT technology continue to enhance spatial resolution while reducing radiation exposure, whereas ongoing MRI innovations are improving soft tissue contrast and acquisition speed.

Moreover, AI is expected to play an increasingly important role in multimodal image fusion workflows. More precisely, AI-assisted algorithms may improve automatic registration, segmentation, lesion detection, and quantitative image analysis, thereby reducing operator dependency while improving diagnostic consistency. Likewise, AI-based segmentation tools may facilitate faster and more reproducible analysis of anatomical structures and pathological lesions. Emerging deep learning and radiomics applications may further expand the diagnostic potential of multimodal imaging in oral and maxillofacial radiology. Collectively, these developments may improve the efficiency, reproducibility, and clinical utility of CBCT-MRI fusion.

Similarly, future investigations should evaluate the role of CBCT-MRI fusion in additional clinical applications, including surgical navigation, orthodontic planning, vascular lesion assessment, and longitudinal treatment monitoring.

Despite promising preliminary findings, future multicenter prospective studies with standardized registration protocols are required to validate the diagnostic and clinical effectiveness of CBCT-MRI fusion across different maxillofacial applications.

The findings of this review should be cautiously interpreted because of the heterogeneity of the included studies, the limited number of clinically validated fusion investigations, and the narrative design of the review.

Conclusion

Our findings revealed that CBCT and MRI provide complementary diagnostic information regarding oral and maxillofacial imaging by combining detailed visualization of osseous structures with superior soft tissue characterization.

It was found that CBCT-MRI fusion extends this complementary approach by enabling simultaneous visualization of hard and soft tissues within a single integrated dataset. Further, current evidence suggests potential benefits in TMJ assessment and selected complex diagnostic scenarios; however, routine clinical implementation remains limited by technical challenges, workflow complexity, and insufficient large-scale validation studies.

Accordingly, future research should focus on standardized fusion protocols, automated registration techniques, and well-designed prospective clinical studies in order to determine the precise clinical indications and added diagnostic value of CBCT-MRI fusion in maxillofacial practice.

At present, CBCT-MRI fusion should be considered a promising adjunctive imaging technique rather than a replacement for established diagnostic workflows.

Authors' Contribution

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Competing Interests

The authors declare that they have no competing interests.

Data Availability Statement

All data analyzed in this narrative review were obtained from previously published studies available in public scientific databases.

Ethical Approval

No ethical approval was required because this study was exclusively based on previously published literature.

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