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Dent Clin N Am 52 (2008) 875–890

THE DENTAL
CLINICS
OF NORTH AMERICA

Contemporary Imaging of the Temporomandibular Joint

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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. As our understanding of TMJ disorders progresses, the development of new treatment algorithms will ensue. Current management of TMJ disorders relies heavily on clinical evaluation, with minor influence from information obtained through TMJ imaging. Although TMJ imaging in a clinical setting may have declined, it still has an expanding role at the research level in the quest for greater understanding of this complex group of joint disorders [1].

The goals for TMJ imaging include evaluating the integrity of the structures when disease is suspected, determining the extent of disease or monitoring its progression when disease is present, and evaluating the effects of treatment. Specific anatomic areas of the TMJ include the mandibular condyle, the glenoid fossa, the articular eminences of the temporal bone, and the soft tissue components of the articular disk, its attachments, and the joint cavity.

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doi:10.1016/j.cden.2008.06.001 ***dental.theclinics.com***

As with any laboratory test or imaging, clear indications should be established to justify the test. The need for TMJ imaging should be determined at an individual level after taking a thorough history and performing an appropriate clinical examination of the patient. The symptoms and signs presented should guide a practitioner to develop a differential diagnosis of possible TMJ pathology. Based on the differential diagnosis, the most appropriate mode of imaging should then be ordered, with consideration given to how the image results will influence overall management. Other factors that should be considered when determining the appropriate mode of imaging include the likelihood of hard or soft tissue pathology, the availability of specialized equipment, the cost of the examination, the amount of radiation exposure, and any contraindications, such as allergy to intravenous contrast agents or pregnancy. The efficacy of the technique will be determined by the quality of the image obtained combined with the skills of the person interpreting the image.

This article reviews the various techniques available for imaging the TMJ, with emphasis on contemporary imaging modalities, and includes a discussion of the method, indications, advantages, and limitations. The following techniques are included: plain film radiography, tomography, panoramic radiology, arthrography, ultrasonography, CT, MRI, and nuclear imaging.

Plain film radiography

Plain films refer to X rays made with a stationary x-ray source and film. Plain films of the TMJ depict only mineralized parts of the joint, such as bone; they do not give any information about nonmineralized cartilage, soft tissues, or the presence of joint effusion. Radiographic changes are often not seen until a sufficient volume of destruction or alteration in bone mineral content has occurred [2]. Plain films are also limited by the superimposition of adjacent structures, which can make visualizing all parts of the joint difficult. To overcome this limitation, multiple plain film techniques have been developed to image the joint from various angles. Plain films are the least expensive and require simple equipment that is often available in the dental office. Although many of these techniques have been superseded by CT, which offers superior anatomic visualization of joint structures, several plain film views have traditionally been used to image the TMJ and have contributed to our diagnosis and treatment of TMJ disorders.

Transcranial view

The introduction of the transcranial view of the TMJ is attributed to Schuller in 1905. In this lateral oblique transcranial projection, the x-ray beam is directed parallel to the long axis of the condyle. At this angulation, the cranial bones are the only structures superimposed over the joint. As a result, a sharp image of the mandibular condyle, articular eminence, and glenoid fossa is obtained (Fig. 1). The transcranial view shows mainly the lateral part of the joint and can be used to determine condylar position and size, depth of the fossa, slope of the eminence, and width of the joint space.

Transmaxillary view

In the transmaxillary view technique, the x-ray beam is directed perpendicular to the long axis of the condyle. Changing the vertical and horizontal orientation helps with condyle and mastoid process superimposition. The lower jaw is also protruded to avoid superimposition of the condyle onto the base of the skull. This view, along with the transcranial view, provides a three-dimensional evaluation of the condyle for fractures, severe degenerative joint disease, and neoplasms.

Submentovertex view

The submentovertex view directs the x-ray beam through the chin region parallel to the posterior border of the ramus toward the base of the skull. This view shows the angulations of the long axes of the condyles relative to a line drawn between the auditory canals and the cephalostat ear rods (if used to position the patient), or to a perpendicular midsagittal line. This view is a useful supplement to examine condylar displacement and rotation in the horizontal plane associated with trauma or facial asymmetry. Because the patient is positioned with full neck extension, this technique is contraindicated in trauma patients who are suspected of neck injury.

Other views

The transpharyngeal view involves placing the x-ray tube close to the contralateral joint and aiming the beam toward the opposite joint, which is adjacent to the film. As a result, the joint nearer the film is in focus, whereas the joint closest to the x-ray source appears out of focus. This

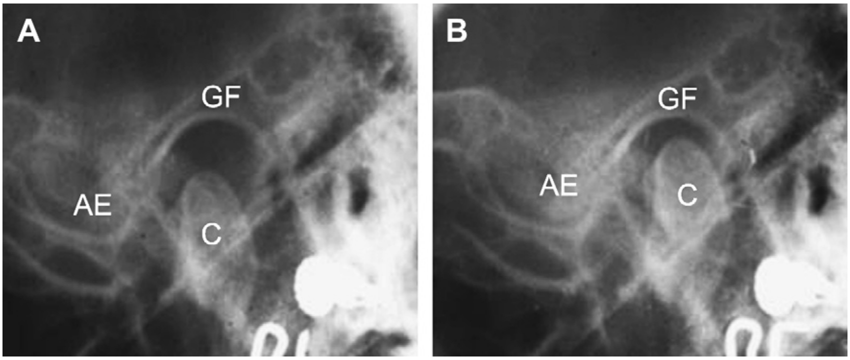

Fig. 1. (*A, B*) Lateral transcranial view of TMJ in open mouth and closed mouth positions. AE, articular eminence; C, condyle; GF, glenoid fossa.

projection provides an acceptable view of the TMJ, condylar neck, mandibular ramus, and zygomatic region.

The Reverse Towne's projection positions the patient's forehead directly against the film. The patient is then instructed to open his/her mouth to bring the condylar head out of the glenoid fossa, thus reducing the superimposition of these structures on one another. The x-ray beam is then positioned behind the patient's occiput at a 30° angle to the horizontal and centered on the condyles. This projection offers an excellent view of the condylar neck and is useful in the trauma setting when a condylar fracture is suspected [3–5].

Posterior-anterior and lateral cephalograms give little information about the TMJ itself because of the superimposition of adjacent bony structures. However, they can be used for serial examinations of patients who have skeletal asymmetry.

With the increasing use and availability of CT and cone-beam CT, the use of plain films for imaging the hard tissues of the TMJ is becoming less popular.

Conventional tomography

Tomography is a radiographic technique that clearly depicts a specific slice or section of the patient. Understanding the concept of sectional images is important because it has become the basis for many modern imaging techniques we use today, such as panoramic radiography and CT. In conventional tomography, the x-ray source and film simultaneously move around a fixed rotation point in opposite directions. Objects lying within a specific plane of interest are seen in focus, whereas those structures outside the predetermined focal plane appear blurred. Varying patterns of tomographic movement, or rotation, can be performed to ensure the clearest view of the bony components of the TMJ and to reduce the problem of superimposition. The disadvantages of tomography include the inability to evaluate soft tissue and the fact that the required equipment is more expensive than a conventional x-ray machine. With the advent of CT and MRI, which have superior low-contrast resolution, conventional film tomography is used less frequently.

Panoramic radiography

This imaging technique is one of the most commonly used by dentists and dental specialists. The fundamental principle behind panoramic radiography is based on the tomographic concept of imaging a section of the body while blurring images outside the desired plane. The x-ray source and film are set opposite to each other and rotate around the whole head with a narrow focal trough so that the TMJs and teeth are in focus, but the adjacent structures are blurred. The narrow focal trough is produced by lead collimators in the shape of a slit located at the x-ray source and the film. The size and shape of the focal trough and the number of rotation centers vary with the manufacturer of the panoramic unit.

Panoramic radiography is a useful screening technique for condylar abnormalities such as erosions, sclerosis, osteophyte formation, resorption, and fractures (Fig. 2). In addition, the panoramic film also gives information about the teeth, mandible, and maxilla, which may help with the overall diagnosis by ruling out odontogenic sources or other pathology of the jaws. However, a disadvantage of panoramic radiography is that the glenoid fossa and articular eminences are not well visualized because of the superimposition of the base of the skull and zygomatic arches. Condylar position also cannot be evaluated because the mouth is slightly open and protruded during this view [3–5].

Arthrography

Arthrography is an imaging method by which radiopaque contrast dye is injected into the lower TMJ spaces under fluoroscopic guidance to image the soft tissue structures. Katzberg and colleagues [6] introduced this modified arthrotomographic technique for TMJ imaging in 1979. Before this, plain films and conventional tomography were the only methods available for imaging the TMJ. In contrast to the previous imaging techniques, which were static views of the joint, arthrography was the first dynamic study of the joint [7]. According to the pattern by which the contrast agent flows, adhesions, disk perforations, and disk function can be studied during open and closing movements. This technique is ideal for small disk perforations and for visualizing the movement of the joints.

The disadvantages of arthrography are that it is an invasive procedure, requiring insertion of a needle into the TMJ by a skilled operator, which may result in complications, such as bleeding and introduction of infection. Another disadvantage is the potential for an allergic reaction to the contrast agent and the high radiation exposure. The fact that a needle is inserted into the joint under anesthesia does, however, afford the operator the opportunity to perform a simultaneous arthrocentesis so that the procedure can be

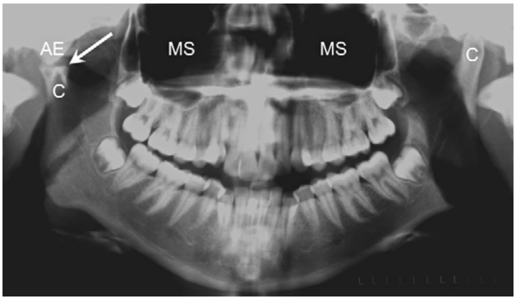

Fig. 2. Panorex. White arrow indicates degenerative changes of right condyle. AE, articular eminence; C, condyle; MS, maxillary sinus.

diagnostic and therapeutic. Arthrography is rarely used today because of its invasiveness and the associated radiation exposure to the patient. Other imaging modalities such as MRI now offer excellent soft tissue depiction without the need for injection of contrast or radiation exposure [5,7].

Ultrasonography

Ultrasonography uses sound waves of high frequency to produce images of the body. As the sound waves travel through the body, they encounter a boundary between tissues of varying densities. Depending on the density, or resistance, of the tissue, reflective echoes are returned to the ultrasound probe at different speeds and relayed to a machine that translates the echoes into a picture.

Ultrasonography has been described in imaging the TMJ with some beneficial, albeit limited, results [8,9]. Most favorable results have been noted in relation to evaluating disk position, with minimal benefit in evaluating hard tissue changes [10–17]. Gateno and colleagues used ultrasonography for intraoperative assessment of condylar position in relation to the glenoid fossa during mandibular ramus osteotomy procedures. Condylar position was identified correctly in 38 of 40 ultrasound images with a sensitivity of 95% [18]. However, later studies using ultrasonography to evaluate condylar erosion and osteoarthritic changes of the condyle found it to be inferior to CT imaging, mainly because of interference by reflective echoes from the glenoid fossa [19–21].

When evaluating TMJ disk position for internal derangement, ultrasonography has shown some benefit, especially when high-resolution, dynamic, real-time ultrasonography is used [12]. However, ultrasonographic evaluation of the TMJ disk position is currently associated with a high number of false-positives, which could ultimately result in overtreatment. Currently, MRI is more accurate and continues to be the gold standard for imaging soft tissue of the TMJ [22].

As advancements in ultrasound probe technology continue, more detailed imaging and improvement in tissue differentiation may contribute to a reduction in the number of false-positives and, therefore, overtreatment. Further research in this imaging modality for the TMJ is needed because ultrasonography offers many advantages, including reduced cost, accessibility, fast results, decreased examination time, and lack of radiation exposure.

CT/cone-beam CT

CT is an imaging method that combines multiple X rays taken at different angles to create cross-sectional images of the body. Each image is considered a "slice" and can be reformatted to create a three-dimensional image of the body [4]. CT has been central to the advancement of diagnostic imaging in the field of medicine. With the recent advent of cone-beam CT, the use of CT imaging in the field of dentistry is becoming integral to the practice of orthodontics, implant dentistry, and oral surgery [23–30]. Cone-beam CT uses a cone-shaped x-ray beam in contrast to the fan-shaped x-ray beam of spiral CT. The beam performs a single rotation around the head of the patient at a constant angle, producing a volumetric data set that is later reconstructed into three-dimensional images. The amount of radiation exposure is smaller and the examination time is shorter, when compared with conventional CT. The current state-of-the-art CT technique is multidetector row CT, in which 16 to 64 detector rows are used along with thin slice profiles, such that volumetric acquisition of data is achieved. Data can then be presented at equal resolution in any plane including the panoramic plane. Reconstruction algorithms and optimal windowing allow for imaging of hard and soft tissue pathology [31].

The application of conventional CT in imaging the TMJ has been most significant in the evaluation of hard tissue or bony changes of the joint. Pathologic changes, such as osteophytes, condylar erosion, fractures, ankylosis, dislocation, and growth abnormalities such as condylar hyperplasia, are optimally viewed on CT (Figs. 3 and 4). Westesson [32] and DeBont [33] found CT to be superior to plain films and MRI for imaging the bony structures of the TMJ. In contrast, Westesson [32] found CT to be less accurate than MRI for imaging the disk. Multidetector row CT can be used to show disk displacement and synovitis, effusions, and erosions [31].

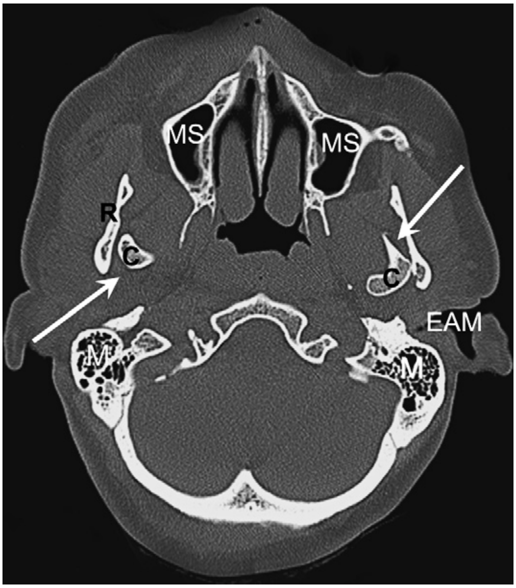

Fig. 3. Axial CT scan in bone windows. White arrows indicate bilateral condyle fractures with anteromedial dislocation. C, condyle; EAM, external auditory meatus; M, mastoid air cells; MS, maxillary sinus; R, ramus.

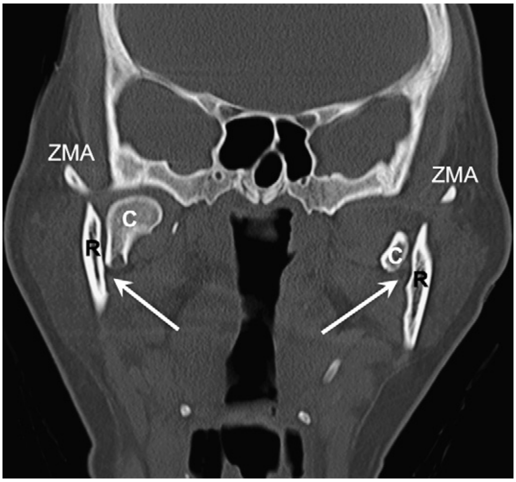

Fig. 4. Coronal CT scan in bone windows. White arrows indicate bilateral condyle fractures with medial displacement. C, condyle; R, ramus; ZMA, zygomatic arch.

The main disadvantages of the use of CT in imaging the TMJ have been radiation exposure, expense, accessibility, and size of the equipment. Cone-beam CT has improved on several of these issues. Less radiation exposure, in-office use, decreased cost, and a more detailed view of the TMJ in the sagittal plane by cone-beam CT has taken this imaging modality in a new direction.

MRI

MRI was first developed in July 1977. MRI uses a powerful magnet, radiowaves, and computer analysis to produce excellent soft tissue images. The magnetic field aligns the magnetization of hydrogen ions within the body, such as those found in fat and water. Radiowaves are used to alter this alignment, which causes the hydrogen ions to emit a weak radio signal that is amplified by the scanner. Additional magnetic fields can then be used to manipulate the signal, to build up information to reconstruct the area of interest. MRI is the most accurate radiographic imaging modality for visualizing TMJ disk position [34] and associated soft tissue structures. The images are presented in T1- and T2-weighted sequences. T1-weighted images are used for visualization of osseous and disk tissues (Fig. 5), whereas T2-weighted images demonstrate inflammation and effusions (Fig. 6). MRI is used to analyze the position of the articular disk in sagittal and coronal planes (Figs. 7 and 8), dynamic assessment of condylar translation and disk movement during opening and closing, disk morphology, joint effusions (Fig. 9), synovitis, osseous erosions, and degenerative joint disease [35,36]. MRI has been widely accepted as a tool for diagnosing

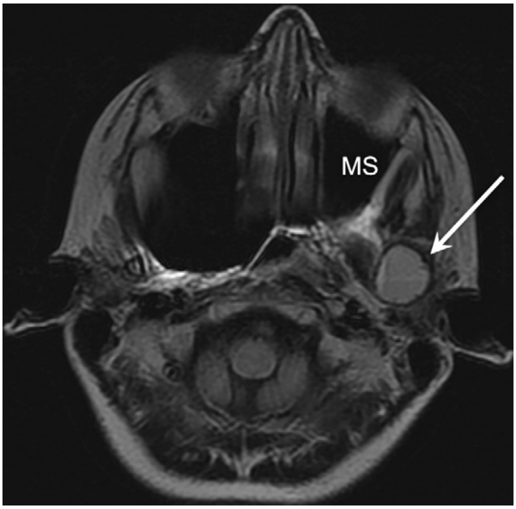

Fig. 5. T1-weighted axial MRI. White arrow indicates cystic lesion of the left condyle with fluid levels. MS, maxillary sinus.

internal derangement and has been reported to be 95% accurate in assessing disk position and form and 93% accurate in assessing osseous changes [37]. MRI helps visualize aspects of TMJ pathology that may help in diagnosing TMJ dysfunction, including thickening of tendon attachments, rupture of retrodiscal tissues, joint effusion, or osteoarthritic changes such as condylar flattening or osteophyte formation. However, the question of whether TMJ

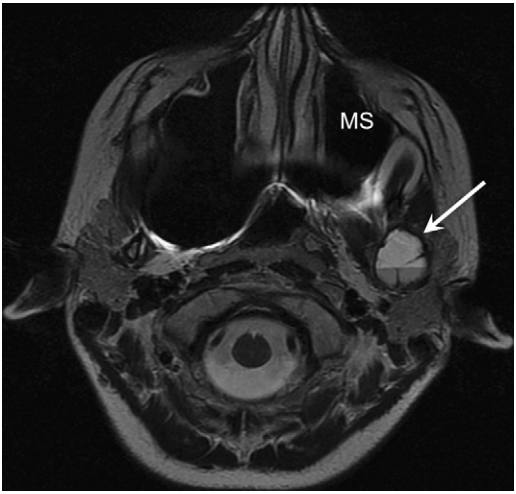

Fig. 6. T2-weighted axial MRI. White arrow indicates cystic lesion of the left condyle with fluid levels. MS, maxillary sinus.

Fig. 7. T1-weighted sagittal MRI of TMJ. Solid white arrow indicates articular disk anteriorly displaced. Broken white arrow indicates a joint effusion. C, condyle; LP, lateral pterygoid; M, mastoid air cells.

disk displacement may be linked to the onset, progression, or cessation of TMJ signs and symptoms remains controversial [38]. Therefore, studies are needed to improve our understanding of the relevance of these radiographic findings as sources of TMJ pain and dysfunction.

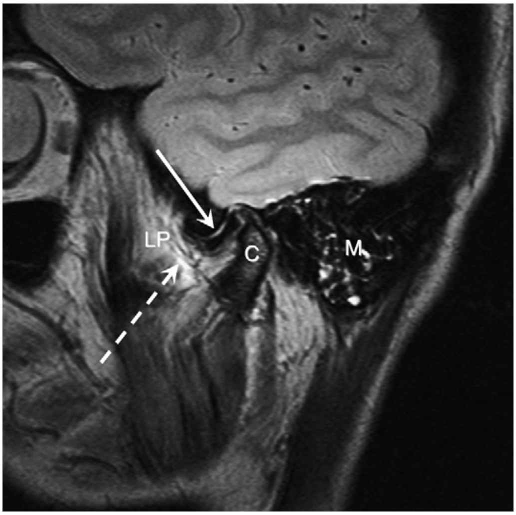

Fig. 8. T2-weighted sagittal view of TMJ. Solid white arrow indicates articular disk anteriorly displaced. Broken white arrow indicates a joint effusion. C, condyle; LP, lateral pterygoid; M, mastoid air cells.

Fig. 9. T2-weighted sagittal MRI. White arrow indicates a joint effusion. C, condyle.

MRI is advantageous because no ionizing radiation is used. However, it requires expensive equipment operated and interpreted by skilled technicians and radiologists. It is also contraindicated in pregnant women and in patients who have implanted metal devices such as pacemakers or aneurysm clips. Titanium dental implants are not a contraindication.

Nuclear medicine

In contrast to the aforementioned imaging modalities, which focus on anatomic integrity, nuclear medicine is unique in that it can assess changes in physiologic function as a direct result of biochemical alterations at the cellular and subcellular level. It is, therefore, used as a physiologic adjunct to the anatomic detail provided by other imaging modalities.

Nuclear medicine uses radionuclide-labeled tracers injected intravenously, which emit gamma radiation. Using a scintillation crystal that fluoresces on interaction with gamma rays, a gamma scintillation camera detects the emitted radiation. The fluorescence is then amplified by a photomultiplier to produce an image. These images are known as radionuclide imaging or nuclear scintigraphy. In bone scintigraphy, such as that used in imaging of the TMJ, the most commonly used radiotracer is technetium diphosphonate, because of its low radiation dose and short half-life. The radiation dose from intravenous injection compares with that of other standard radiographic procedures. Uptake of the radionuclide corresponds with the metabolic activity in the area of the body being examined and depends on local blood flow, vascular permeability, enzymatic action, and the amount of mineralized bone crystals and immature collagen that bind to phosphate.

Since the introduction of nuclear imaging in the early 1950s, technologic advances in the concept of tomography have enabled single-photon emission computed tomography (SPECT) and positron emission tomography (PET) to overcome the disadvantages of image distortion and superimposition associated with planar nuclear imaging. Because the formed image seen in planar nuclear imaging represents radiation emission from a general area rather than a specific anatomic location, nuclear activity from adjacent structures may be superimposed on the area of interest and may present a distorted view.

This disadvantage is similar to the limitation of plain films when compared with CT. Just as CT improved on the one-dimensional view of plain films by using multiple detectors or a single moving detector to acquire multiple transaxial slices, SPECT acquires multiple images or "slices" by rotating the gamma scintillation camera 360° around the patient. These slices can then be stacked to give a three-dimensional representation (axial, coronal, and sagittal) of the distribution of the radionuclide in the patient, providing images with improved resolution and anatomic localization (Figs. 10 and 11). SPECT can also be combined with anatomic data acquired by CT to form functional anatomic mapping. This combination enables early detection and precise location of the bony remodeling and may be a more accurate interpretation than SPECT alone. This combination uses low radiation dose and is highly sensitive and specific when compared with conventional radiography and tomography [4].

A more recent development in nuclear imaging is PET, which is reported to have sensitivity 100 times that of a gamma camera. PET uses positron-emitting

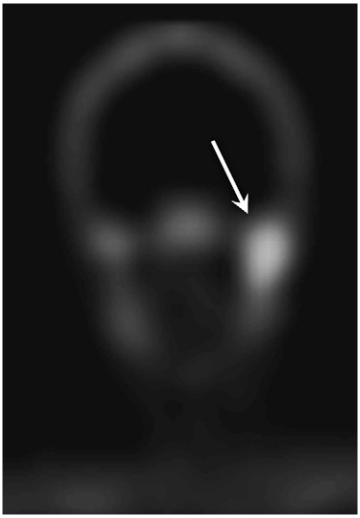

Fig. 10. Coronal view of SPECT bone scan. White arrow indicates increased uptake in the lesion in the left condyle.

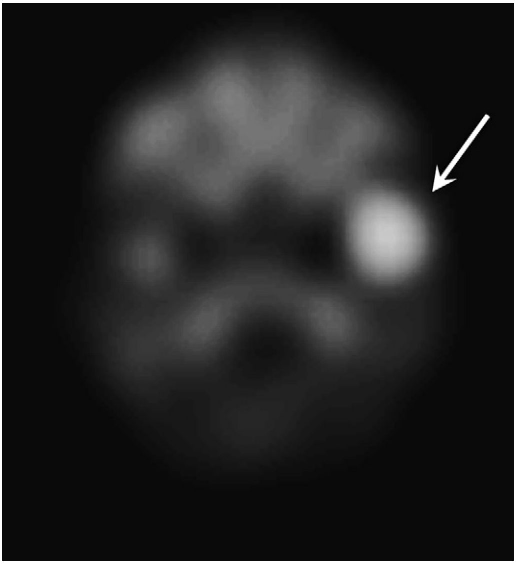

Fig. 11. Axial view of SPECT bone scan. White arrow indicates increased uptake in the lesion in the left condyle.

isotopes. When emitted from the tissue, the positrons interact with adjacent electrons to produce two gamma rays traveling in opposite directions. Multiple detectors are placed within the PET scanners and, by a process called annihilation coincidence detection, several gamma emissions can be detected at nearly the same time.

Nuclear imaging in the evaluation of the TMJ is useful when assessing skeletal growth, condylar hyperplasia, synovitis, and the quantification of arthritis in patients who have rheumatoid arthritis or osteoarthritis. Although bone scintigraphy has a high sensitivity for bone metabolism, it also has a low specificity in that it cannot differentiate among conditions such as bone healing, growth, infection, arthritic changes, or tumors. A 10% increase in osteolytic or osteogenic activity can be seen using nuclear imaging compared with the 40% to 50% decalcification needed to occur before changes are identified using conventional radiography [39]. However, the cause of the osteolytic or osteogenic activity cannot be determined from nuclear imaging alone. In addition, nuclear imaging is helpful in determining joint stability before dental rehabilitation, orthodontic therapy, or orthognathic surgery; in diagnosing fibro-osseous lesions, vascular lesions, osteomyelitis, metastatic disease; and in follow-up evaluations of primary tumors [39]. It can also be used in the evaluation of osseous allografts by demonstrating the establishment of blood flow to the grafted area and observing uptake patterns between the remaining jaw and graft site.

The main disadvantages of nuclear imaging of the TMJ include its inability to reveal the morphology of the osseous components or disk displacement and the need for intravenous injection of radioactive pharmaceutics, which results in whole body radiation exposure. Results of nuclear imaging are also nonspecific; however, when used in combination with other imaging modalities, it can be a useful adjunct to aid in diagnosis of metabolic TMJ conditions.

Summary

After a thorough review of the literature, it is clear that multiple imaging modalities are available for evaluation of the TMJ. The need for TMJ imaging should be assessed on an individual basis, depending on the signs and symptoms obtained and the working diagnoses.

Based on the evidence currently available, MRI continues to be the gold standard for imaging disk position and the soft tissues of the TMJ, including joint effusions. In contrast, CT is the ideal imaging choice for evaluating hard tissues, adding improvement in accessibility and radiation dosage with the use of the new cone-beam CT. For more specific TMJ pathology, nuclear imaging is useful in determining if the process is in an active or quiescent phase.

As advancements in this area continue, our understanding of this complex joint and its pathology will follow, which will lead to more defined imaging indications and ultimately, to improved treatment outcomes.

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