Diagnostic imaging has been of recent and unique importance in substantiating the clinically suspected existence of internal derangements of the temporomandibular joint (TMJ) caused by disk displacement. These abnormalities were first depicted by arthrography and now are confirmed with modern advances in state-of-the-art imaging technology. The purpose of this review is to provide an insight into the pathophysiology of internal derangements of the TMJ and to provide an overview of the relative merits of the differing imaging modalities in the rapidly evolving diagnostic armamentarium.

NORMAL AND ABNORMAL TMJ ANATOMY AND FUNCTION

The TMJ disk is a biconcave fibrous structure interposed between the surface of the condyle inferiorly and the articulating portion of the temporal bone superiorly. The posterior portion of the disk, termed the posterior band, lies at the 12 o'clock position relative to the condylar head when the jaw is closed and the condyle rests in the glenoid fossa. When the jaw opens, the condyle rotates and translates anteriorly toward the apex of the tubercle, and the thin mid-portion of the disk remains interposed between the condyle and tubercle. In the sagittal plane, this portion of the disk has a bow-tie configuration and in the coronal plane an arc-shaped configuration. It is important to consider that the disk is a three-dimensional structure, though most anatomic depictions are of the sagittal plane only. The disk is attached posteriorly to the temporal bone and condyle by the posterior ligament or bilaminar zone, which consists of loose fibroelastotic tissue. The disk is also firmly attached to the joint capsule and neck of the condyle both medially and laterally. Anteriorly, the disk is attached to the joint capsule, anteromedially, it is attached to the upper belly of the lateral pterygoid muscle. The disk separates the upper and lower joint spaces into two communicating spaces lined by synovial tissue. The lower belly of the lateral pterygoid muscle is a muscle of mastication which attaches to the neck of the condyle but not to the disk per se. The entire joint is surrounded by a dense, fibrous capsule, and external to the capsule is a lateral ligament that strongly reinforces the lateral wall of the capsule.

The bone structures of the joint consist of the condyle and the articulating portions of the temporal bone (glenoid fossa and articular eminence or "tubercle"). Jaw opening requires a coordinated movement of the condyle, muscles of mastication, and the disk. The disk and condyle move anteriorly in a synchronized fashion, the biconcave disk being interposed between the convex condylar surface inferiorly and the convex margins of the temporal bone superiorly. During jaw closing the disk continues to maintain its interposed position and moves in a coordinated fashion between the condyle and the temporal bone. TMJ mechanical dysfunction results when the disk is no longer correctly positioned, leading to mechanical incoordination. An important, but often unappreciated, aspect of the TMJ articulation is the necessity for a coordinated action by both TMJs functionally unified by the bone yolk of the mandible. This helps explain the high prevalence of bilateral abnormalities in contradistinction to other joint abnormalities caused by trauma.

The most common intraarticular abnormalities of the TMJ are internal derangement and degenerative arthritis (4-12). These two conditions appear to be linked by a cause-and-effect relationship. Internal derangement is defined as an abnormal positional and functional relationship between the disk and the mandibular condyle and the articulating surfaces of the temporal bone. Osteoarthritis, a primarily noninflammatory disorder of diarthrodial joints, is characterized by degeneration and abrasion of the articular cartilage and by simultaneous remodeling processes in the underlying bone.

A general classification scheme subgroups the various disk positional conditions as (a) superior or 12 o'clock (normal), (b) anterior, (c) anteromedial (Fig 3b), (d) anterolateral, (e) medial (Fig 3c), and (f) lateral. Abnormalities c and d represent rotational displacements. To challenge further the radiologist's interpretive expertise, the functional aspects of the disorder multiply the combinations of abnormality. The functional aspects are (a) coordinated (normal) disk function, (b) disk displacement with reduction, and (c) disk displacement without reduction.

If the disk is displaced anteriorly, it is a transient or locked disk position.

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Abbreviation: TMJ = temporomandibular joint.
yet snaps or clicks into normal position when the jaw opens, the terminology for this condition is disk displacement with reduction. Clinically, this is associated with both opening and closing clicking sounds and is often associated with joint, muscular, and facial pain. Disk displacement with reduction is both an anatomic and a functional disorder that is cyclic in nature, as shown in the diagrammatic depiction of the position of the disk relative to the condyle and tubercle with the jaw in the opening and closing phases of the functional jaw cycle (Fig 4a). This has been termed "reciprocal clicking" (6,14). Clinically, the reciprocal click can be characterized as early, intermediate, or late, depending on the distance from the fossa at which the disk re-assumes its normal anatomic relationship as the condyle translates forward.

In some patients the disk remains anterior to the condyle regardless of jaw position (Fig 4b). This is often associated with painful limitation of jaw opening ("closed lock"). Since condylar translatory mobility is commonly (but not always) hindered on the affected side only, one may observe a deviation of the mandible away from the midline toward the affected side with maximal jaw opening. Keep in mind, however, that in patients with a long-standing disk displacement, there may be no limitation or deviation of jaw opening due to disruption of the posterior disk ligament.

A sequela of disk displacement without reduction is a torn, detached, or disrupted posterior disk ligament (4,5,8,10-12). The functionally important region of the posterior disk ligament to maintain the disk on top of the condylar head is irreversibly lost. The bone on bone condition that results when the convex bone surface of the condyle articulates directly with the convex bone surface of the temporal bone leads to progressive articular degeneration and arthritis. The associated plain radiographic findings of a flattened condyle and tubercle are nearly pathognomonic of subacute to chronic disk detachment (Fig 5).

In conjunction with functional and anatomic disk derangement, intrinsic alteration of the disk per se also develops (9,11,15). Included is a change in the configuration or morphology of the disk from biconcave to biconvex. Marked deformity and thickening of the disk is an even more striking sequela. These alterations are typically associated with degenerative changes of the condylar head and tubercle with remodeling and osteophytosis. Morphologic changes in the disk are also associated with alterations in disk histology leading to metaplastic hyaline cartilage, hyalinization, accumulation of foci of calcium deposits, and abnormal collagen patterns (16). In those articulations where the posterior disk ligament has not torn, a conversion of the posterior disk ligament to fibrotic tissue has occasionally been observed (17,18). Teleologically this suggests a biologic adaptation resulting in the formation of a new load-bearing region having significant implications for treatment.

**CLINICAL PREDICTABILITY OF INTERNAL DERANGEMENTS OF THE TMJ**

Signs and symptoms of TMJ internal derangements are common, occurring in 4% to 28% of the adult population. The frequency is higher in women by a ratio of approximately 8:1; the factors responsible for this predominance are not certain. Causes of TMJ disorders include trauma, bruxism, stress, and occlusal abnormalities.

The clinical signs and symptoms of TMJ internal derangement are not consistently reliable for accurate assessment of the exact extent of the internal derangement. A recent prospective clinical investigation in 188 patients with signs and symptoms of TMJ pain and dysfunction compared the clinical signs and symptoms with the arthrographic depiction of intra-articular disease (19). Attempts were made to establish which of those clinical signs and symptoms are the best predictors of the condition of the joint depicted by arthrography. The results revealed that the overall clinical accuracy for the various aspects of internal derangement was approximately 70%. Those signs and symptoms that did show a statistically significant relationship were manifestations of mechanical abnormalities of jaw function secondary to disk...
displacement. These parameters included: (a) the maximum degree of jaw opening as measured by the interincisor opening, (b) condylar translation as assessed with fluoroscopy, (c) deviation of the jaw from the midline upon maximal jaw opening, and (d) lateral or side-to-side movements of the jaw. The location and intensity of pain did not distinguish patients with from those without internal derangements, and there was no consistent relationship between internal derangements and occlusal findings. Joint sounds emanating from the TMJ did show a significant relationship to the extent of internal derangement.

JOINT SOUNDS

TMJ sounds are the most frequent finding in patients with TMJ disorders and represent a salient factor for any imaging assessment. According to epidemiological studies, clicking has been recognized to occur in between 14% and 44% of the general population (20–24). Clicking sounds have been ascribed to a variety of mechanisms, including disk displacement, condylar subluxation, deviations in the form or shape of any of the articulating surfaces, loose bodies, and fibrous bands or adhesions within the joint spaces (Table 1). Arthrographic observations and direct inspections in patients and cadaver material support the concept that clicking is frequently associated with anterior disk displacement.

Epidemiological evidence also suggests that joint crepitus occurs in 10%–24% of the adult population (20,21). Joint crepitus has been considered a clinical sign indicative of structural damage to the articular surfaces or, more specifically, a sign
of arthritis. My experience, however, does not suggest that joint crepitus is always a reliable sign of arthritis.

The absence of joint sounds, it must be emphasized, is not an indication of a normal joint.

Various characteristics of the TMJ clicking sound are listed in Table 2; these have largely been derived from detailed analysis by means of high-speed cinematography of the movement of the disk and condyle in cadaver TMJs with clicking (23, 24). The opening click is associated with an event that occurs in the range of 12–36 milliseconds and the closing click in the range of 6–8 milliseconds. The opening click is produced when the condyle and the disk impact on the temporal bone. The eminence click associated with jaw subluxation, on the other hand, is usually a jolting type of sound, rather than the snapping sound that occurs with disk displacements (25).

Macroscopically detectable alterations in the shape of the articular surfaces of the TMJ were reported in as many as 45% of autopsy specimens (26). These deviations in form are local thickenings of the articular tissue layers, usually focal in nature and usually occurring in the lateral regions of the joint surfaces. Extensive tooth loss was identified as a predisposing factor for the occurrence of changes in morphology and arthrosis in the TMJ.

Miller et al (1985) described 16 patients who presented with clicking of the TMJ associated with a displaced but nonreducing disk (27). These cases demonstrated that an audible clicking sound associated with internal disk derangements need not imply reduction of the displaced disk. The findings both at surgery and on radiography suggested that extensive alterations in the surface contours of both the disk and the condylar head could be a mechanism for the clicking sound observed in this series of patients. Thus, deviations in form and disk displacement with or without reduction can either singly or in combination lead to a variety of joint sounds.

**IMAGING**

**Indications for Imaging**

Imaging is recommended for those patients who are experiencing TMJ pain and who have a suspected internal derangement as the cause. There are two major components to the clinical presentation: (a) the subjective component, that is, pain and discomfort; and (b) the objective or mechanical component, that is, clicking and/or range-of-motion abnormalities of the jaw. The subjective component of the problem is very difficult to define in concrete terms. It is my experience that most patients will have an internal derangement of the TMJ when a mechanical and/or range-of-motion abnormality is present or is in the patient's clinical history. Thus, the mechanical aspects of TMJ internal derangements are the major clinical finding that, when associated with pain, warrant an imaging protocol.

**Plain Radiography**

The most common radiograph of the TMJ is the transcranial view of both the right and left sides with the jaw closed and opened. These images are acquired as a screening evaluation but are obviously not useful in depicting the soft-tissue elements of the articulation. Positive findings on transcranial radiographs in patients symptomatic for TMJ disease are in the range of 5%–10% (28). The transcranial radiograph depicts only the lateral third of the condyle, joint space, and temporal bone.

Positive findings observed on transcranial radiographs are those of degenerative joint disease, usually most prominent in the lateral third of the condylar head; limitation of condylar translation (translation of the condyle less than to the apex of the tubercle at maximal jaw opening); and, very uncommonly, calcified loose bodies within the fossa.

Much discussion and controversy has focused on the significance of the position of the condyle within the fossa as a predictor of internal derangement of the TMJ (14, 29). A posteriorly positioned condyle within the fossa when the jaw is closed has been reported to be associated with an anteriorly displaced disk. This is not a reliable finding for internal derangement.

**Tomography**

The same findings of joint disease as depicted on transcranial radiographs are also visible on sagittal tomograms of the TMJ. However, the sensitivity of multidirectional tomography for changes of degenerative joint disease is greater than that of conventional radiography (28, 30), because multidirectional tomography can depict multiple regions of the condylar surface and can do so with finer anatomic resolution. The major disadvantage of multidirectional tomography is the high radiation dose.

**Arthrography**

Transcranial or tomographic radiographs suffice for simple delineation of the osseous structures of the TMJ. Arthrography is indicated for evaluations of the soft-tissue components of the TMJ, especially disk position, function, and morphology in those patients presenting with a suspected internal derangement. In patients
Figure 6. Lower-joint-space, single-contrast arthrogram depicting disk displacement with reduction. (a) Contrast material is in the lower joint space (arrow), and this demonstrates that the posterior band of the disk is anterior to the 12 o’clock position of the condyle (C) and creates a concave impression (arrow) on the anterior recess of the joint space. T = tubercle. (b) Reduction of the displacement of the disk. The jaw is now maximally opened and the condyle (C) is beyond the margin of apex of the tubercle (T). The disk has now reduced and the contrast material has cleared from the anterior recess of the joint space and has flowed into the posterior recess of the joint space (arrow). Compare with Figures 4a and 10a, 10b.

clinically suspected of having internal derangement of the TMJ, arthrographic findings are commonly positive in between 75% and 80% of examinations (4,8,9,19). The arthrographic procedure for depiction of the lower joint space has been previously described in detail (7,8). This entails the injection of a water-soluble contrast material into the lower and/or upper joint compartments under fluoroscopic guidance and the use of a 23-gauge scalp vein needle. Approximately 0.4–0.5 mL of contrast medium is injected into the lower compartment under fluoroscopic observation. We use approximately 0.03 mL of 1:1000 epinephrine mixed with 3 mL of contrast material to allow intraarticular containment of contrast medium for subsequent imaging.

Following the injection of contrast material into the articulation, fluoroscopic-dynamic videotape images are recorded during opening and closing of the jaw. Spot radiographs under fluoroscopic guidance are obtained during the fluoroscopic procedure for patient records. In those patients having disk displacement without reduction or in those articulations that are normal or indeterminate, multidirectional tomography (arthrotomography) is performed following the fluoroscopic component of the examination. The arthrotomographic examination involves sagittal, 3-mm-thick tomographic planes of imaging through the articulation with the jaw closed and maximally opened.

The objective of the dynamic-fluoroscopic phase of the examination is to evaluate disk function during opening and closing of the jaw (31). The arthrotographer’s impression during this initial phase of the examination is vital for a complete and accurate diagnosis.

The objective of TMJ arthrotomography is to survey the joint space from medial to central to lateral in order to detect the type and degree of disk displacement with reduction is shown in Figure 6. Perforations of the posterior disk attachment are detected when contrast material flows freely into the upper joint compartment when the needle is precisely positioned in the lower joint compartment.

A major advantage of arthrography over other imaging modalities is that it allows an optimal assessment of the dynamic aspects of joint function and dysfunction. Knowledge of these dynamic aspects can also be used to initiate treatment with protrusive jaw splints. The precise position of the displacement phase of the disk with greater degrees of jaw closing can be determined and documented using fast-setting puttylike material injected between the teeth at the time of arthrography (32,33). The positional relationships of the upper and lower incisors are thus documented in conjunction with the arthrotographic diagnosis and with confirmation of reestablishment of normal disk/condyle anatomic relationships.

Contrast material alone may be introduced into the lower joint compartment or into the lower and upper joint compartments; contrast material and air may be introduced into the lower and upper joint compartments. The accuracy rates are sufficiently high with all three techniques; thus, I am an advocate of the simplest and least invasive approach possible (34). Lower-space, single-contrast arthrography with video fluoroscopy has a high accuracy rate and is the simplest to perform of the preferred techniques. This technique shows disk position and function but is not, however, optimal for evaluation of the configuration of the disk. If configurational changes are of primary importance, both upper and lower joint spaces should be opacified in all cases.

The advantages of arthrography are: (a) it accurately depicts the anatomic relationship of the disk to the condyle and temporal bone, (b) it enables a dynamic functional assessment of normal and abnormal physiology, (c) it is easy to perform in experienced hands, (d) it has limited requirements for specialized imaging technology, and (e) it is relatively inexpensive compared with computed tomography (CT) and magnetic resonance (MR) imaging. The disadvantages of arthrography are: (a) it involves substantial radiation dose in a predominantly young, female population; (b) it is an invasive procedure; (c) its successful performance requires training and experience; (d) it cannot accurately depict bone pathology; (e) it is probably less precise than MR imaging in demonstrating anatomic, positional abnormalities; and (f) it cannot directly depict the soft-tissue components of the articulation.

Significant complications from TMJ arthrography in experienced hands are uncommon. One of the most frequent complications is contrast medium extravasation into the capsule and soft tissues around the joint, which causes pain. Nonionic contrast media will be the agents of choice to minimize this discomfort. Vagal reactions are not infrequent; if a severe hypotensive response with bradycardia should occur, one must be prepared to administer 0.6 mg of atropine intravenously. Transient facial nerve palsies may result from too vigorous infiltration of lidocaine.

Computed Tomography

CT scanning of the TMJ enjoyed a great deal of success and interest soon after the development of TMJ
arthrography partly due to its own rapid technological development and noninvasive nature (35-38). Direct sagittal, thin-section CT of the TMJ with the jaw closed and opened and with bone and soft-tissue settings, and finely detailed axial CT scans of the TMJ with parasagittal reconstructions were reported to be successful for demonstrating internal derangements and osseous disease. CT scanning has, however, decreased dramatically in the assessment of TMJ internal derangements since the advent of MR imaging with surface coils, because the soft-tissue contrast and anatomic detail on MR images is markedly superior to those obtained with CT.

We still use CT scanning when fine detail in bone anatomy is of primary importance. Three-dimensional CT is valuable in the assessment of osseous deformities of the jaw.

Magnetic Resonance Imaging

MR imaging with surface coils is a proved method for the assessment of internal derangements of the TMJ and is rapidly surpassing arthrography and CT as the imaging method of choice (39-48). The major advantages of MR imaging in comparison with arthrography and CT are: (a) it is noninvasive, (b) it requires no ionizing radiation for image acquisition, (c) it permits direct visualization of the disk and joint structures, and (d) multiplanar imaging is readily obtained and more easily interpretable. Comparative studies of cryosectional cadaver material and multiplanar MR images have demonstrated the high accuracy of MR imaging.

At the University of Rochester Magnetic Resonance Center, MR imaging of the TMJ is the second most commonly performed study. (Head MR imaging is the first, and cervical spine and lumbar spine MR studies are third and fourth, respectively.) The total examination time for a bilateral TMJ assessment is the least of all other complete studies. A suggested technique is shown in Table 3 for a high-field-strength system. Midfield-strength systems may require longer acquisition times for comparable image quality because of additional numbers of excitations. A dual-surface-coil technique is used for bilateral imaging (49). However, a single-coil technique for a unilateral study could employ a similar pulse sequence protocol but on one side at a time. MR imaging is performed with the body coil as the transmitter and two surface coils, 6.5 cm in diameter, as the receivers. The patient is positioned supine, and the surface coils are placed against both TMJ regions (Fig 7). Our method acquires MR images in parallel from both members of the paired TMJs by means of the two surface-coil receivers. Sets of images are always obtained in both the closed- and open-jaw positions. The imaging protocol we have found useful is as follows (Table 3): (a) an axial localizer (scout) with a repetition time (TR) of 400 msec, an echo time (TE) of 20 msec (400/20), field of view (FOV) of 20 cm, 5-mm section thickness, 256×128 matrix, and one excitation (imaging time 56 sec); (b) 3-mm interleaved sagittal sections of both TMJs with the jaw closed and with 1.000/20, FOV 16 cm, 256×128 matrix, and two excitations (imaging time 4 min, 19 sec); (c) 3-mm interleaved sagittal sections of both TMJs with the jaw opened and with the same parameters as in b but with one excitation (imaging time 2 min, 21 sec); and (d) 3-mm coronal images of both right and left TMJs with the jaw closed, 1.000/20, FOV 16 cm, 256×128 matrix, and one excitation (imaging time 2 min, 21 sec).

A lower signal-to-noise ratio is acceptable in the open-jaw position when the disk has been clearly depicted in the closed-jaw position. It is necessary to minimize the imaging time over which the patient must keep the jaw open. This can be uncomfortable for the patient in the supine position as saliva collects in the back of the pharynx.

Syringes of variable sizes can be used as bite blocks during the open jaw phase of the imaging procedure (Fig 6). The syringe is wrapped with water-soaked gauze and the size of the syringe is selected to accommodate the degree of jaw opening obtainable by the patient at the time of presentation for MR imaging.

The necessity for coronal images is not yet fully defined but can be determined based on an on-line assessment of the anatomy in the sagittal imaging plane (48). If the disk cannot be demonstrated in the sagittal images, the coronal images are clearly indicated (Fig 8). The osseous anatomy can also be better evaluated with two imaging planes, preferably sagittal and coronal.

In routine imaging we have found no clearly established advantages in specifically T1 or T2 weighting since the disk has low signal intensity at all pulse sequences and the lateral pterygoid fat pad is very bright on proton-weighted sequences. This technique provides excellent contrast between the disk and tissues of the articulation. The need to demonstrate edema behind the disk or fluid within the joint spaces may lead one to acquire T2-weighted sequences as suggested by Harms et al. (1985) (39). I recommend T2-weighted sequences in patients being assessed following acute trauma to the TMJ, especially when condylar fractures and suspected intraarticular injuries are involved.

The normal TMJ demonstrated by MR images in the sagittal closed-, sagittal open-, and coronal closed-jaw positions is depicted in Figure 9. In the sagittal plane the disk has a configuration like that of a biconcave lens with the posterior band lying at the 12 o'clock position relative to the condylar head (Fig 9a). The low signal intensity of the fibrous disk is clearly depicted because of the relatively bright signal intensity emanating from the surrounding soft tissues and lateral pterygoid fat pad. The cortex of the condylar head has no signal but is well depicted because of

![Figure 7. Placement of 6-cm surface coils for bilateral TMJ imaging with the jaw open; a syringe wrapped in saline-soaked gauze is used as a bite block.](image-url)

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* TE for all pulse sequences = 20 msec.
Figure 8. MR images of chronic, anteromedial disk displacement without reduction associated with condylar degeneration. (a) In the closed-jaw position, sagittal plane of imaging, the condyle is noted to be flattened and irregular (arrows). The disk cannot be visualized in the sagittal imaging plane. (b) Coronal image with the jaw closed shows the medial disk (arrow) displacement. The disk is of low signal intensity and is far medial to the condyle (C). (c) Sagittal image with the jaw maximally opened shows the deformed, completely displaced disk (open arrows), representing disk displacement without reduction. Note the low signal intensity of the entire condyle (arrowheads) representing degeneration (TR/TE = 1,000/20 msec).

Figure 9. MR images of the normal TMJ with jaw in closed and open positions. (a) Jaw in the closed position, sagittal image. The image demonstrates the normal biconcave lens-like configuration of the disk (arrows, D), with the posterior band in the superior (12 o'clock) position. The image also demonstrates the attachment of the superior belly of lateral pterygoid muscle to the anterior band of the disk (arrowheads). C = condyle. (b) Jaw in the open position, sagittal image. The disk is interposed between the condyle (C) and tubercle (T). Relatively high signal (arrow) is often noted in the posterior band of the disk. The disk is attached to the neck of the condyle via firm capsular (arrowheads) attachment. (c) Coronal image with the jaw closed demonstrates the normal position of the arched-shaped disk (arrows).

The relatively bright signal intensity of the contiguous cartilaginous and synovial tissues superiorly, and the bright signal of the fatty marrow in its cancellous portion inferiorly. The disk has a bow-tie configuration with maximal jaw opening and maintains its position interposed between the convexity of the condyle inferiorly and the convexity of the tubercle superi orly (Fig 9b). The posterior disk attachment has a bright signal relative to the posterior band of the disk due to the rich network of fatty tissue contrasted with the low signal intensity of the fibrous disk. In some instances there is a small region of high signal intensity within the posterior band of the disk as described in the meniscus of the knee. This is probably a normal anatomic landmark representing mucin deposits and is of no known clinical significance. The insertion of the superior belly of the lateral pterygoid muscle is sometimes demonstrated on MR images as a low-signal-intensity, threadlike structure attaching on the anteromedial aspect of the disk (Fig 9a). In the coronal plane the disk has an arc-shaped configuration with the medial margin of the disk attaching to the medial pole of the condyle and with the lateral margin attaching to the lateral pole of the condyle (Fig 9c). In sideways displacements the disk is noted to be shifted beyond the polar regions of the condyle (Figs 3b, 8b).

An example of a chronically displaced disk is shown in Figure 8c. The disk has an abnormal configuration, is completely displaced anterior to the condylar head, and does not reduce with attempted maximal jaw opening. Abnormalities in the condylar head are also clearly depicted. The coronal plane of imaging shows a medial displacement in conjunction with the anterior displacement, the condition thus representing a rotational anteromedial displacement.
Figure 10. Disk displacement with reduction demonstrated in the sagittal and coronal planes of imaging and with MR depiction of anatomic correction following application of protrusive intraoral splint. (a) Sagittal image through the TMJ showing anterior displacement of the disk; the posterior band is demonstrated by the arrow, C = condyle. (b) With the jaw open, the disk (arrows) is now in a normal relationship to the condylar head (C) inferiorly and the tubercle superiorly. (c) The jaw is now fitted with the intraoral protrusive splint and this sagittal MR image demonstrates the recaptured position (normal position) of the disk (arrows) relative to the bony condyle (C). The splint maintains the jaw in a forward position at all times when the jaw is closed, keeping the condyle anterior and beneath the slightly displaced disk. (d) Coronal image through the same joint shows a marked medial component to the disk displacement (arrow) with the jaw closed and not in the protrusive splint. C = condyle. (e) Coronal image through the joint, now with the jaw in the protrusive splint and confirming an improved relationship between the disk (arrow) and condyle (C) compared with the nonsplinted image in d.

MR imaging can be used for assessment of the efficacy of protrusive splint therapy in addition to the clear depiction of the underlying stage of internal derangement. Figure 10a–e shows a disk displacement with reduction and with a rotational anteromedial component. The sagittal images also show recapture of the disk with the jaw slightly protruded (Fig 10c) in the splint and demonstrate some improvement in the sideways position of the disk with the splint (Fig 10d, 10e). This provides a more precise anatomic evaluation than can be obtained by any other imaging modality.

MR imaging is an important modality for the evaluation of postsurgical changes (50,51). It can help confirm surgical correction of disk displacement and can also help identify postsurgical failures. An example of a postsurgical complication resulting from the insertion of a Teflon-Proplast implant is shown in Figure 11. The Teflon-Proplast implant is demonstrated to be correctly placed in the fossa but is associated with a marked amount of exuberant granulation tissue response and condylar degeneration.

The disadvantages of MR imaging are the inability to depict perforations of the posterior ligament and the limitation to static images. The application of gradient-recalled acquisition in the steady state (GRASS) shows some promise in depicting sequential positions of the disk; however, the dynamics of the clicking event cannot be depicted due to the relatively long imaging times (52,53).

Radionuclide Imaging

Radionuclide imaging of the TMJ by means of conventional skeletal imaging techniques is valuable as a screening test for osseous disease of the TMJ (54,55). This screening test appears more sensitive than plain radiography, CT, or MR imaging. Thus, the advantages of radionuclide imaging are similar to those advantages noted in other joints. The radionuclide technique can be performed simply with very minimal radiation dose to the patient and can be an invaluable screening test. Not only can degenerative joint disease and remodeling of the TMJ be detected, but other pathologic conditions in and around the TMJ that mimick or produce TMJ pain can also be revealed.

Imaging Algorithm

The first step in the examination of a patient presenting with TMJ pain and dysfunction is plain radiography, usually transcranial radiography, as a screening test. This is, however, rarely definitive when an internal derangement is clinically suspected. Radionuclide skeletal imaging of both TMJs is a more sensitive screening technique and can be used to help establish objective evidence for organic disease of either the TMJ or areas of regional anatomy. Currently, this technique is underutilized.

Following the clinical evaluation and the screening examination by
as that the patient’s signs and symptoms are a direct result of the anatomic and mechanical abnormalities arising from disk displacement (56-58). Thus, correction of the anatomic abnormality and associated dysfunctional component will lead to an alleviation of the patient’s symptoms. The clinical goals emphasize improvement in the quality of life rather than treatment of disability or avoidance of death. Major treatment alternatives offered to the patient include (a) reassurance but no clinical intervention; (b) intraoral splint therapy, either flat splints or intrusive splints; (c) arthroscopy; (d) surgery to include disk plication, disectomy, or implantation; (e) medication alone or medication in association with alternatives b, c, or d.

The two major classes of splints employed for TMJ internal derangements are flat and intrusive intraoral appliances. The flat splint is designed to create a vertical separation of the occlusion in order to alleviate the superior and posterior thrust of the condylar head on the soft tissue components of the articulation. Flat splints are not used to correct the anatomic derangement of disk displacement but to manage the symptoms related to condylar impingement on the intraarticular soft tissue elements.

The protrusive splint, on the other hand, is designed to place the lower jaw in a forward position in order to reestablish a normal condylar relationship with the anteriorly displaced disk. The clinical success rate with protrusive splints is high. If an accurate diagnosis has been achieved and precise jaw position has been established either clinically (and confirmed with MR imaging) or from arthroscopy, the patient is required to wear the splint at all times. If protrusive splint therapy is successful and alleviates signs and symptoms of internal derangements of the TMJ, the patient is then offered a more long-term option of either occlusal adjustment alone, or occlusal adjustment by means of orthodontics. When the occlusion has been appropriately altered to maintain the forward jaw position, the protrusive splint is no longer needed.

TMJ arthroscopy is a new technique that makes use of fiberoptic small-diameter technology analogous to that used in knee arthroscopy (59,60). The technique is used in part to detect intraarticular adhesions and to free the articulation from restriction either because of these adher

TREATMENT OBJECTIVES IN A NUTSHELL

A comprehensive description of the treatment of internal derangements of the TMJ is beyond the scope of this review. There are, however, specific treatment philosophies that will place in perspective the importance of accurate diagnosis and characterization of internal derangements by radiologists.

The major hypothesis in the treatment plan for internal derangement is the disk displacement and dysfunction or because of internal derangement. This technique does not correct the internal derangement, and the exact mechanism for patient improvement is as yet unclear. As a diagnostic tool, arthroscopy is not accurate in determining disk position since only the upper joint compartment can be entered and visualized (60). Thus, the relationship of the disk to the important bone landmarks of the condyle cannot be accurately assessed.

The most commonly performed surgical procedure of the TMJ is a disk plication in which the stretched posterior ligament of the displaced disk is partially resected and the weakened remnants reattached; thus placing the posterior band of the disk back to the 12 o’clock position relative to the condylar head (14, 56).

This technique is most commonly performed in those patients presenting with disk displacement without reduction and without major deformity of disk morphology. The success rate from disk plication with careful patient selection is approximately 90%.

Diskectomy is regaining popularity for the treatment of TMJ internal derangements (58). Diskectomy is primarily used in those patients who have a displaced, nonreducing disk with associated deformities of disk morphology. Diskectomy is also used in those patients with chronically detached disks associated with degenerative changes of the condyle and turbinate. The placement of permanent alloplastic implants within the TMJ after disectomy initially experienced popularity (16,58). However, this technique has since fallen into disfavor due to the possibility of foreign-body reaction (Fig 11), implant degeneration or fracture, and implant displacement (45,50,61).

Medical management for patients with TMJ internal derangements includes antiinflammatory agents such as aspirin, Tylenol, and ibuprofen. The pharmacologic management protocol for TMJ pain and dysfunction is similar to that for degenerative conditions of the rest of the musculoskeletal system.

FUTURE PERSPECTIVES

Further developments in the radiologic assessment of internal derangements of the TMJ will probably continue to focus on improved understanding and depiction of the normal and pathologic anatomy by means of multiplanar and three-di-

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mensional imaging techniques. As with degenerative diseases of the disk of the spine, it is possible that MR spectroscopic analysis may be helpful in evaluating metabolic and biochemical changes. Previous reports have suggested abnormalities of lactate accumulation and intervent-ebral and peridiscal (of the spine) pH parameters in the presence of degeneration and herniation (62,63). Growing evidence also suggests sig-
ificant changes in the histopathology of the TMJ disk and posterior liga-
ment in association with internal de-
rangeinent (15,16).

The dynamics of TMJ internal de-
rangeinent are an important compo-
nent of the pathophysiology of dis-
ease, and, thus, cine MR imaging techniques will provide a valuable tool, especially if imaging times can be decreased to milliseconds (64). MR spectroscopy of the acute effects on high-energy phosphates of mecha-
nical jaw stress with exercise is also an important area of future research.

Comparisons of high- with mid-
field-strength magnetic systems are of practical importance for diagnostic accuracy, but only preliminary in-
sights have been acquired in this area.

CONCLUSION

Rapid strides have been achieved in our understanding of TMJ internal de-
rangeinent related to disk displacement based in large part on advanced imaging technology. MR imaging and spectroscopy, as both a diagno-
tic and research instrument, will continue to advance our understanding of the pathophysiology of this multi-
faceted and prevalent clinical disor-
der.

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