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IMAGING MODALITIES OF TEMPOROMANDIBULAR JOINT: A REVIEW

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ABSTRACT

Temporomandibular disorders are common, most frequently in young to middle-aged women, and most settle with supportive treatment. Small percentage of cases that do not respond to conservative management and when the diagnosis is no doubt imaging is indicated. Our understanding and interest in the diagnosis and management of patients with various types of temporomandibular joint (TMJ) disorders has increased as research has identified structural abnormalities and disease mechanisms associated with some of these disorders. There has also been remarkable progress in the imaging of the TMJ along with these discoveries. Assessment of the integrity and relationships of the hard and soft tissues, including the mandibular condyle, the glenoid fossa and articular eminence of the temporal bone, and the articular disk and its attachments are the goals of imaging the TMJ. A variety of modalities can be used to image the TMJ, including conventional radiography, computed tomography (CT), cone beam CT, ultrasonography, magnetic resonance imaging (MRI). The present review outlines the brief knowledge and indications of the most frequently used imaging techniques in TMD diagnosis.

KEYWORDS

Temporomandibular joint, Computed Tomography, Magnetic Resonance Imaging, Cone Beam Computed Tomography

INTRODUCTION

TMJ is a synovial, condylar and hinge-type joint.[1] It is the joint between condylar head of the mandible and the mandibular fossa of the temporal bone.[2] TJM is defined as a ginglymoarthrodial joint.[3] because it has a rotational movement in the sagittal plane and a translation movement on its own axis - this translation movement generates more movement.[4] These movements are constrained by various passive factors, as well as passive tension of the ligaments and muscles.[5] The temporomandibular joint (TMJ) plays a crucial role in mastication, jaw mobility, verbal, and emotional expression. The prevalence of chronic TMJ pain ranges from 5 to 31%, and the incidence of first-time pain is 4% per year.[6,7] Temporomandibular disorders are defined as a subgroup of craniofacial pain problems that involve the TMJ, masticatory muscles, and associated head and neck musculoskeletal structures. [8,9] The American Academy of Orofacial Pain has expanded on this classification, as shown in [Table 1].[10] Temporomandibular disorders are most commonly reported in young to middle-aged adults (20 to 50 years of age). The female-to-male ratio of patients seeking care has been reported as ranging from 3:1 to as high as 9:1. [11,12] Despite the high prevalence of temporomandibular disorders, signs, and symptoms, only 5 to 10% of those with symptoms require treatment, given the wide spectrum of symptoms and the fact that the natural history of this disorder suggests that in up to 40% of patients the symptoms resolve spontaneously. [13,14] The diagnosis and management of temporomandibular disorders (TMD) require both clinical and imaging examinations of the temporomandibular joint (TMJ).[15] The need for imaging of the TMJ should be established on the basis of selection criteria. *Selection criteria* represent those clinical signs and symptoms that suggest that a radiographic examination would contribute to the proper diagnosis and care of the patient. [16] They provide a rationale for selecting among the various imaging modalities, with the goal of obtaining the necessary diagnostic information without unnecessary patient expense or radiation exposure.[17] Because of the anatomic complexity of the TMJ, imaging can be difficult. Choosing the proper imaging technique is essential. [15] Previously, orthopantomography was considered a gold standard for imaging TMJ since teeth and other structures of the jaws were also seen on the image. However, the superimposition of the base of the skull and zygomatic arch restricted the evaluation of the condyle and glenoid fossa in the panoramic film.[18] Conventional radiography, nowadays, is of limited interest. The use of flat plane films for TMJ pathology is not sufficient, because this joint requires three-dimensional imaging views. Osseous changes are better visualized with CT and cone beam CT. Cone beam CT provides high-resolution multiplanar reconstruction of the TMJ, with a low radiation dose, without superimposition of the bony structures. High-resolution ultrasonography is a non-invasive, dynamic, inexpensive imaging technique, which can be useful in diagnosing TMJ disc displacements. The diagnostic value of high-resolution ultrasonography is strictly dependent on the examiner's skills and on the equipment used. MRI is a non-invasive technique, considered to be the gold standard in imaging the soft tissue components of the TMJ. MRI is used to evaluate the articular disc in terms of location and morphology. Moreover, the early signs of TMD and the presence of joint effusion can be determined. [15] Knowledge of the normal imaging appearance of the TMJ, its appearance on radiological examination, and interventional techniques are useful for providing a meaningful radiologic contribution. Thus, imaging plays a key role in delineating the anatomic changes of the TMJ, assisting in identifying the category of TMD, assessing treatment response, providing therapeutic intervention, and guiding surgical management. [19]

INDICATIONS FOR IMAGING OF TMJ

The principal indications for imaging include suspected advanced internal derangement; arthritis; failure of medical treatment; and in cases when the diagnosis of TMD is in doubt: atypical pain, sensory or motor dysfunction, or a palpable mass.[20] A variety of diseases affect the TMJ including the following: congenital and developmental malformations of the mandible and/or cranial bones; acquired disorders, including neoplasia, fractures, dislocations, ankylosis and disk displacement; inflammatory diseases that produce synovitis and capsulitis; a wide range of arthritis; and various posttreatment conditions.[17]

IMAGING PROTOCOLS FOR TMJ

- CBCT of the TMJ's (exact parameters vary with the vendor)

_ Closed-mouth acquisition with a field of view (FOV) of 150_50 mm.
The height of 50 mm allows coverage from above the TMJ to the mid-ramus level with a 15 s imaging time
_ Voxel size of between 0.1e0.3 mm. Resolution is proportional to the radiation dose
_ Open-mouth scans can also be performed to assess condylar mobility
_ Large FOV (160_160 up to 240_190 mm), lower resolution (and dose) scans are used for assessment of dentofacial deformity, including the TMJs, for treatment planning

- MDCT of the TMJs

_ Multidetector (64e256 sections) CT acquisitions in the closed- and open-mouth positions from above the TMJ to the mid-ramus level, 140kV
_ Thin overlapping images reconstructed into coronal oblique (i.e., parallel to the long axis of the mandibular condyle) and sagittal oblique (perpendicular to the long axis of the condyle) reconstructions, using bone and soft-tissue algorithms

- MRI of the TMJs

_ Ideally, at 3 T, using dual phased-array surface coils
_ Proton-density-weighted coronal oblique and sagittal oblique sequences of each TMJ
_ T2-weighted fat-saturated sagittal oblique sequences of each TMJ

_ With maximum mouth opening (the mouth can be held open, for example with a syringe), fast T2-weighted sagittal oblique of each TMJ. [20]

Panoramic Radiography:
— Equipment should have a range of tube potential settings, preferably from 60 to 90 kV.
— The beam height at the receiving slit of cassette holder should not be greater than the film in use (normally 125 mm or 150 mm). The width of the beam should not be greater than 5 mm.
— Equipment should be provided with adequate patient-positioning aids incorporating light beam markers.
— New equipment should provide facilities for field-limitation techniques.
— Diagnostic reference levels (DRLs) 65 mGy mm for an adult panoramic Radiograph. [21]

PLAIN FILM RADIOGRAPHY

The term *plain films* refer to radiographs made with a stationary x-ray source and film. Plain films of the TMJ depict only the mineralized parts of the joint but do not reveal nonmineralized cartilage and soft tissues.[17] Different angulations are used to avoid the superposition of the temporal bone and the opposite TMJ: lateral oblique transcranial projections, anterior-posterior projections, submental-vertex projection, transpharyngeal view. [15] The most common and most well-established plain film technique for examination of the TMJ is the transcranial projection of both the right and left sides with the jaw closed and opened. It is recommended that, in addition to the transcranial projection, an anteroposterior projection should be used to depict the central and medial parts of the condyle.[18] Plain radiography is useful in depicting degenerative joint disease in advanced stages. Positive findings observed on transcranial radiographs are those of degenerative joint disease of TMJ in the range of 5%-10%.[18]
Contact technique introduced by Parma is not recommended due to high radiation dose and superposition of bony structures. The condyle position could also be assessed, but large variations of condyle position in the glenoid fossa were found, even in asymptomatic population. [22,23] Some studies have shown that the position of the condyle in the fossa is of little clinical significance.[24] Other studies suggest that the posterior position of the mandibular condyle in regard to the fossa, could represent an indirect sign of an anterior disc displacement. [25,26]

PANORAMIC RADIOGRAPHY

Panoramic radiography, also known as orthopantography (OPG) or panoramic tomography, makes it possible to depict in a single image a complete representation of the jaws, teeth, temporomandibular joints (TMJ), and the alveolar lobes of the maxillary sinuses.[27]

Previously, orthopantomograph was considered a gold standard for imaging TMJ since teeth and other structures of the jaws were also seen on the image. However, the superimposition of the base of the skull and zygomatic arch restricted the evaluation of the condyle and glenoid fossa in the panoramic film.[18] Panoramic radiography can help evaluate the following:
• degenerative bone changes (only in late stages; it is inadequate for the early detection of osseous modifications);
• asymmetries of the condyles
• hyperplasia, hypoplasia, Trauma, tumours.[15]
Some panoramic machines have special TMJ techniques that permit placement of opened and closed views of both condyles on a single film. However, the image layer still reveals anatomic areas more than twice the width of the condylar head, which should be compared with the 1 to 4 mm wide layers obtained in conventional tomography.[17] More definitive osseous assessment of the TMJ is accomplished using complex motion tomography, and magnetic resonance imaging (MRI) is the examination of choice for evaluation of the disc and peri condylar soft tissues. [28]

ARTHROGRAPHY

Early attempts at TMJ arthrography were undertaken by Nørgaard in the 1940s. Katzberg and colleagues introduced this modified arthrotomographic technique for TMJ imaging in 1979.[29] For conventional single-contrast arthrography, only one contrast medium is used, i.e., high attenuating iodine contrast media. Double-contrast technique requires a combination of high- and low-attenuating contrast media, it is complicated to perform, require longer exposure time and operator experience; therefore, the technique is rarely utilized. The administered contrast medium should have a high concentration of iodine (300 mg iodine/mL), since only small amounts of solution can be injected into the TMJ (1.5–2 mL).
.[17,30-32]

Indications:

1.Evaluation of the soft tissues of the TMJ to determine the position, configuration and dynamic function of the disc; interpreted by observing the shape of the contrast material on either side of the disk and its flow within its own compartment as the patient opens and closes the mouth. "Fig.1"

2. For verification of suspected adherences in the disc or posterior attachment and loose bodies in the TMJ.

3. Perforation of the disk or disk attachment can be determined by flow of contrast medium into one space after injection of the other. Arthrotomography itself gives little information about osseous structures because of the presence of the opaque contrast material, Synovial fluid sampling (arthrocentesis) and lavage of the joint can accompany this procedure.

4. Posttraumatic complaints may also be an indication for arthroscopy. [17,30-33]

Contraindications:

1. Previous reaction to iodine contrast media (can be overcome with corticosteroid premedication);

2. Anticoagulant medication or bleeding disorders;

3. Patient anxiety;

4. Infection in the pre-auricular area. [31]

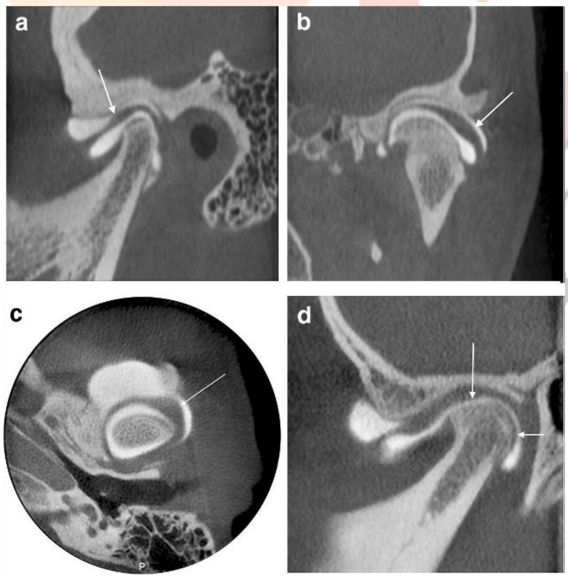

FIGURE 1: Arthrotomography of the TMJ (left side). **a** The disc is anteriorly displaced with the posterior band (arrow) placed anterior to the condyle, **b** the disc is laterally displaced (arrow) in the coronal plane and in **c** the axial plane the anterolateral disc displacement (arrow) is depicted, **d** sagittal plane depicting medial part of the joint, showing contrast media in direct contact with the bone superior on the condyle indicating loss of cartilage (long arrow) contrary to the posterior part of the caput showing the cartilage as a gap between the bone and the contrast media (short arrow). [32]

CONVENTIONAL TOMOGRAPHY

The major advantage of tomography over plain film imaging is the ability to provide multiple thin sections through the region of interest. For evaluation of osseous tissue, complex motion tomography is considered more reliable than linear tomography.[34] The major disadvantage of tomography is the lack of visualization of the soft tissues of the joint (disc, synovial membrane, ligaments, lateral pterygoid muscle) TMJ disc pathology and lateral pterygoid muscle pathology is better assessed with MRI. [15,22,35,36]

COMPUTED TOMOGRAPHY

This imaging technique overcomes the distortion or superimposition of plain film radiography and the blurring of structures outside the image layer of conventional tomography, but suffers from volume averaging artifacts that are most likely on small curved cortical bone surfaces. Signs of degenerative changes in the joint, like surface erosions, osteophytes, remodelling, subcortical sclerosis, articular surface flattening can be evaluated using CT. CT is the main radiological investigation for tumours, growth development anomalies and fractures. Basically, any CT examination of the TMJ should focus on the following: intactness of the cortex, normal size and shape of the condyles and their centered position in the fossa, the adequate joint spaces, centric relation loading zone.[15] Autopsy studies performed for the assessment of condylar abnormalities showed better results for CT than MRI. [37] the accuracy of the disc displacement was only 40%-67% in CT in studies of autopsy specimen materials. The accuracy of osseous changes of TMJ in CT compared with cadaver material was 66%-87%. [18] Wesetesson et al. found a sensitivity of 75 % and a specificity of 100% for the diagnosis of condylar bony changes. [38] “Fig.2”

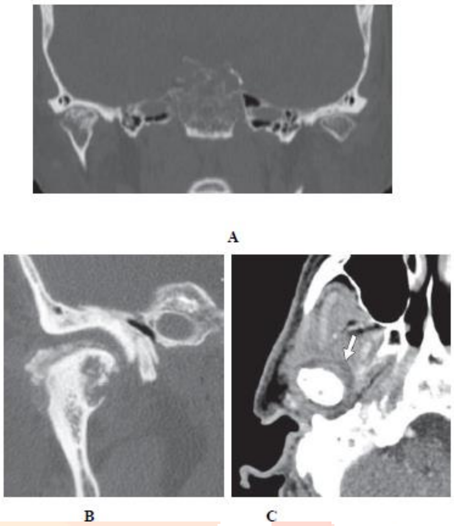

FIGURE 2: **A,** 55-year-old man with avascular necrosis. Coronal CT image in bone window of both temporomandibular joints (TMJs) shows joint space narrowing of both, with subchondral sclerosis and subchondral cystic change. Increased serpiginous sclerosis in right mandibular condyle is due to avascular necrosis. **B,** 58-year-old woman with calcium pyrophosphate dehydrate deposition disease. Sagittal CT image in soft-tissue window shows linear chondrocalcinosis of TMJ, flattening of condyle, and subchondral cysts. **C,** 35-year-old man with septic arthritis who presented with fever and elevated erythrocyte sedimentation rate. Axial contrast-enhanced CT image in soft-tissue window shows joint effusion in right TMJ (*arrow*) with enhancement. Joint aspiration confirmed septic arthritis.[19]

CONE BEAM COMPUTED TOMOGRAPHY

CBCT is an X-ray imaging technique in which a cone-beam of X-rays is rotated around the object, the signal being collected on a twodimensional (2D) detector. It provides a 3D volumetric dataset composed of a series of 2D projections During the scan a series of 360 exposures or projections, one for each degree of rotation, is acquired, which provides the raw digital data for reconstruction of the exposed volume by computer algorithm.[39] These images are then reconstructed and visualized in different planes. “fig.3” [40] CBCT was first introduced in the field of dentistry in the late 1990s by Mozzo et al. (Mozzo et al., 1998) and Arai et al. (Arai et al., 1999).[41] A review published by Silvia Caruso et al pointed out the main contributions of cone beam CT in the field of TMJ:

• allows the calculation of volume and surface of the condyle;
• improves qualitative analyses of condylar surface and allows detecting the mandibular condyle shape;
• improves the accuracy of linear measurements of mandibular condyle;
• clarifies that, in case of facial asymmetry, the condyles are often symmetric, while joint space can change between the two sides; • clarifies the position of the condyle in the fossa. [42]

Indications for CBCT in TMJ Diagnostics:

• Evaluation of TMJ anatomy [42]
• Evaluation of condylar position in malocclusion [43]
• Developmental anomalies of TMJ, e.g., bifid condyle, condylar hyperplasia, coronoid hyperplasia [44]
• Osteoarthritis including assessment of osteophytes, erosion, flattening, subchondral sclerosis, and pseudocysts [45]

• Follow-up of progression or treatment of degenerative joint disease [46]
• Rheumatoid arthritis and juvenile idiopathic arthritis [47]
• Assessment of internal derangement, also in conjunction with MRI [48,49]
• Relationship between the superior semicircular canal of the vestibulum and TMJ symptoms [50]
• Condylar fractures [51] • TMJ ankylosis [52]
• TMJ cysts and tumors including synovial chondromatosis and metastasis
• Changes in TMJ after mandibulotomy
• Misdiagnosis of temporomandibular joint disorder in tumors
• Measurement of styloid process length in patients with temporomandibular joint disorder (TMD)
• Image-guided puncture [40]

There are no absolute contraindications for CBCT, and pregnancy is a relative contraindication. [40]

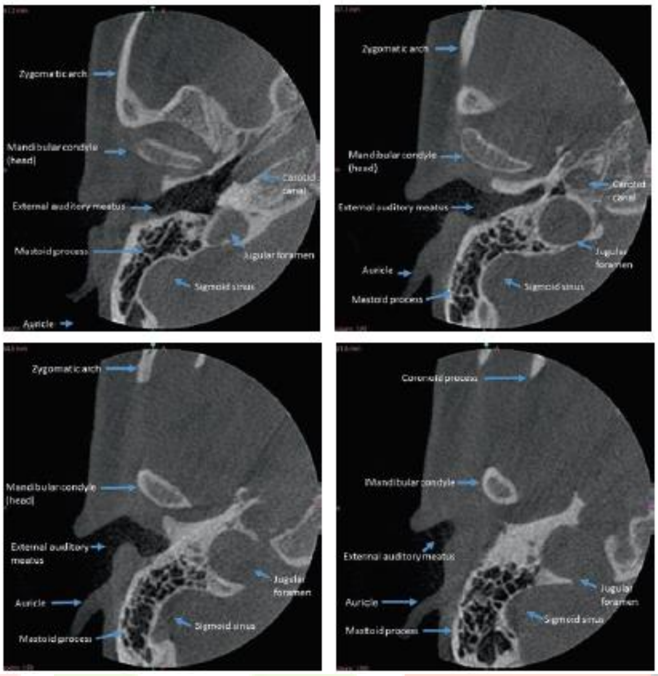

FIGURE 3: (**a**–**d**) Radiological anatomy of the TMJ in CBCT—axial slices. [40]

ULTRASONOGRAPHY

High-resolution ultrasonography (US) was first used for TMJ exploration in 1991, by Nabeih et al, using a 3.5 MHz transducer. and in 1992, Stefanoff et al., evaluated the TMJ disc in asymptomatic volunteers with a 5-MHz transducer and reported successful results. [53,54,55] The new transducers invented have a a high focus depth and narrow wave beam. The rebound potential of bone surface is as much as 2/3 waves and only 1/3rd propogate down to deeper anatomic structures. [18] Although it is a non-invasive, dynamic, inexpensive procedure, it is not commonly used in TMJ exploration. It serves both for diagnosis and diff erential diagnosis and for the comparison of therapeutic results in treating internal joint defects. [15,18] Being a real time investigation, it provides information about disc position, during mouth opening. [54] US examination is useful in depicting disc displacement and effusion. Normally, the disc is situated between two hyperechoic lines represented by the mandibular condyle and the articular eminence. If the disc is displaced in the closed-mouth position, the diagnosis is disc displacement. If the disc returns to its normal position during opening, the diagnosis is disc displacement with reduction. [15] One difficulty of US is the possibility to obtain clear images, especially in the open-mouth position, due to the overlying osseous structures. Another limitation of US is that the medial part of the disc cannot be visualized. [15,54] “Fig. 4” [56]

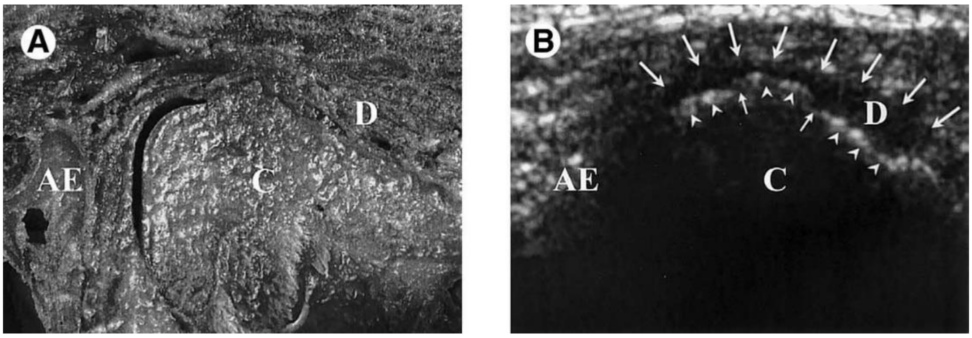

FIGURE 4: (A) Parasagittal section shows disc disrupted and displaced anteriorly to condyle, and presence of condylar erosion. (AE, articular eminence; C, condyle; D, disc). (B) Longitudinal high-resolution sonography scan (same joint as A) shows anterosuperior TMJ compartment with disc (arrows) anterior to condyle (arrowheads), and presence of condylar erosion (small arrows) (AE, articular eminence; C, condyle; D, disc) (top, anterior; left, superior). [56]

MAGNETIC RESONANCE IMAGING

Magnetic resonance imaging is a non-invasive technique that uses a magnetic field and radiofrequency pulses instead of ionizing radiation to produce the images.[17] MRI of the TMJ allows assessment of DD, effusions, synovitis, the articular cortices, sub-articular marrow, the muscles of mastication, adjacent parotid tissue, and the external auditory canal.[20] In addition, abnormalities within the bone marrow of the condyle and within the muscles and surrounding soft tissues can be detected. Other information obtainable includes the presence of soft tissue ingrowths, fibrosis, and joint effusion, the latter of which has been correlated to pain in the joint.[57] MRI has also been claimed to detect avascular necrosis of the condylar head and myxoid degeneration of the disk. [58] Images can be obtained in all planes (sagittal, axial, coronal). In most scanning sequences, T1 weighted, T2 weighted and proton-density (PD) images are obtained. The PD images serve to visualize the disc-condyle relationship, while T2-weighted images are used in diagnosing inflammation in the joint. [15] Normal disc position, evaluated in the sagittal plane, is with the junction of posterior band aligned approximately at 12 o'clock, position relative to the condyle. Disc displacement is diagnosed when the posterior band sits in an anterior, posterior, medial or lateral position with regard to the condylar surface. [59] "Fig.5" Synovitis can be clearly visualized on MRI images. [60]

MRI is contraindicated in certain patients, such as those with pacemakers, intracranial vascular clips, and metal particles in the eye or other vital structures. [17]

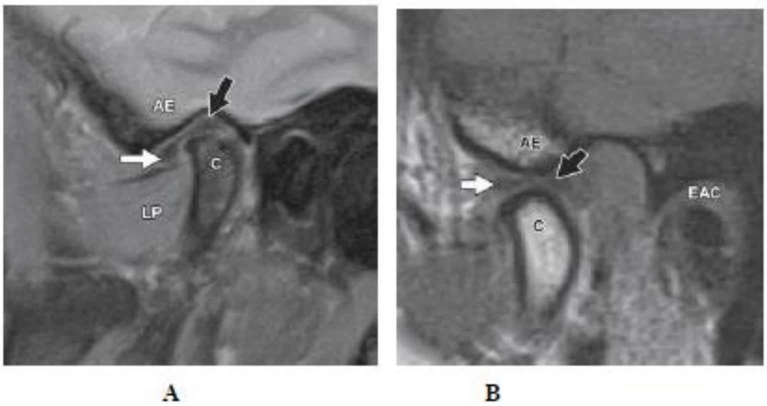

FIGURE 5: 35-year-old woman. Closed-mouth proton density–weighted fat-saturated image (**A**) and open-mouth T1-weighted sagittal image (**B**) show hypoechoic biconcave shaped disk with anterior (*white arrow*) and posterior (*black arrow*) bands. Posterior band of disk is at 11–12 o'clock position in closed-mouth view. Lateral pterygoid muscle (LP) is anterior to condyle (C). AE = articular eminence, EAC = external auditory canal. [19

NUCLEAR MEDICINE

Nuclear medicine deals with diagnostics and therapy using radioactive isotopes emitting beta or gamma radiation. When administered to a patient, radioactivity emitted by a radiopharmaceutical is being registered. As various tissues and organs differently accumulate this tracer, changes in radioisotope intake are detectable, especially when tissue metabolism rate is disturbed by a pathological process. Registration of radiation can be performed by means of a single static gamma camera (also known as a scintillation camera), one or more rotating gamma cameras or multiheaded gamma cameras. Depending on the type of registration device, the imaging methods are divided into scintigraphy, single-photon emission computed tomography (SPECT) and

positron emission tomography (PET).[61] SPECT uses the same radiopharmaceuticals as scintigraphy, but the acquired images are more precise regarding localisation of areas of tracer uptake. Further precision is gained when SPECT is combined with a CT scanner (SPECT/CT).
The following applications of SPECT in TMJ imaging were reported:
• Unilateral condylar hyperplasia
• Bone tracer uptake in patients suffering from TMJ pain
• Osteoarthritis
• Quantitative evaluation of temporomandibular joint disorder (TMD)
• Evaluation of the effects of functional orthopaedic treatment of TMJ. [61]
The first study to evaluate the clinical utility of FDG-PET/CT in patients with TMD was published in 2013 by Lee et al. They concluded that PET/CT showed high TMJ uptake rations in patients with osteoarthritis, while accuracy and sensitivity were higher than in conventional bone scintigraphy. [62] Suh et al. [13] investigated patients with temporomandibular joint disorder (TMD) by means of PET-CT with 8 F-sodium fluoride (NaF) as tracer and found out that this imaging modality was useful in arthralgic TMJ and TMD osteoarthritis and a correlation with the patients' response to splint therapy was ascertained.[61] "fig.6"

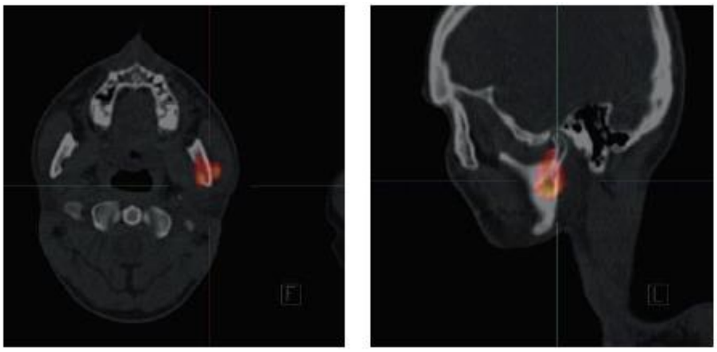

FIGURE 6: 18F-FDG PET-CT scan demonstrating increased uptake in primary lymphoma of the left mandibular ramus and left masseter muscle. (**a**) Axial image, (**b**) coronal slice (the images are reproduced courtesy of Prof. Leszek Królicki, Head of the Department of Nuclear Medicine of the Medical University of Warsaw, Poland) [61]

CONCLUSION

Imaging modalities of the temporomandibular joint (TMJ) have continued to evolve during the past decade. With the advent of newer techniques and computer enhancements, TMJ imaging has enabled a better appreciation for TMJ anatomy and function. Correlation of these images with clinical findings has led to an improved understanding of the pathophysiology of TMJ disorders. Knowledge of the normal imaging appearance of the TMJ, its appearance on radiological examination, and interventional techniques are useful for providing a meaningful radiologic contribution.

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