

REVIEW ARTICLE

Beyond the conventional Radiograph: The Future of TMJ ImagingRavi Madan¹, Meenakshi Tyagi², Reena Mittal¹, Lakshya Tuteja²**Abstract**

Temporomandibular joint (TMJ) disorders are clinical conditions characterized by pain and dysfunction of the jaw joint and masticatory muscles. Diagnosis is essential for management and imaging plays a pivotal role in assessment. Recently, TMJ imaging has undergone significant technological evolution, transitioning from conventional radiographs to advanced modalities such as magnetic resonance imaging (MRI), computed tomography (CT), cone-beam computed tomography (CBCT), ultrasound (US) and emerging functional imaging techniques. This article reviews the advancements in TMJ imaging, evaluates clinical applications, compares modalities and explores future directions, including artificial intelligence (AI) and imaging biomarkers.

Introduction

The masticatory system is a functional unit of the body primarily responsible for chewing, speaking and swallowing. Its components comprises of bones, joints, ligaments, teeth and muscles. The masticatory system is a complex and highly refined unit.

The area where the cranio-mandibular articulation occurs is called the temporomandibular joint. The TMJ is formed by the mandibular condyle fitting into the mandibular fossa of the temporal bone. It provides for hinging movement in one plane and is therefore called as ginglymoid joint. However, at the same time it also provides for gliding movement which classified it as arthroidal joint. Thus, it is technically considered as ginglymo arthroidal joint.

Temporomandibular joint disorders (TMD) encompass a spectrum of conditions affecting the TMJ, masticatory muscles and associated structures. Clinical diagnosis alone often lacks sensitivity and specificity, necessitating imaging to assess osseous and soft tissue abnormalities, guide treatment, and monitor outcomes. Traditional imaging techniques provided limited views, but advances in radiologic technology have transformed TMJ diagnostics.²

Imaging Anatomy of the Temporomandibular Joint

A clear understanding of the normal anatomy and morphology of the temporomandibular joint (TMJ) is essential to avoid misinterpretation of normal variants as pathology.

Mandibular Component

The mandibular condyle is an ellipsoid bony process extending from the mandibular ramus by a narrow neck. It measures approximately 20 mm mediolaterally and 8–10 mm anteroposteriorly. Considerable variation exists in condylar shape (flat, round, or convex), emphasizing the importance of recognizing normal morphologic diversity. The medial and lateral poles define the long axis of the condyle, which is angulated 15–33° to the sagittal plane. (Fig. 1) A mediolateral ridge on the anterior surface marks the superior limit of the pterygoid fovea, the attachment site of the lateral pterygoid muscle. This ridge should not be mistaken for an osteophyte. Cortical borders may be poorly defined in children but are normally visible in adults.²



Fig. 1 Anterior view of the mandibular condyle. LP, Lateral pole; MP, medial pole; PF, pterygoid fovea

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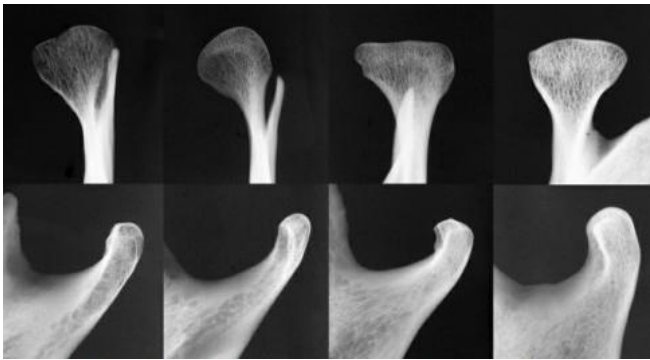


Fig. 2 Images of the mandibular condyle demonstrates the extensive variability in condylar shape: heart shaped, round, flat, and with large medial and lateral poles. The upper row are coronal views with the corresponding lateral views immediately below.

Temporal Component

The temporal component consists of the mandibular (glenoid) fossa posteriorly and the articular eminence anteriorly. The posterior slope of the eminence, the fossa roof, and the summit form a gentle “S-shaped” contour in the sagittal plane. The roof of the fossa is thin and separates the joint from the middle cranial fossa. Glenoid fossa depth and eminence development depend on functional loading; both are underdeveloped in early childhood and mature by approximately 4 years of age. Pneumatization of the articular eminence is a recognized normal variant.

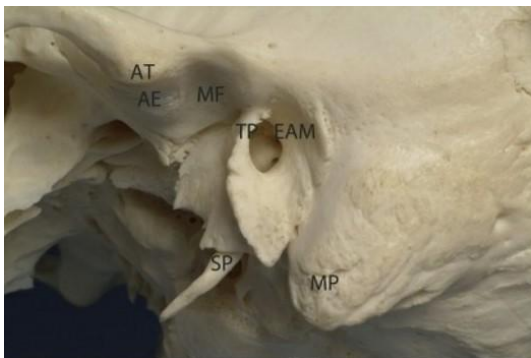


Fig. 3 Lateral and inferior view of the skull showing the temporal component of the temporomandibular joint. AE, Articular eminence; AT, articular tubercle; EAM, external auditory meatus; MF, mandibular fossa; MP, mastoid process; SP, styloid process; TP, tympanic plate.

Interarticular Disc and Retrodiscal Tissues

The articular disc is composed of dense fibrous connective tissue and has a biconcave shape with thick anterior and posterior bands and a thin intermediate zone. In the closed position, the posterior band lies at approximately the 11-o’clock position relative to the condyle. The disc is stabilized by collateral ligaments and attachments to the joint capsule, lateral pterygoid muscle, and retrodiscal tissues. The posterior attachment (bilaminar zone) contains elastic fibers and vascular tissue that permit disc translation

and recoil during mandibular movement. Compression or displacement of this tissue may contribute to TMJ pain.¹

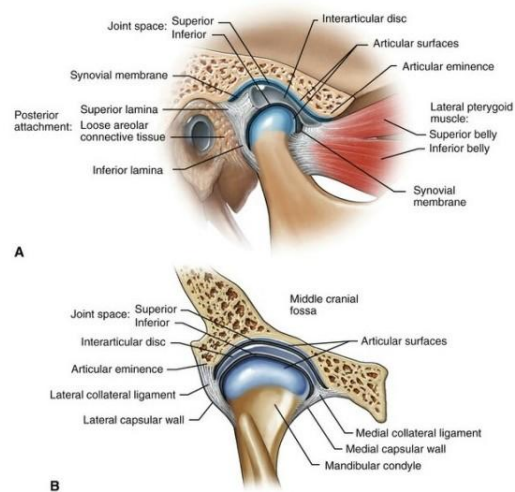


Fig. 4 Lateral (A) and coronal (B) views of normal temporomandibular joint anatomy.

Traditional Imaging Modalities

1. Conventional Radiography

The **panoramic view**, also known as an **orthopantomogram (OPG)**, is a commonly employed imaging technique in dental practices. It offers a broad, two-dimensional representation of the jaws, maxillofacial bones, teeth, and TMJs in a single image. One of its significant advantages is that it provides a **general screening of the condyles** with minimal patient discomfort and low radiation exposure.

By using slight modifications of the standard panoramic technique, clinicians can enhance the visibility of the TMJs. When properly executed, this technique minimizes the superimposition of adjacent structures over the condyles, allowing for a more accurate preliminary evaluation. This is especially useful in identifying gross osseous abnormalities such as condylar asymmetry, fractures, flattening, or significant degenerative changes. The panoramic image captures both TMJs simultaneously, facilitating a comparative assessment of bilateral structures.⁵

2. Computed Tomography (CT) and Cone-Beam Computed Tomography (CBCT)

2.1. Conventional CT

CT revolutionized osseous evaluation of the TMJ with cross-sectional imaging, enabling detailed assessment of condylar morphology, erosions, osteophytes and joint space alterations. Nevertheless, high radiation dose limited its routine use, especially in younger patients

2.2. CBCT

Cone-beam computed tomography has rapidly become the modality of choice for osseous TMJ evaluation due to:

- Lower radiation dose compared with conventional CT.

- High spatial resolution for bone detail.
 - 3D reconstructions facilitating volumetric analysis.
- CBCT has improved diagnostic accuracy for condylar flattening, subcortical cysts, ankylosis, and other degenerative changes. It also enables quantitative measures such as condylar volume and surface mapping, supporting pre-surgical planning.



Fig.5 Normal Condylar Images With CBCT. A, anterior view of the TM joint in the closed position. B, lateral view TM joint.

3. Magnetic Resonance Imaging (MRI)

MRI remains the gold standard for soft tissue evaluation of the TMJ due to its superior contrast resolution without ionizing radiation. Key advancements include:

3.1. Disc Imaging

- Visualization of disc morphology and position.
- Detection of internal derangements such as disc displacement with or without reduction.

3.2. Inflammatory and Joint Effusion Assessment

- Fluid-sensitive sequences (e.g., T2-weighted and STIR) to detect effusion and synovitis.
- Evaluation of retrodiscal tissue changes.

3.3. Advanced MRI Techniques

- **Dynamic MRI:** Allows assessment of disc movement during jaw opening and closing, improving interpretation of functional abnormalities.
- **High-Resolution MRI:** Uses dedicated TMJ coils and smaller field-of-view for enhanced image detail.

- **Diffusion-Weighted Imaging (DWI) and T2 Mapping:** Emerging techniques to quantify tissue microstructure, potentially identifying early degenerative changes before morphological alterations.⁴

4. Ultrasound (US)

Ultrasound is emerging as a useful tool in TMJ imaging due to its low cost, lack of radiation, and dynamic capability. Recent advances include:

- High-frequency transducers (up to 15 MHz) providing improved resolution.
- Real-time imaging of disc motion and joint space narrowing.
- Correlation with MRI findings in specific clinical contexts, particularly for assessing anterior disc displacement and inflammatory changes.

However, US remains operator-dependent and limited for assessing deep joint structures.

It has become an increasingly valued adjunct imaging modality in assessing temporomandibular joint (TMJ) disorders, offering a real-time, non-invasive, portable, and low-cost alternative to MRI and CT, particularly useful in patients contraindicated for MRI due to claustrophobia or implants. First introduced for TMJ evaluation in the early 1990s by Nabeih and colleagues and further developed by Emshoff, high-resolution ultrasound (HR-US) has since been widely studied to detect internal derangement, articular effusion, and condylar bone changes.⁶

5. Functional and Molecular Imaging

Advanced imaging modalities are expanding into functional assessment:

5.1. Positron Emission Tomography (PET)

PET (especially combined with CT or MRI) has been explored to detect metabolic activity associated with inflammation and osteoarthritis.

5.2. SPECT/CT

Single-photon emission computed tomography combined with CT provides both functional and anatomical information, beneficial in evaluating active bone remodeling and pain generators.

In certain clinical scenarios, it is also essential to determine whether there is **active inflammation** in the TMJ, especially when distinguishing between degenerative conditions such as osteoarthritis and the non-inflammatory, end-stage changes of osteoarthrosis. While standard radiographs and CBCT can show morphological changes of the condyle, they cannot differentiate between active and dormant disease processes. In such cases, **bone scintigraphy**, also known as a bone scan, becomes useful.

6. Artificial Intelligence and Quantitative Imaging

Artificial intelligence (AI), machine learning (ML), and radiomics are rapidly influencing TMJ imaging:

- **Automated segmentation** of condyles and discs.
- **Computer-aided diagnosis (CAD)** to detect subtle pathological features.

- Quantitative biomarkers derived from texture analysis to predict disease progression and treatment response.
- Integration with clinical data to create predictive models.

These tools promise to enhance diagnostic accuracy, reduce inter-observer variability, and enable personalized treatment planning.

Artificial intelligence, especially deep learning and machine learning has begun transforming TMJ imaging by enabling faster, more objective detection and classification of disorders using modalities like MRI, CBCT, ultrasound, and panoramic radiography. A recent systematic review covering applications of AI to TMJ MRI demonstrated that deep learning models (e.g., MobileNetV2, ResNet) achieved high accuracy in determining disc position, with sensitivities ranging from ~0.74 to 1.0 and specificities up to 0.96, and overall diagnostic accuracy exceeding 83%.⁷⁻⁹

Contrast-Enhanced CT (CECT) in TMJ Imaging

Contrast-enhanced CT is used as an adjunct in temporomandibular joint (TMJ) imaging when soft tissue or pathological conditions need better evaluation.

- It involves intravenous injection of iodine-based contrast to enhance vascular structures and inflamed tissues.
- CECT helps in detecting inflammatory changes, synovitis, tumors, and infective conditions affecting the TMJ.
- It improves visualization of joint capsule, surrounding soft tissues, and vascular involvement, which are not well seen on plain CT.
- It is particularly useful in cases of suspected neoplasms, osteomyelitis, or post-traumatic complications.
- However, for detailed soft tissue assessment like disc position, MRI remains the gold standard.

Future recommendations

Future research should focus on:

- Multi-modal imaging protocols to combine structural and functional data.
- AI-driven tools for routine clinical workflows.
- Longitudinal studies validating imaging biomarkers for disease progression.
- Low-dose techniques and portable imaging for broader accessibility.

Conclusion

Advancements in TMJ imaging have transformed the diagnosis and management of TMJ disorders. The synergistic application of CBCT, MRI, US, and emerging functional imaging technologies enables comprehensive evaluation of complex pathology. Integrating these modalities with AI and quantitative methods will further refine diagnostic precision and therapeutic outcomes. Ongoing research and clinical innovation are expected to continue driving the field forward.

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