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The Role of Imaging in Temporomandibular Joint Disorders: A Narrative Review

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ABSTRACT: Temporomandibular disorders encompass a broad spectrum of intra-articular and extra-articular conditions in which imaging is essential when structural joint disease is suspected. This narrative review summarizes the roles of conventional radiography, cone-beam computed tomography (CBCT), multidetector computed tomography, magnetic resonance imaging (MRI), ultrasonography, nuclear medicine, and emerging computational methods in TMJ assessment. CBCT provides high-spatial-resolution evaluation of osseous morphology, degenerative change, trauma, ankylosis, developmental abnormalities and mineralized lesions, whereas MRI remains the reference technique for direct evaluation of the articular disc, internal derangement, effusion, marrow changes and inflammatory soft-tissue abnormalities. The review also discusses the Sivan 3D CBCT Volumetric Imaging Protocol, a dual-mode post-processing strategy proposed for integrated visualization of TMJ disc and osseous structures from CBCT data. Advanced quantitative MRI, three-dimensional segmentation, radiomics and artificial intelligence are increasingly shifting TMJ imaging from purely descriptive morphology toward objective and potentially predictive assessment. Imaging should remain clinically driven, and structural abnormalities should always be interpreted in conjunction with symptoms and functional findings.

KEYWORDS: Temporomandibular joint, temporomandibular disorders, CBCT, MRI, internal derangement, osteoarthritis, Sivan 3D CBCT protocol, artificial intelligence.

I. INTRODUCTION

Temporomandibular disorders (TMDs) comprise a heterogeneous group of musculoskeletal and neuromuscular conditions involving the temporomandibular joint (TMJ), masticatory muscles, and associated structures [1,2]. They represent an important cause of non-odontogenic orofacial pain and commonly manifest as preauricular pain, joint sounds, limitation or deviation of mandibular movement, locking, and impaired masticatory function [2]. Although the diagnosis of TMDs is predominantly based on clinical history and examination, imaging assumes an important role when intra-articular pathology, structural osseous abnormalities, trauma, developmental disturbances, inflammatory arthropathy, ankylosis, or neoplastic disease is suspected [1,3,4].

The TMJ is structurally complex because it contains both mineralized and non-mineralized components. The mandibular condyle, mandibular fossa, and articular eminence require high-resolution assessment of mineralized tissues, whereas the articular disc, retrodiscal tissues, capsule, synovium, ligaments, and joint fluid require techniques with high soft-tissue contrast [4,5]. Since these tissue classes have markedly different imaging characteristics, no single conventional modality can optimally demonstrate every component of the joint [1,4].

The selection of an imaging technique should therefore be driven by the clinical question rather than by routine use of a particular modality [1,3]. Contemporary diagnostic imaging of TMJ disorders requires complementary assessment of osseous and soft-tissue structures, with the examination selected according to the suspected pathology and diagnostic objective [4,6]. Conventional radiography provides an initial overview but is restricted by geometric distortion and superimposition. Cone-beam computed tomography (CBCT) has become central to high-resolution assessment of osseous morphology and degenerative change [7–13], while magnetic resonance imaging (MRI) remains the reference technique for direct visualization of the articular disc, internal derangement, joint effusion, marrow

abnormalities, and several inflammatory conditions [1,4,5,14–17].

Imaging findings must also be interpreted in the clinical context. Disc displacement and osseous remodeling may occur in asymptomatic individuals; thus, the presence of an imaging abnormality alone does not establish the cause of symptoms [15,18]. This distinction is particularly important in TMDs because pain intensity, functional limitation, structural change, and disease activity do not always progress in parallel.

Recent developments have expanded TMJ imaging beyond conventional morphological evaluation. Three-dimensional reconstruction, quantitative MRI, dynamic imaging, radiomics, automated segmentation, and artificial intelligence (AI) are increasingly being investigated for objective characterization of joint structure and function [19–21]. The purpose of this narrative review is to summarize the principal imaging modalities used in TMDs, describe their clinical indications and characteristic imaging appearances, discuss limitations and modality selection, and highlight emerging technologies relevant to future TMJ assessment.

II. MATERIALS AND METHODS

Search Strategy

A narrative literature review was conducted to identify relevant publications concerning imaging of temporomandibular joint disorders. Electronic searches were undertaken in PubMed/MEDLINE, Scopus, Web of Science, and Google Scholar, with literature available up to August 2026 considered for inclusion. The search combined terms related to the joint, disease category, conventional and advanced imaging, and computational analysis.

Search terms included “temporomandibular joint,” “temporomandibular disorders,” “TMD,” “TMJ imaging,” “cone-beam computed tomography,” “CBCT,” “computed tomography,” “magnetic resonance imaging,” “MRI,” “articular disc displacement,” “internal derangement,” “TMJ osteoarthritis,” “degenerative joint disease,” “ultrasonography,” “SPECT,” “bone scintigraphy,” “radiomics,” “artificial intelligence,” “deep learning,” and “three-dimensional TMJ imaging.” Boolean combinations such as “temporomandibular joint AND magnetic resonance imaging,” “temporomandibular joint AND cone-beam computed tomography,” “TMJ AND internal derangement,” “TMJ AND osteoarthritis,” and “temporomandibular joint AND artificial intelligence” were used.

Priority was given to professional position statements, systematic reviews, meta-analyses, diagnostic accuracy studies, prospective and retrospective clinical investigations, and reports describing emerging imaging techniques. Reference lists of selected publications were manually screened for additional relevant articles. Publications were included when they addressed imaging technique, imaging findings, diagnostic applications, modality selection, or technological advances directly related to TMJ disorders. Articles dealing exclusively with treatment without a relevant imaging component were excluded. Because the objective was to provide a broad clinical and technological synthesis rather than a quantitative estimate of a narrowly defined outcome, a narrative methodology was adopted and no meta-analysis was performed.

III. IMAGING ANATOMY OF THE TEMPOROMANDIBULAR JOINT

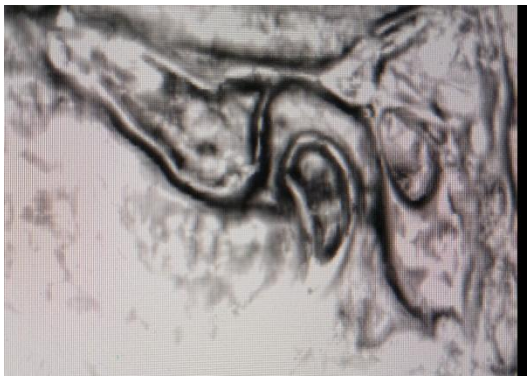

Figure 1. Representative sagittal Sivan 3D CBCT dual-mode rendering demonstrating the relationship of the mandibular condyle, articular eminence, and intra-articular soft-tissue region.

The TMJ is a bilateral synovial articulation formed by the mandibular condyle and the mandibular fossa and articular eminence of the temporal bone [4,5]. Unlike most synovial joints, the articular surfaces are predominantly covered by fibrocartilage. A fibrocartilaginous disc divides the joint into superior and inferior compartments and contributes to load distribution and coordinated mandibular movement [5,14]. The corresponding sagittal Sivan 3D CBCT appearance of the joint is illustrated in Figure 1.

The normal disc is biconcave and consists of an anterior band, thin intermediate zone, and posterior band. On MRI it usually exhibits low signal intensity because of its dense fibrous composition [4,5]. In the closed-mouth position, the posterior band is conventionally located near the superior aspect of the condyle, while the intermediate zone lies between the condylar surface and articular eminence. During opening, initial

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rotation in the inferior compartment is followed by anterior translation of the condyle-disc complex along the articular eminence [5].

Normal condylar shape demonstrates substantial interindividual variability. Mild flattening, asymmetry, and remodeling may represent adaptive change rather than disease [8,22]. Imaging should therefore be interpreted in relation to age, symptoms, mandibular function, and other clinical findings.

IV. CONVENTIONAL RADIOGRAPHY

Panoramic radiography is commonly available in dental practice and may provide an initial or incidental overview of the condyles. It can demonstrate gross asymmetry, marked deformity, advanced degenerative change, fracture, hyperplasia, hypoplasia, and selected osseous lesions [1,23]. However, magnification, projection distortion, superimposition, and patient-positioning variability reduce its sensitivity for subtle TMJ pathology [7,23]. Early cortical erosion, small osteophytes, and subchondral abnormalities may be missed [7,11].

Historical transcranial, transpharyngeal, and linear tomographic projections have largely been replaced by cross-sectional imaging. Conventional radiography also provides no direct visualization of the articular disc or other intra-articular soft tissues; therefore, it cannot exclude internal derangement [1].

V. CONE-BEAM COMPUTED TOMOGRAPHY

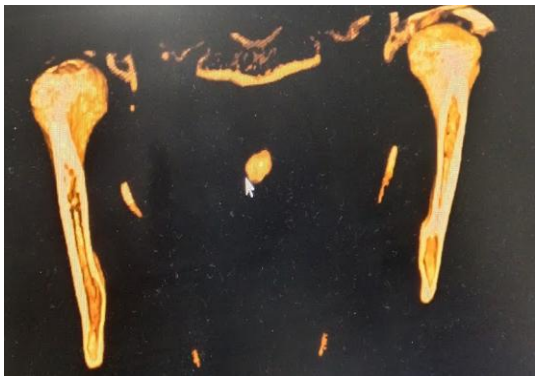

Figure 2. Three-dimensional CBCT volumetric rendering of the bilateral temporomandibular joint region.

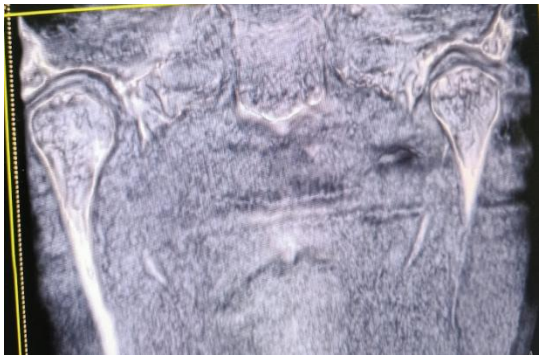

Figure 3. Coronal Sivan 3D CBCT dual-mode rendering demonstrating bilateral temporomandibular joint morphology.

Figure 4. Sagittal CBCT reconstruction demonstrating the osseous relationship between the mandibular condyle, mandibular fossa, and articular eminence.

CBCT has become one of the most important imaging techniques for detailed evaluation of TMJ osseous structures because it provides high-spatial-resolution multiplanar visualization with relatively efficient radiation use in dentomaxillofacial applications [7–10]. Axial, coronal, sagittal, corrected sagittal, and corrected coronal reconstructions permit assessment of the condylar head, mandibular fossa, articular eminence, joint spaces, and adjacent osseous structures without the superimposition inherent to two-dimensional radiography [7]. Representative three-dimensional and multiplanar CBCT appearances are shown in Figures 2–4.

CBCT is particularly useful for detecting cortical erosion, osteophytes, subchondral sclerosis, cyst-like subchondral defects, flattening, deformity, fractures, ankylosis, developmental abnormalities, and mineralized intra-articular bodies [8–13]. Comparative studies have shown improved osseous assessment with CBCT compared with panoramic and conventional tomographic techniques [7,11]. Current professional recommendations support CT-based imaging, particularly CBCT when appropriate in dentomaxillofacial practice, for suspected osseous TMJ abnormalities [1,3].

The major limitation of conventional CBCT is poor intrinsic soft-tissue contrast. The articular disc, synovium, joint capsule, retrodiscal tissues, and joint effusion cannot ordinarily be characterized with the reliability of MRI [1,4]. Consequently, a normal osseous CBCT examination does not exclude internal derangement or early inflammatory disease. Field of view, voxel size, and exposure should be selected according to the diagnostic task and radiation-protection principles [1].

VI. THE SIVAN 3D CBCT VOLUMETRIC IMAGING PROTOCOL

The Sivan 3D CBCT Volumetric Imaging Protocol is a recently described post-processing approach intended to extend the conventional osseous role of CBCT by improving simultaneous visualization of the TMJ disc, retrodiscal tissue, and adjacent osseous structures from a single CBCT dataset [24]. The technique incorporates dual-mode volumetric rendering, voxel-intensity modulation, and anisotropic filtering to enhance tissue interfaces that are poorly conspicuous on standard CBCT reconstructions [24].

In the original retrospective validation study, anonymized CBCT volumes from 42 patients with TMD were processed using the protocol and compared with conventional CBCT and MRI. Fifteen expert raters evaluated eight diagnostic parameters. The enhanced CBCT images demonstrated excellent inter- and intra-rater reliability, with reported intraclass correlation coefficients greater than 0.95, and significantly improved visualization of both soft- and hard-tissue TMJ structures in the study dataset [24]. The protocol was specifically developed to provide an integrated three-dimensional view in which the articular disc, retrodiscal region, condylar surface, and temporal component can be interpreted together. The potential clinical value of this approach lies in combined structural visualization and three-dimensional orientation from a single CBCT acquisition, particularly in settings where MRI access is limited. Nevertheless, it should currently be regarded as an emerging post-processing technique rather than a universal substitute for conventional MRI. The original evidence is derived from a single validation study, and independent multicenter replication, scanner-level reproducibility testing, and broader validation across disease categories are required before it can be considered equivalent to established MRI protocols for soft-tissue diagnosis [24].

VII. IMAGING OF DEGENERATIVE JOINT DISEASE

Degenerative joint disease is an important intra-articular component of the TMD spectrum and involves structural alteration of cartilage, subchondral bone, disc, and synovium [12,13,22]. CBCT findings may include cortical erosion, osteophyte formation, subchondral sclerosis, cyst-like subchondral defects, flattening, altered condylar contour, and advanced deformity [8–13]. Erosion appears as focal interruption or irregularity of the normally smooth cortical surface, osteophytes as marginal osseous projections, and sclerosis as increased subcortical density. Subchondral cyst-like lesions appear as localized areas of decreased density within the subcortical bone [8–12].

Flattening requires cautious interpretation because it may represent adaptive remodeling, particularly when it is not accompanied by erosion, osteophyte formation, sclerosis, or subcortical defects [12,22]. MRI complements CBCT by demonstrating disc degeneration, effusion, marrow abnormalities, and other soft-tissue manifestations [16,17]. Importantly, radiographic severity does not consistently parallel pain severity or functional limitation [13,22].

VIII. MAGNETIC RESONANCE IMAGING

MRI is regarded as the principal imaging modality for assessment of the soft-tissue components of the TMJ [1,4,5,14]. Its major advantage is direct visualization of the articular disc without ionizing radiation. It also demonstrates joint effusion, retrodiscal tissue, synovial abnormalities, bone marrow changes, and surrounding soft tissues [4,5,16,17].

Typical TMJ MRI protocols include oblique sagittal images oriented perpendicular to the long axis of the condyle and oblique coronal images approximately parallel to the condylar axis [4,5]. Closed- and open-mouth acquisitions are especially important in suspected internal derangement because they permit assessment of disc-condyle relationships during mandibular translation [1,5].

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Proton-density or intermediate-weighted sequences provide anatomic detail, whereas T2-weighted or other fluid-sensitive sequences facilitate evaluation of effusion and inflammatory abnormalities [4,5]. A representative sagittal MR appearance of the low-signal articular disc is shown in Figure 5.

IX. DISC DISPLACEMENT WITH REDUCTION

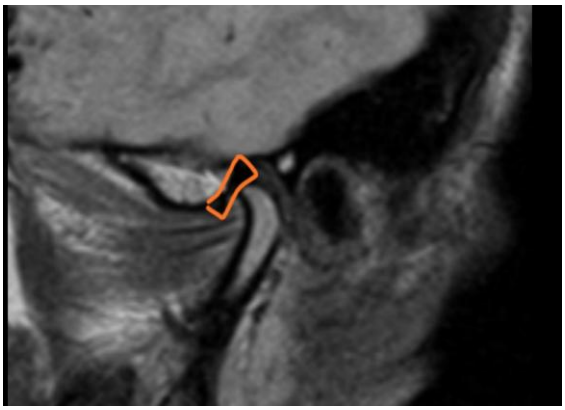

Figure 5. Sagittal MR image of the temporomandibular joint demonstrating the low-signal articular disc in relation to the mandibular condyle.

Disc displacement is one of the most extensively studied structural manifestations of internal derangement [5,14,15,18]. In disc displacement with reduction, the disc is displaced from its normal relationship with the condyle in the closed-mouth position, most commonly anteriorly, but returns to an approximately normal relationship during mouth opening [5,14]. Clinically, recapture may produce a clicking sound. MRI demonstrates the abnormal closed-mouth position and subsequent reduction during opening [4,5,14]. The disc may initially retain a biconcave configuration, although chronic displacement can be associated with thickening, folding, shortening, or deformation [5].

Disc displacement can also be found in asymptomatic individuals [15,18]; therefore, MRI findings must be interpreted with clinical symptoms and functional examination rather than in isolation.

X. DISC DISPLACEMENT WITHOUT REDUCTION

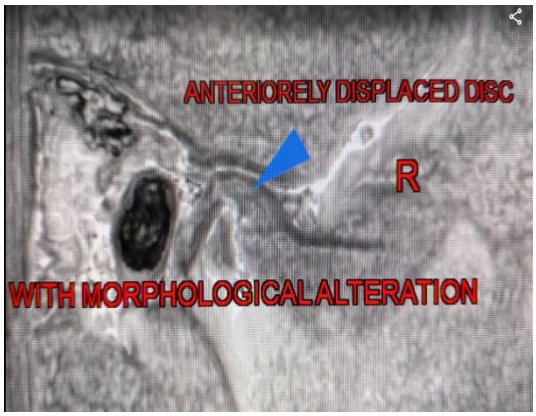

Figure 6. Sivan 3D CBCT dual-mode volumetric rendering demonstrating anterior displacement of the temporomandibular joint disc with associated morphological alteration.

Figure 7. Representative sagittal MR image of the temporomandibular joint demonstrating the disc-condyle relationship.

In disc displacement without reduction, the displaced articular disc fails to return to a normal relationship with the condyle during opening [5,14]. Patients may present with pain, restricted opening, mandibular deviation, or a history of closed locking [2]. MRI demonstrates persistent displacement on both closed- and open-mouth images, and condylar translation may be restricted, especially in the acute stage [4,5,14]. With chronicity, adaptive tissue changes may permit partial recovery of mouth opening despite persistent non-reducing displacement [5]. Figure 6 demonstrates anterior disc displacement with morphological alteration using the Sivan 3D CBCT dual-mode rendering technique, while Figure 7 illustrates the disc-condyle relationship on sagittal MRI.

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XI. JOINT EFFUSION, SYNOVIAL ABNORMALITIES, AND BONE MARROW CHANGES

Joint effusion is best detected on fluid-sensitive MRI sequences, where it appears as high signal intensity within the superior and/or inferior joint compartments [4,16,17]. Small amounts of fluid may occur physiologically, whereas more conspicuous effusion can accompany internal derangement, inflammation, or degenerative disease [16,17]. Effusion is therefore a supportive rather than independently diagnostic finding.

Synovitis may manifest as synovial thickening and enhancement after intravenous contrast administration. Contrast-enhanced MRI is not usually required for uncomplicated internal derangement but is useful when inflammatory arthropathy, infection, or neoplasia is suspected [4,17]. Bone marrow edema-like change typically shows low T1 signal and increased signal on fluid-sensitive sequences and may reflect active inflammatory or degenerative processes. Chronic sclerosis generally exhibits low signal intensity across multiple sequences [4,17].

XII. INFLAMMATORY ARTHROPATHIES

Systemic inflammatory arthropathies including rheumatoid arthritis, juvenile idiopathic arthritis, psoriatic arthritis, and ankylosing spondylitis can involve the TMJ [4,17]. MRI is particularly valuable in early disease because synovitis, effusion, and marrow edema-like changes may precede major cortical destruction [4,17]. Advanced disease may demonstrate erosions, flattening, reduced condylar volume, deformity, sclerosis, and occasionally ankylosis. In juvenile idiopathic arthritis, chronic inflammation may interfere with mandibular growth and contribute to micrognathia, retrognathia, asymmetry, and occlusal disturbance. MRI is useful for active inflammatory changes, while CBCT provides detailed assessment of established osseous deformity [1,4].

XIII. TRAUMA AND ANKYLOSIS

Condylar fractures represent an important subset of mandibular trauma. Imaging should determine fracture location, displacement, angulation, fragmentation, and the relationship of the condylar segment to the mandibular fossa [1,23]. Panoramic radiography may identify obvious fractures but can underestimate displacement. CBCT provides high-resolution multiplanar visualization of isolated dentomaxillofacial fractures, while multidetector CT is generally preferred in extensive facial trauma because it allows rapid assessment of the entire craniofacial skeleton and associated injuries [1]. MRI is not routinely required in acute fracture but can demonstrate associated disc displacement, capsular injury, hematoma, or other soft-tissue abnormalities when clinically relevant [4].

TMJ ankylosis may be fibrous or osseous and frequently follows trauma or infection. CT and CBCT are central to osseous ankylosis because they demonstrate the three-dimensional extent of the ankylotic mass, medial extension, distortion of the condyle and temporal component, and relationship to skull-base structures [1]. Three-dimensional renderings may aid surgical planning, although multiplanar source images remain essential. MRI is useful when fibrous ankylosis or residual soft-tissue structures require assessment.

XIV. DEVELOPMENTAL, GROWTH, AND NEOPLASTIC DISORDERS

Developmental and growth-related TMJ abnormalities include condylar aplasia, hypoplasia, hyperplasia, and other craniofacial growth disturbances. CBCT provides detailed three-dimensional assessment of condylar morphology, dimensions, asymmetry, and mandibular skeletal changes [1]. In suspected condylar hyperplasia, morphological imaging alone may not determine whether growth remains active. Bone scintigraphy or SPECT can provide supplementary information regarding relative skeletal metabolic activity, but uptake should be interpreted together with longitudinal clinical assessment and serial morphologic imaging.

A range of benign, malignant, and tumor-like lesions may involve the TMJ, including osteochondroma, osteoma, chondroblastoma, synovial chondromatosis, tenosynovial giant-cell tumor, primary malignancy, and metastatic disease [4,23]. CT or CBCT is useful for mineralized and osseous lesions, whereas MRI is superior for non-mineralized bodies, synovial proliferation, joint distension, and soft-tissue extension. Aggressive bone destruction, a rapidly enlarging mass, sensory disturbance, or severe progressive pain should prompt contrast-enhanced cross-sectional imaging and broader investigation.

XV. ULTRASONOGRAPHY AND NUCLEAR MEDICINE

Ultrasonography is a non-ionizing, relatively inexpensive, portable technique that permits dynamic assessment of selected superficial TMJ structures [25]. High-frequency ultrasound has been investigated for articular disc position,

effusion, capsular abnormalities, and condylar translation. Its limitations include restricted acoustic access because of surrounding bone and strong dependence on operator technique [25]. It may serve as an adjunct in selected settings but does not currently replace MRI for comprehensive internal derangement assessment [1,25].

Bone scintigraphy and SPECT provide information about osteoblastic and skeletal metabolic activity rather than detailed morphology. Their most established TMJ application is assessment of suspected active condylar hyperplasia. PET/CT and PET/MRI have limited routine roles in TMDs but may be relevant when malignant, metastatic, inflammatory, or metabolically active disease affects the joint region.

XVI. IMAGING SELECTION ACCORDING TO CLINICAL INDICATION

Contemporary TMJ imaging should be question-driven [1,3]. Patients with predominantly muscular symptoms and no evidence of intra-articular or osseous disease may not require imaging initially [1,2]. Suspected osseous degeneration, fracture, ankylosis, developmental abnormality, or bone lesion generally favors CBCT or CT-based evaluation [1,7]. Suspected disc displacement, closed locking, internal derangement, effusion, synovial abnormality, or marrow change favors MRI [1,4,5]. Multidetector CT is particularly useful for complex trauma or disease extending beyond the immediate TMJ region, while ultrasonography and nuclear medicine should be reserved for specific indications.

XVII. RECENT ADVANCES: QUANTITATIVE IMAGING, ARTIFICIAL INTELLIGENCE, AND RADIOMICS

TMJ imaging is progressively moving from qualitative morphology toward quantitative and functional characterization [20,21]. Three-dimensional segmentation can quantify condylar volume, shape, asymmetry, remodeling, and postoperative change. Structured visual volumetric analysis of three-dimensional CBCT datasets has also been proposed for diagnostic characterization of maxillofacial lesions, demonstrating the broader value of volumetric interpretation beyond conventional two-dimensional assessment [26]. Advanced MRI techniques including T2 and T2* mapping, T1rho imaging, diffusion-based techniques, and ultrashort echo-time approaches are being investigated for assessment of tissue microstructure and biochemical change [20,21]. Dynamic or cine MRI can demonstrate disc-condyle motion throughout opening and closing rather than relying only on static terminal positions [20].

Artificial intelligence is emerging as an important area of TMJ imaging research [19,20]. Deep-learning models have been evaluated for automated TMJ localization, condylar segmentation, identification of degenerative changes, and analysis of disc position. Automated segmentation may reduce analysis time and improve reproducibility. Radiomics extends quantitative analysis by extracting image-derived variables related to shape, intensity distribution, texture, and spatial heterogeneity, which may ultimately serve as biomarkers of degeneration, inflammatory activity, progression, or treatment response.

However, current AI and radiomic investigations remain limited by relatively small datasets, heterogeneous acquisition protocols, variable reference standards, risk of overfitting, and inadequate external validation [19,20]. Future translation will require multicenter datasets, standardized imaging protocols, transparent reporting, independent testing, and demonstration of clinically meaningful incremental benefit.

XVIII. FUTURE PERSPECTIVES

The future of TMJ imaging is likely to depend on integration of structural, functional, and quantitative information rather than competition between individual modalities [20,21]. CBCT can provide detailed osseous morphology, while MRI characterizes the disc, synovium, fluid, marrow, and other non-mineralized components [1,4]. Advanced post-processing, including the Sivan 3D CBCT approach, represents an attempt to narrow this traditional separation by extracting additional diagnostically useful information from CBCT datasets [24].

Integration of three-dimensional morphology, quantitative imaging biomarkers, radiomics, AI, and clinical variables may eventually permit more comprehensive phenotyping of TMDs. Such approaches could help distinguish active disease from stable remodeling, identify patients at increased risk of progression, quantify treatment response, and support individualized management. Achieving this will require harmonized diagnostic terminology, standardized acquisition and post-processing, longitudinal outcome data, and robust multicenter validation.

XIX. CONCLUSION

Imaging plays an essential complementary role in the diagnosis and management of selected temporomandibular joint disorders. The choice of

modality should be based primarily on the clinical question and tissue of interest. Conventional radiography provides an initial overview but has limited sensitivity for subtle intra-articular abnormalities. CBCT offers high-resolution assessment of osseous structures and is particularly valuable for degenerative changes, fracture, ankylosis, developmental abnormalities, and mineralized lesions. MRI remains the reference imaging technique for the articular disc, internal derangement, joint effusion, marrow abnormalities, and inflammatory or other soft-tissue pathology.

Emerging post-processing and quantitative techniques are expanding the diagnostic landscape. The Sivan 3D CBCT Volumetric Imaging Protocol has introduced a dual-mode CBCT-based strategy for integrated visualization of disc, retrodiscal tissue, and adjacent bone, although further independent validation is required before it can be positioned alongside established MRI standards [24]. Quantitative MRI, three-dimensional analysis, radiomics, and AI are likewise shifting TMJ imaging toward more objective disease characterization. Ultimately, imaging findings must always be correlated with clinical signs, symptoms, and functional status because structural abnormalities may also occur in asymptomatic individuals.

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