Correlations Between Anatomic and MRI Sections of Human Cadaver Temporomandibular Joints in the Coronal and Sagittal Planes

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Cadaver material was used in this study to correlate sequential sagittal and coronal T1-weighted magnetic resonance images against anatomic detail. Magnetic resonance imaging (MRI) was found to accurately represent soft tissues in normal and deranged joints. In contrast to previous reports, MRI was found to accurately represent the discal-retrodiscal junction and did not appear to give false positive findings for disc displacement. Magnetic resonance imaging provided good images of bony outline, particularly in coronal views. Difficulties in interpretation arose when different adjoining tissues produced the same MR image; the central tendon of the lateral pterygoid muscle can appear as an extension of the disc, imaging as a distorted and displaced disc. In anatomic sections, a medial hernia sac in the lower joint space was seen as a constant indicator of the medial component of disc displacement; however, this was not evident in sagittal and coronal T1-weighted images. Fibrocartilaginous remodeling of the articular surface projecting into a discal perforation presented the same image as normal discal tissue. Because discs are often thinned over the lateral pole, it is difficult to determine whether discal tissue is present between the articular surfaces when MRI is at its present resolution. Subcortical bone spaces may be misinterpreted as areas of avascular necrosis and osteochondritis dissecans. It is recommended that an imaging sequence of the TMJ include a mid-condyle image and lateral, central, and medial sagittal images; however, the lateral sagittal image is the most difficult to interpret.
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Pain and dysfunction of the temporomandibular joint (TMJ) affects a significant proportion of the population. Recent studies[1] of patients presenting to a general dental practice for treatment of temporomandibular disorders (TMD) reported that 31% of these patients demonstrated internal derangement, and 39% demonstrated arthritic changes. Diagnosis and treatment of these patients is difficult and ideally requires visualization of the hard and soft tissues of the TMJ.

Current radiographic techniques such as plain films, panoramic views, arthrography, and computerized tomography (CT) are useful for evaluating TMJ bone abnormalities, but the poor results in soft tissue imaging through these techniques leads to difficulties in interpretation.[2,3] Magnetic resonance imaging (MRI) has been developed as a noninvasive imaging modality that does not expose the patient to ionizing radiation or known biologic hazards, and it has the potential to produce high-quality tomographic images with greater soft tissue contrast than those obtained with other techniques.[4,5] Studies[2,6–12] have reported that MRI provides confirmation of location and deformation of the disc and identification of degenerative and inflammatory joint pathology of the TMJ.

Recent studies[2,6–12] of TMJ patient groups comparing clinical, arthrographic, CT, and surgical findings with MR images have reported that this new modality provides excellent visualization of both soft and hard tissues. In comparison to MRI, it was considered that arthrography does not provide visualization of all joint structures, and it provides no information relating to tissue characteristics. Limitations also existed in interpreting surgical findings because only the lateral part of the joint can be exposed. It is important that there is a gold standard against which the accuracy of each new diagnostic modality can be evaluated.

The cadaver model provides an opportunity to compare the imaging modality with the anatomic structures. Fixed cadaver material is more readily available than fresh autopsy specimens, and it has been suggested that MRI signal characteristics are similar between these two types of material.[13] However, at this time, it has not been determined what changes, if any, occur in MR imaging between living, fresh autopsy specimens and fixed cadaver tissue. Recent cadaver studies[14–17] comparing MR images with cryosections have reported that MRI is accurate in imaging the osseous, muscular, and fibrous components of the TMJ.

Cadaver studies assessing the accuracy of coronal versus sagittal MR imaging techniques to identify disc and joint pathology suggest that both views are necessary to spatially localize the disc. This was particularly recommended for MR views in which the disc failed to image in sagittal sections or in which the fossa appeared to be empty.[17,18]

Areas of controversy have arisen in the clinical application and interpretation of MRI. Difficulties were reported in assessing disc position in joints with severely thinned discs.[19] It has also been reported that MR imaging fails to identify perforations in the disc or retrodiscal tissues.[2,14] There is disagreement as to whether MRI accurately identifies the discal-retrodiscal junction in sagittal images.[7,20] It has been suggested that the posterior band of the disc may image with a signal intensity similar to that of retrodiscal tissue, and the posterior part of the intermediate zone of the disc may be falsely interpreted as the discal-retrodiscal tissue junction, leading to a diagnosis of a displaced disc.

Certain MR signal characteristics seen in the head of the condyle have been described as representing the pathologic conditions of avascular necrosis and osteochondritis dissecans.[21] It is necessary to assess whether this signal represents the pathology as described or whether it is a representation of normal tissues such as enlarged bone marrow spaces or condensed bone. The use of the cadaver gold standard makes it possible to investigate these controversies and to decide which MRI plane of orientation provides maximum diagnostic information with minimum imaging time.

The aim of this study was to obtain sequential T1-weighted MR images of both normal and abnormal TM joints of cadavers in the coronal and sagittal planes and to compare these findings with the corresponding anatomic sections.

Materials and Methods

Ten human cadaver heads were taken from subjects whose ages ranged from 40 to 85 years. Sagittal and coronal MRI scans were obtained of the heads after perfusion with formalin (6% to 8%), phenol (8%), glycerin (15%), and ethanol (20%). The MRI scans were obtained by stabilizing the complete head in the 0.5-tesla Philips Gyroscan S5 MRI system (Best, The Netherlands) using a head holder incorporating one 10-cm round receive-only TMJ surface coil. Axial localizing MR images were used to establish a parasagittal plane of orientation at right angles to the long axis of the condyle. Sequential T1-weighted spin-echo multislice MRI scans were obtained at 3-mm intervals, with no interslice distance, sagittally from the lateral pole to the medial pole and coronally from the anterior part of the disc to the posterior wall of the fossa. A special imaging protocol was employed with a 23-cm field of view, 256 × 256 matrix, 400-m/s repetition time, 30-m/s echo time, and four excitations for each image.

After sagittal and coronal MRI scans were obtained, each TMJ was removed from the skull as a block using a band saw and was prepared and processed as previously described by Wilkinson and Crowley.[22] Briefly, each block was bound anteriorly by the posterior wall of the maxilla, superiorly by the middle cranial fossa, posteriorly by the external acoustic meatus, inferiorly by the ramus of the mandible, and medially by the medial pterygoid plate. This tissue was then washed under running water until preserving fluid was no longer evident. The block was placed in decalcifying solution (Decalcifier II, Surgipath, Grayslake, IL) until there was radiographic evidence of complete decalcification. The right joints were sectioned in the sagittal plane until the lateral pole of the joint could be identified, and then sequentially at 3-mm intervals to match the previously obtained sagittal MR images. The left joints were sectioned in the coronal plane until the anterior rim of the condyle could be identified, and then sequentially at 3-mm intervals to match the previously obtained coronal MR images.

The anatomic sections were photographed for comparison with the matching T1-weighted MR printed images. In the sagittal plane, line drawings of these prints were used to correlate the position of the discal-retrodiscal junction between the corresponding sagittal anatomic and MR sections. Each joint was assessed as having normal anatomy, anteromedial disc displacement, lateral disc displacement, disc perforation, or articular surface remodeling.

Results

Twenty human cadaver TM joints were imaged and dissected. One joint was lost in preparation and was not included in this study. A total of eight joints exhibited clinically normal anatomy, and 11 joints exhibited a range of joint pathology (Table 1).

Magnetic Resonance Images of Sagittally Dissected Joints

Ten right TM joints were dissected in the sagittal plane. Five of these joints demonstrated normal anatomy; the other five joints exhibited a range of joint pathology (Table 1).

Joint Showing Normal Anatomy (Joint 3R). Joint 3R demonstrated normal anatomy with the posterior band of the disc at the 1-o'clock position and the junction with the retrodiscal tissues clearly evident (Fig 1a). The sagittal MR images of this joint demonstrated the bow-tie–like appearance of the disc. Fatty bands and the central tendon of the lateral pterygoid muscle were seen as high-signal images (Fig 1b).

The coronal MR image of the same joint demonstrated normal anatomy with the disc contrasted between the cortical plates, and the medial and lateral capsule highlighted as a vertical low-signal band (Fig 1c). There was a low-signal area, subcortical in the center of the condyle, but no corresponding degenerative changes were evident in matching sagittal anatomic sections.

Joint Showing Normal Anatomy (Joint 2R). Joint 2R demonstrated normal anatomy with the posterior slope of the eminence being vertical. The posterior band of the disc was located at the 1-o'clock position with the anterior part of the retrodiscal tissues over the crest of the condyle (Fig 2a).

The low-signal MR image of the disc in the lateral view of the joint accurately imaged the position of the posterior band of the disc (Fig 2b). The posterior joint capsule imaged as a band of low signal. The dense low-signal MR image of the cortical plate on the anterior reflection of the crest of the eminence in this lateral section represented the root of the zygoma.

The coronal MR view (Fig 2c) showed an irregular outline of the articulating surfaces in the medial half of the joint, suggesting degenerative changes. However, these surfaces appeared normal in sagittal anatomic and MR images.

Joint Showing Normal Anatomy (Joint 4R). Joint 4R demonstrated normal anatomy in sagittal sections with the posterior band of the disc at the 1-o'clock position (Fig 3a). The central tendon of the lateral pterygoid muscle was seen inserting into the pterygoid fovea. The retrodiscal tissues had a

Table 1 Range of Pathology Seen in the Joints

	Sagittally dissected joints										Coronally dissected joints										
	1R	2R	3R	4R	5R	6R	7R	8R	9R	10R	1L	2L	3L	4L	5L	6L	7L	8L	9L	10L	Total
Normal anatomy		√	√	√	√					√			*		√			√		√	8/19
Anteromedial disc displacement	√					√	√		√			√				√	√		√		8/19
Lateral disc displacement											√										1/19
Perforated disc																	√				1/19
Articular changes								√						√		√					3/19

*Lost in preparation.

highly vascular appearance, and their junction with the discal tissues was clearly identifiable. The posterior capsule had a fibrous bandlike appearance adjacent to the parotid gland.

In sagittal MR images, the junction of the low-signal disc and the high-signal retrodiscal tissues were accurately imaged; this correlated well with the anatomic section of the junction (Fig 3b). The upper central tendon of the lateral pterygoid muscle was represented by a horizontal band of low-signal image that joined the low-signal image of the foot of the disc, giving a false appearance of a displaced and folded disc. The posterior capsule of the retrodiscal tissues imaged as a low-signal band.

In coronal MR images, the articular surface of the medial half of the condyle suggested degenerative changes that were not evident in sagittal anatomic sections (Fig 3c).

Joint Showing Anteromedial Displacement With Remodeling (Joint 9R). Laterally, joint 9R demonstrated normal anatomy with the thickened posterior band of the disc at the 1-o-clock position (Fig 4a). Medial sections of the joint showed severe anteroposterior narrowing of the condyle and the bulk of the disc displaced anteromedially (Fig 4b).

Sagittal MRI sections accurately imaged the condyle in the lateral and medial parts of the joint. In the lateral part of the joint, horizontal bands of low signal imaged inferiorly to the eminence, inserting into the pterygoid fovea and most likely representing the anterior capsule and the central tendon of the lateral pterygoid muscle (Fig 4c). The low-signal area forming the posterior half of the superior band was interpreted as the foot of the disc. In the medial part of the joint, the anteromedially displaced disc in front of the narrowed condyle was well imaged, with the position of the discal-retrodiscal junction accurately represented (Fig 4d).

The coronal MRI views through the center of the condyle clearly depicted the joint space and the lateral capsule, but there was no clear indication that the disc was displaced medially (Fig 4e).

Joint Showing Medial Displacement (Joint 6R). Joint 6R demonstrated a direct medial displacement with the posterior band of the disc remaining at the 12-o'clock position (Fig 5a). In lateral views, the lateral discal ligament and disc were thinned over the lateral pole. There were large subcortical marrow spaces in the lateral half of the condylar head.

Sagittal MR images through the lateral half of the joint accurately imaged the thickened cortical plate of the condylar head. The eminence was poorly imaged as a result of its changing contour as it narrowed to form the root of the zygomatic arch (Fig 5b). Laterally, the thinned discal and retrodiscal tissues were poorly imaged. The subcortical spaces in the lateral part of the condyle imaged as a lower signal against the high signal of the bone marrow.

Coronal MR images of the joint demonstrated normal contour of the articulating surfaces (Fig 5c). In the medial half of the joint, the disc was imaged as a medium signal; thinning of the disc laterally resulted in blending of the signals of the fossa and the condyle. Lower-signal bands medially and laterally corresponded to the insertion of the capsule into the condyle. Areas of low signal within the marrow space of the condyle correlated with the subcortical spaces seen in the anatomic sections.

Magnetic Resonance Images of Coronally Dissected Joints

Nine left TM joints were dissected in the coronal plane. Three of these joints demonstrated normal anatomy; the other six joints exhibited a range of joint pathology (see Table 1).

Joint Showing Normal Anatomy (Joint 10L). Joint 10L demonstrated normal anatomy with a narrowing of the disc over the lateral pole (Fig 6a). In coronal MRI views, the cortical bone of the condyle and fossa was well visualized, and the dimensions of the disc were accurately represented (Fig 6b). The lateral capsule of the joint was clearly visible in the MRI views highlighted against the bright signal image of the parotid gland and adipose tissue laterally.

Sagittal MRI views also illustrated normal TMJ structures with the bow-tie–like appearance of the disc well outlined between condyle and fossa (Fig 6c). The junction between the posterior band of the disc and the retrodiscal tissues was at the 1-o'clock position, and the foot of the disc is adjacent to the crest of the eminence.

Joint Showing Anterior Disc Displacement With Remodeling (Joint 6L). Coronal anatomic sections demonstrated an anterior disc displacement and marked remodeling of the head of the condyle (Fig 7a). The discal and retrodiscal tissues had undergone structural changes to conform to the altered condylar shape. Large subcortical cystlike spaces were evident in the bone marrow.

Coronal MR images accurately represented the irregular contour of the articular surface of the condyle from the lateral to the medial pole (Fig 7b). The cystlike spaces seen in anatomic sections imaged as areas of low signal. In sagittal MR images, the low-signal mass anterior to the condyle

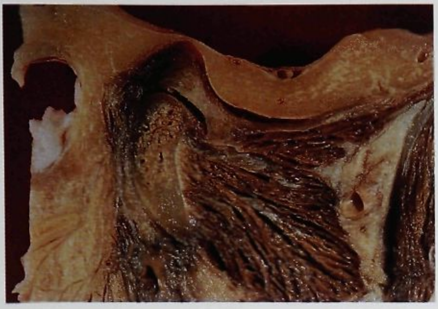

Fig 1a Medial sagittal anatomic section through a right TMJ (joint 3R). This joint demonstrates normal anatomy with the posterior band at the 1-o'clock position. A fatty band is evident between the two heads of lateral pterygoid.

Fig 1b A T1-weighted MR image of the same medial sagittal section of joint 3R as seen in Fig 1a. The disc has a typical bow-tie–like appearance. Fatty bands and the central tendon of the lateral pterygoid muscle were seen as high-signal images.

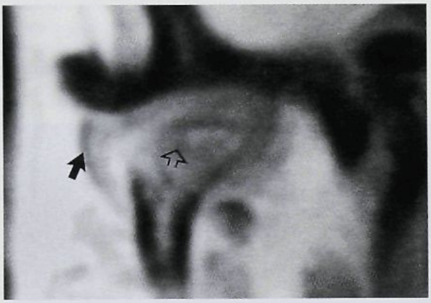

Fig 1c A T1-weighted coronal MR image through the center of the condyle of joint 3R. Discal tissue and medial and lateral capsular tissue *(dark arrow)* are well imaged. A subcortical low-signal area is seen in the center of the condyle *(open arrow)*. The bone of the fossa, the middle cranial fossa, and the root of the zygoma are clearly imaged in this section.

confirmed the anteriorly displaced disc (Fig 7c). The articular surface of the anterior slope of the condyle was flattened but did not have an irregular outline.

Joint Showing Anteromedial Disc Displacement With Remodeling (Joint 9L). Joint 9L showed an anteromedial displacement of the articular disc with elongation of the lateral discal ligament over the lateral pole of the condyle and folding of the medial discal ligament with the development of a hernia sac (Fig 8a). The condyle and articular fossa showed evidence of remodeling.

In coronal MR images, a narrowing of the joint space over the lateral pole was accurately represented (Fig 8b). The medially displaced disc was poorly represented and was seen as a medium/high-signal mass filling the medial joint space. The remodeling of the head of the condyle was accurately depicted in the MRI. The sagittal MR images showed the posterior band at the 2-o'clock position, confirming the anteromedial disc displacement (Fig 8c).

Joint Showing Anteromedial Disc Displacement With Remodeling (Joint 2L). Joint 2L showed a severely anteromedially displaced disc (Fig 9a). The displacement was associated with remodeling of the medial surface of the condyle, elongation of the lateral discal ligament, and folding of the medial discal ligament forming a medial recess in the inferior joint space.

In coronal MR images, the disc displacement was seen as a low-signal mass adjacent to the medial pole of the condyle (Fig 9b). However, this image underrepresented the severity of the displacement. Sagittal images of the medial part of the joint showed a low-signal mass anteriorly, suggestive of a displaced disc (Fig 9c).

Fig 2a Lateral sagittal anatomic section through a right TMJ (joint 2R). This joint demonstrates normal joint anatomy with a vertical posterior slope of the eminence and the posterior part of the disc at the 1-o'clock position.

Fig 2b A T1-weighted MR image of the same lateral sagittal section of joint 2R as seen in Fig 2a. The disc, condyle, and temporal surfaces overlap as an area of low signal. The dense cortical bone of the root of the zygoma is imaged anterior to the crest of the eminence. The posterior joint capsule images as a band of low signal *(arrow)*.

Fig 2c A T1-weighted coronal MR image through the center of the condyle of joint 2R. There is an irregular cortical outline of the medial aspect of the joint.

Joint Showing Anteromedial Disc Displacement and Lateral Discal Perforation (Joint 7L). Joint 7L demonstrated a medially displaced disc with marked narrowing of the joint space over the lateral pole and perforation of the lateral discal ligament (Fig 10a). The medial discal ligament was folded under the body of the disc, creating a medial recess or hernia sac in the inferior joint space.

Coronal MR images showed the mass of the disc displaced medially (Fig 10b). The roof of the fossa laterally had a signal intensity similar to that of discal tissues. This gave the appearance of an even thickness of discal tissue from the medial side to the lateral side, failing to indicate the narrowing of the joint space and the lateral discal perforation. In lateral sagittal MRI views, the eminence appeared flattened, and there was narrowing of the joint space laterally (Fig 10c).

Joint Showing Laterally Displaced Disc (Joint 1L). A coronal anatomic cut through the posterior slope of the eminence demonstrated medial and lateral deviations in form. The discal tissue showed as an island inside the fossa (Fig 11a). A coronal anatomic section through the crest of the condyle demonstrated a laterally displaced disc (Fig 11b). It appeared that the bulk of the disc was

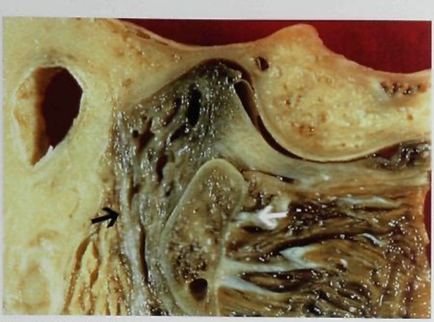

Fig 3a Medial sagittal anatomic section through a right TMJ (joint 4R). This joint demonstrates normal anatomy with the posterior band of the disc at the 1-o'clock position. The retrodiscal tissues have a highly vascular appearance, and the posterior capsule has a bandlike appearance *(black arrow)*. Two bands of the central tendon of lateral pterygoid muscle are seen inserting into the condyle. The upper-most band is adjacent to the foot of the disc, giving a false image of a displaced disc folded on itself *(white arrow)*.

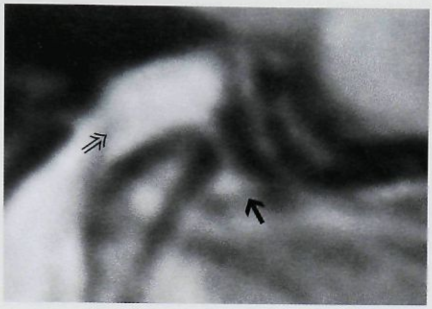

Fig 3b A T1-weighted MR image of the same medial sagittal section of joint 4R as seen in Fig 3a. The low signal of the condyle and temporal surfaces are well imaged. The position and shape of the disc and junction with the retrodiscal tissues accurately reflect the anatomic section. The low signal of the posterior capsule clearly contrasts with the high-signal retrodiscal tissues and parotid gland *(open arrow)*. The upper central tendon of the lateral pterygoid muscle is represented by a horizontal band of low-signal blending with the low signal of the foot of the disc *(solid arrow)*, falsely giving the appearance of a displaced, bent disc.

Fig 3c A T1-weighted coronal MR image through the crest of the condyle of joint 4R. Irregularities in signal on the medial aspect of the condyle suggest articular surface changes that are not evident in the sagittal anatomic sections.

displaced laterally with disruption of the medial discal ligament, suggesting trauma as the etiology.

In coronal MR images, the same disc displacement was poorly imaged (Fig 11c). A low-signal mass adjacent to the lateral pole of the condyle was the only indication of the bulk of the disc.

Joint Showing Degenerative Changes (Joint 4L). Joint 4L demonstrated marked degenerative changes in the medial half of the condyle (Fig 12a). The remnant of disc was seen over the lateral pole and did not continue past the center of the condyle. The retrodiscal tissues over the medial part of the condyle were abnormal and demonstrated clefting.

In coronal MR images, the irregular cortical plate in the medial half of the joint was accurately imaged (Fig 12b). The discal remnant was seen over the lateral pole of the joint as a medium-signal image. No indication was given of the thinning of the disc over the lateral pole of the joint. The higher signal of the retrodiscal tissues were seen over the medial half of the joint.

Sagittal images of the medial part of the joint (Fig 12c) did not show severe changes. The bow-tie–like appearance of the disc suggested a normal disc-condyle relationship.

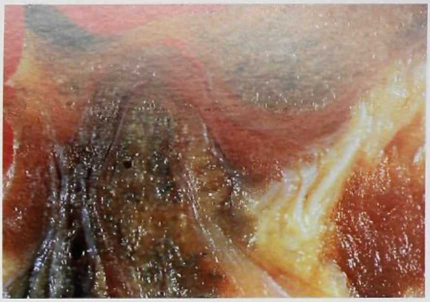

Fig 4a Lateral sagittal anatomic section through a right TMJ (joint 9R). This joint demonstrates normal anatomy with the posterior band of the disc at the 1-o'clock position. There is flattening of the head of the condyle and the crest of the eminence. A band of fatty tissue is present running from the neck of the condyle to the roof of the infratemporal fossa.

Fig 4b Medial sagittal anatomic section through the same joint as seen in Fig 4a (joint 9R). The disc is positioned anteromedially in front of the severely narrowed condyle.

Fig 4c *(Left)* A T1-weighted MR image of the same lateral section of joint 9R as seen in Fig 4a. The flattening of the anterior aspect of the condyle and crest of the eminence are well imaged. The horizontal low-signal band below the crest of the eminence represents the foot of the disc and the anterior capsule. A more inferior horizontal band that inserts into the neck of the condyle represents the central tendon of the lateral pterygoid muscle. A band of high signal running from the neck of the condyle to the infratemporal fossa represents the band of fatty tissue.

Fig 4d A T1-weighted MR image of the same medial section of joint 9R as seen in Figure 4b. The anteromedially displaced disc is well imaged in front of the narrowed condyle with the position of the retrodiscal junction accurately imaged.

Fig 4e A T1-weighted coronal MR image through the crest of the condyle of joint 9R. The lateral joint capsule and joint space are clearly imaged.

Fig 5a Lateral sagittal anatomic section through a right TMJ (joint 6R). The disc and retrodiscal tissues are thinned over the head of the condyle. Marrow spaces are seen in the upper half of the condylar head.

Fig 5b A T1-weighted MR image of the same lateral sagittal section of joint 6R as seen in Fig 5a. The outline of the condylar head matches the anatomic section, and the marrow spaces are imaged as areas of low signal.

Fig 5c A T1-weighted coronal MR image through the center of the condyle of joint 6R. The cortical outline of the condyle and temporal surface is well imaged, but the thinned discal tissues are not well imaged. Low-signal subcortical images seen laterally correlate with the marrow spaces seen in lateral sagittal anatomic section (Fig 5a).

Discussion

Magnetic resonance imaging is a noninvasive procedure that has the potential to produce high-quality tomographic images in any plane with excellent soft tissue resolution without exposing the patient to ionizing radiation or known biologic hazards. Contrast between tissues in MR images is not dependent on tissue density; it reflects variations in molecular structure and tissue characteristics, allowing examiners to discriminate among osseous, muscular, fibrous, adipose, and vascular tissue.

Bone marrow within the condyle, zygomatic process, and articular eminence is easily identified in T1 images because of its high signal. The lateral pterygoid muscle and vascular retrodiscal tissues produce an intermediate signal. The densely collagenous disc is characterized by a medium-low signal. Cortical bone has a very low-signal image, and bony abnormalities such as osteophytes are well highlighted when adjacent to tissues with a medium-high signal.

The aim of the present study was to use a cadaver gold standard to assess the ability of MRI to accurately represent anatomic structures and to identify anatomic features that assist in interpretation as well as those that create difficulties in interpretation.

Anatomic and MRI Features That Assist Interpretation of TMJ Structures

Differences Among Osseous, Muscular, and Fibrous Components. Variation among osseous, muscular, and fibrous components provides good

Fig 6a Coronal anatomic section through the center of the condyle of a left TMJ (joint 10L). Joint 10L demonstrates normal anatomy, but the disc is reduced in thickness over the lateral pole. The lateral capsule is seen running from the lateral pole of the condyle to the root of the zygoma.

Fig 6b A T1-weighted MR image of the same coronal section of joint 10L as seen in Fig 6a. The disc is well imaged as an area of medium density between the cortical plates of the condyle and the temporal component, with reduced joint space over the lateral pole. The lateral capsule is highlighted against the high-signal adipose tissue *(arrow)*.

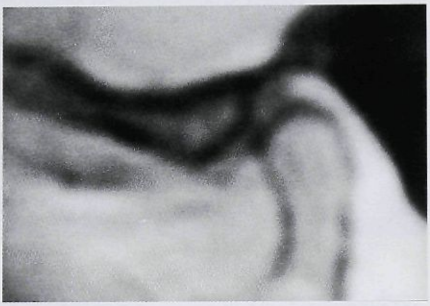

Fig 6c A T1-weighted midsagittal MR image of joint 10L. The posterior band of the disc is at the 1-o'clock position, and the disc is well outlined, creating a bow-tie effect.

contrast in MR images. Cortical bone with a characteristic low signal provides an accurate outline of the glenoid fossa, articular eminence, and mandibular condyle. The signal of the cortical bone is highlighted between the high-signal image of the bone marrow and the intermediate signal of the intracapsular soft tissues. In coronal views, the lateral pterygoid muscle insertion to the pterygoid fovea can be identified by a discontinuity in the low-signal cortical plate of the condyle (Figs 9b and 11c).

Disc position and shape are well imaged because the densely collagenous fibrous connective tissue of the disc has an intermediate MRI signal that provides good contrast between osseous and soft tissue components of the TMJ (Figs 1b and 3b). In the present study, the interpretation of disc position was assisted by the series of six sequential images from medial to lateral, with a similar bow-tie–like appearance.

In sagittal sections, the vascular retrodiscal tissues presented as an area of high signal bounded by the low signal of the condyle and fossa. Anteriorly, the contrast between this high-signal area and the intermediate signal of the posterior band of the disc assisted in identifying the discal-

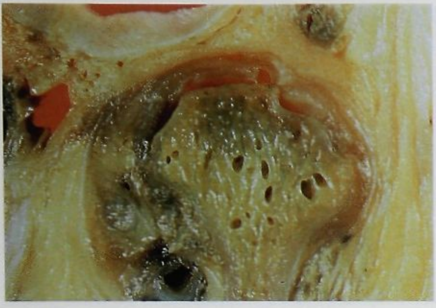

Fig 7a Coronal anatomic section through the center of the condyle of a left TMJ (joint 6L). This joint demonstrates marked remodeling of the crest of the condyle with the disc undergoing structural changes. Large subcortical cystlike spaces are evident in the bone marrow.

Fig 7b A T1-weighted MR image of the same coronal section of joint 6L as seen in Fig 7a. The remodeled cortical surface of the condyle is well imaged. The dimensions of the joint space are accurately imaged, outlining the thinned discal tissues. The subcortical cyst spaces are evident as areas of low signal. Vertical bands of high-signal images lateral to the joint represent planes of adipose tissue as seen in the anatomic section (Fig 7a).

Fig 7c A T1-weighted midsagittal MR image of joint 6L. A low-signal area anterior to the head of the condyle represents an anteriorly displaced disc. The rectangular appearance of the head of the condyle suggests remodeling.

retrodiscal junction (Figs 1b and 3b). The dense fibrous posterior capsule of the joint formed the posterior and inferior boundary of the retrodiscal tissues and was frequently seen in sagittal images as a low-signal band running from the condyle to the squamotympanic fissure (Fig 3b). In coronal views, the medial and lateral capsules were well imaged against the low signal of the cortical bone of the fossa and the high signal of the tissues lateral to the joint (Fig 1c).

The superior and inferior heads of the lateral pterygoid were clearly seen in sagittal sections in the medial half of the joint with the higher-signal bands of the central tendon and fatty tissue imaged between the two heads (Figs 1b and 3c).

Biconcave Appearance of Disc. In sagittal MR images, the disc has a biconcave appearance. In this study, the differences in discal thickness and collagen fiber orientation between the central part of the disc and the thicker anterior and posterior bands and the central part of the disc gave a characteristic bow-tie–like appearance to the disc in MR images. This bow-tie–like appearance is often absent in the lateral third of the joint where the disc is thinner and where there is superimposition of the cortical plates, making it difficult to interpret lateral images (Fig 5b).

Fig 8a Coronal anatomic section through the center of the condyle of a left TMJ (joint 9L). This joint demonstrates remodeling and internal derangement. The disc is anteromedially displaced with elongation of the lateral discal ligament and reduction of the joint space laterally. The medial discal ligament is folded on itself with the development of a medial recess or hernia sac *(arrow)*.

Fig 8b A T1-weighted MR image of the same coronal section of joint 9L as seen in Fig 8a. The remodeling of the condyle and the reduction of the joint space laterally are well imaged. The displaced disc is visualized filling the medial joint space.

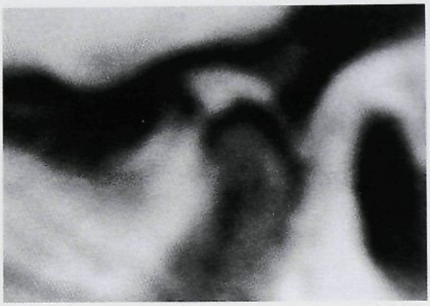

Fig 8c A T1-weighted midsagittal MR image of joint 9L. The crest of the condyle exhibits an irregular contour, suggesting remodeling as seen in the anatomic section (Fig 8a). The discal-retrodiscal junction is positioned opposite the anterior rim of the condyle, with the anterior part of the disc at the crest of the eminence, which indicated an anteriorly displaced disc.

In the literature, there is controversy regarding the extent to which the disc and its attachments can be accurately imaged. Roberts et al[23] stated that the boundary between the intermediate zone and the posterior band can be mistaken for the boundary between the posterior band and the posterior attachment. This would lead to the conclusion that the disc is in a more anterior position than it actually is. Scapino[20] reported that variations in signal intensity in the posterior band of the disc may occur because of regional variations in the vascularity and content of polyanionic glycosaminoglycans in this area, resulting in difficulties in identification of the junction of the posterior band of the disc and the retrodiscal tissues. Westesson et al[14] reported that difficulties in distinguishing the discal-retrodiscal junction occurred in joints demonstrating perforated or mediolateral disc displacements. Accurate interpretation of the disc position and shape by MRI requires clear identification of the structures involved. In the present study, line drawings of sagittal anatomic sections demonstrated that the discal-retrodiscal junction could be accurately identified by sagittal MR images.

Accuracy. With magnetic resonance imaging, disc displacements are accurately imaged. Magnetic

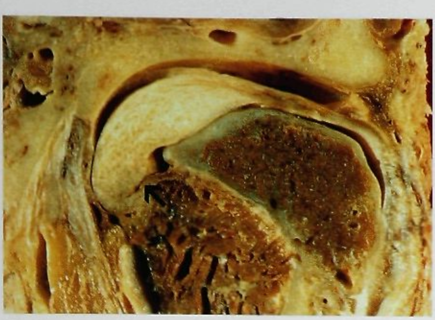

Fig 9a Coronal anatomic section through the center of the condyle of a left TMJ (joint 2L). This joint demonstrates an anteromedially displaced disc. The disc is thinned and elongated over the lateral surface of the condyle, with elongation of the lateral discal ligament. The head of the condyle shows remodeling medially with folding of the medial discal ligament forming a hernia sac *(arrow)*.

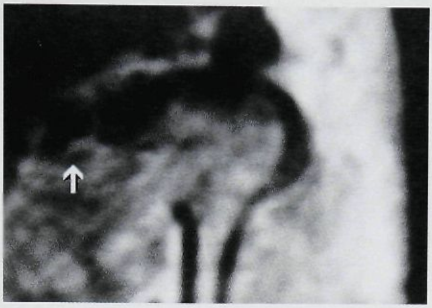

Fig 9b A T1-weighted MR image of the same coronal section of joint 2L as seen in Fig 9a. The anteromedially displaced disc is evident as an area of low signal over the medial surface of the condyle. The discal ligament is seen folded on itself medially *(arrow)*.

Fig 9c A T1-weighted sagittal image through the medial third of the condyle of joint 2L. There is a low-signal mass anterior to the condyle, indicating an anteriorly displaced disc.

resonance imaging accurately indicates disc position; the more common anteromedial displacements are characterized in sagittal views by the posterior band imaged forward of the crest of the condyle, and by a low-signal area medial to the medial pole in the midcondyle coronal view. The medial hernia sac seen in anatomic sections as the disc displaced medially was not imaged in either sagittal or coronal MRI views (Figs 8a, 9a, and 10a). This may be better imaged in T2-weighted images, which would highlight this fluid-filled space.

In a direct medial disc displacement, sagittal images are of limited value because the posterior band of the disc may still be over the crest of the condyle. In central coronal MR images, the combination of an area of low signal medially and the absence of disc space laterally enhanced the representation of a medially displaced disc (Fig 8b).

Interpretation of disc position over the lateral pole is difficult because this is the area where the joint space is narrowest and the disc is often thinned and has lost its bow-tie–like appearance. In an early derangement, where the disc is displaced only over the lateral pole, it was difficult to determine through MRI whether the disc was thinned and displaced or just thinned (Fig 5a).

Fig 10a Coronal anatomic section through the center of the condyle of a left TMJ (joint 7L). This joint demonstrates a medially displaced disc with narrowing of the joint space over the lateral pole, perforation of the lateral discal ligament, and the development of a medial hernia sac.

Fig 10b A T1-weighted MR image of the same coronal section of joint 7L as seen in Fig 10a. The mass of the displaced disc is seen medially. The lateral roof of the fossa has a signal intensity similar to that of discal tissues and fails to indicate the narrowing of the joint space and the lateral perforation.

Fig 10c A T1-weighted sagittal MR image through the lateral pole of the condyle of joint 7L. The eminence and fossa appear flattened, and the joint space is narrowed.

Magnetic resonance imaging also failed to indicate lateral discal perforation in both sagittal and coronal views (Figs 10b and 10c).

Westesson et al[14] and Tasaki and Westesson[17] reported that errors in diagnosis of lateral disc displacements occurred when only lateral sagittal images were used and that additional coronal images were required to visualize this type of displacement. The present study found that lateral disc displacements can be identified from coronal MRI views as a band of low signal adjacent to the lateral pole (Fig 11c). Sagittal MR images may not be contributory as the expected bow tie is absent because there may be no disc tissue present over the head of the condyle.

The authors of the present study suggest that the combination of lateral, central, and medial sagittal images and a midcondyle image will provide a three-dimensional interpretation of the anteromedial, direct medial, and lateral disc displacements. The results of the present study indicate that lateral sagittal images provide limited diagnostic information when the lateral joint space and disc thickness is reduced.

Irregular Bony Outlines. Irregular bony outlines are well imaged in coronal MR images. Subtle changes in the contour of the cortical bone were accurately imaged by central coronal MR images, which is in agreement with Tasaki and Westesson[17] and Schwaighofer et al[19] (Figs 2d, 3c, and 7b). Frequently, sagittal MR images failed to identify articular surface remodeling (Fig 12c). In contrast, the coronal view of the same joint gave a more accurate representation of the changes in

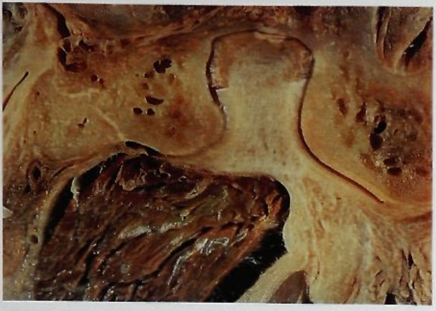

Fig 11a Coronal anatomic section through the articular eminence of a left TMJ (joint 1L). The disc is seen as an island of soft tissue in a concavity of the posterior slope of the eminence. The superior and inferior lateral pterygoid muscle are cut transversely anterior to their insertion in the pterygoid fovea.

Fig 11b Coronal anatomic section through the center of the condyle of the same joint as seen in Fig 11a (joint 1L). This section demonstrates a laterally displaced disc with disruption of the medial discal ligament.

Fig 11c A T1-weighted MR image of the same coronal section of joint 1L as seen in Fig 11b. The severe lateral displacement is poorly imaged. A band of low signal is evident adjacent to the lateral pole of the condyle.

contour of the cortical bone of the articular surface from lateral to medial, clearly depicting erosion and flattening of the condyle (Fig 12b). This strengthens the recommendation that a central coronal view should be included in the TMJ screening sequence.

Anatomic and MRI Features That Create Difficulties in Interpretation of TMJ Structures

Differences in Appearance of Architecture of a Structure. Variations in a structure's normal internal architecture may be misinterpreted in MR images. There is often an expectation that each separate component of the TMJ should image in a homogeneous manner. Scapino[20] has described individual structural entities such as the disc or the retrodiscal tissues as being composed of many cellular and extracellular matrix components with varying orientation and density. The MR image of such a structural entity may lack homogeneity but accurately reflects the histologic diversity of that joint component.

However, the reverse may be true in interpreting MR images of joints demonstrating remodeling or degenerative joint disease where these changes appear to image as normal tissue. In Fig 10b, the remodeling and thickening of the roof of the fossa laterally was accurately imaged reflecting its remodeled cellular components. However, this might be misinterpreted as representing a normal joint space laterally, failing to image a severe disc perforation. Lateral sagittal images also failed to identify discal perforation in this area (Fig 10c).

Fig 12a Coronal anatomic section through the center of the condyle of a left TMJ (joint 4L). The joint shows degenerative changes in the medial half of the condylar head and the articular fossa. This anatomic section displays clefting of the retrodiscal tissues medially and elongation of the lateral discal ligament.

Fig 12b A T1-weighted MR image of the same coronal section of joint 4L as seen in Fig 12a. The irregular outline of the medial half of the articular surface of the condyle and the joint space dimension are well represented.

Fig 12c A T1-weighted midsagittal MR image of joint 4L. Degenerative changes are not evident in the condyle or temporal component of this joint. The disc has a normal bow-tie–like appearance.

This reflects the difficulty of T1-weighted images in differentiating between discal thinning and discal perforation. The T2-weighted images, which highlight fluid-filled spaces, may be better able to image discal perforations.

Overlapping Joint Structures. Low-signal MR images from different joint structures may overlap, and difficulties can occur. In Fig 2b, the discal tissues had an unusually low signal that was indistinguishable from the cortical bone of the condyle and fossa, but it was still possible to determine the junction of the disc with the retrodiscal tissues. This again occurred with an anteriorly displaced disc in Fig 8b where the disc had the same signal as cortical bone in coronal images, making it difficult to diagnose disc position.

Difficulty in Identifying Condylar Soft Tissues Versus Discal Tissues in Sagittal Views. Soft tissues surrounding the condyle with discal tissues may be confused in sagittal MR images. Studies using arthrography, CT, and MRI have often described severely displaced discs as being folded on themselves.[6] There is a potential for the central tendon of the lateral pterygoid muscle to be confused with discal tissues. For example, in Fig 3b, the upper central tendon joins the low-signal image of the foot of the disc, giving a false appearance of a displaced and folded disc.

Difficulty in Interpreting Coronal Views of Deranged and Degenerative Joints. Disc and bony surfaces may be difficult to interpret in coronal MR images of deranged and degenerative joints. Frequently, severe internal derangements are not clearly visualized in coronal MR images of joints with severe degenerative changes involving a significantly thinned disc.[17,19] Difficulties occur in distinguishing the disc from the joint spaces and surrounding tissues where degenerative changes are occurring in the joint, and the pathologic tissues image with an equal signal intensity. In the coronal MR image of joint 2L (Fig 9b), the low signal of the condyle and the roof of the fossa blends with the low-signal discal tissue, making it difficult to interpret the medially displaced disc.

In Fig 10b, failure of the articular surface of the lateral rim of the fossa to be imaged as a low-signal area led to the appearance of this joint having an extremely wide joint space. The articular surface that failed to image appeared dense macroscopically but might have reflected a microscopic increase in fibrocartilaginous tissue with a higher signal than would be expected from normal cortical bone. This would result in a false negative finding in a severely deranged joint with a lateral discal perforation.

Marrow Spaces of the TMJ. Marrow spaces in bony structures of the TMJ are difficult to interpret. There has been discussion in the literature[21] suggesting that MR images showing low-signal subcortical areas in the condyle may indicate the presence of avascular necrosis and osteochondritis dissecans. The question must be asked as to whether other conditions may present similar low-signal areas in the condyle to avoid making false positive diagnosis of these conditions. Bone marrow may contain enlarged marrow spaces that could be described as subcortical cystlike spaces, and these may also present as a low-signal subcortical MR image (Figs 1c, 5b, and 7b). Caution is suggested in interpreting these normal variations as pathologic entities.

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Resumen

Correlaciones Entre las Secciones Anatómicas e Imágenes de Resonancia Magnética de Articulaciones Temporomandibulares en Cadáveres Humanos en los Planos Coronales y Sagitales

En este estudio se utilizaron cadáveres para correlacionar imágenes de resonancia magnética (IRM) consecutivas sagitales y coronales cargadas con T1, con detalles anatómicos. Se encontró que las IRM representaban exactamente los tejidos blandos en las articulaciones normales y trastornadas. En contraste con reportes anteriores, la técnica de IRM representó exactamente la unión entre el disco y la parte retrodiscal y no pareció indicar hallazgos positivos falsos en desplazamientos del disco. La técnica de IRM suministró buenas imágenes del contorno óseo, particularmente en las vistas coronales. Se encontraron dificultades en la interpretación cuando diferentes tejidos adyacentes produjeron la misma imagen de resonancia magnética; el tendón central del músculo pterigoideo lateral puede aparecer como una extensión del disco; dando una imagen de un disco distorsionado y desplazado. En secciones anatómicas, se vio una bolsa de una hernia media en el espacio de la articulación inferior, como un indicador constante del componente medio del desplazamiento del disco; sin embargo, esto no fue evidente en las imágenes sagitales y coronales cargadas con T1. La remodelación fibrocartilaginosa de la superficie articular proyectada hacia una perforación del disco presentó la misma imagen que la del tejido correspondiente a un disco normal. Debido a que los discos son a menudo adelgazados en el polo lateral, es difícil determinar si el tejido del disco está presente entre las superficies articulares cuando las IRM están en su resolución presente. Los espacios óseos subcorticales pueden ser mal interpretados como áreas de necrosis avascular y osteocondritis desecante. Se recomienda que una secuencia de imágenes de la articulación temporomandibular incluya una imagen del cóndilo medio, lo mismo que una imagen lateral, central y sagital media; sin embargo, la imagen sagital lateral es la mas difícil de interpretar.

Zusammenfassung

Korrelationen zwischen anatomischen und MRI-Schnitten von Kiefergelenken menschlicher Leichen in der Koronal- und Sagittalebene

Anhand von Leichengelenken wurden sequentielle sagittale und koronale T1-gewichtete MR-Bilder und anatomische Details miteinander korreliert. Magnetresonanztomographie (MRI) erwies sich als geeignetes Verfahren für die genaue Abbildung von Weichgeweben in normalen und veränderten Gelenken. Im Gegensatz zu vorangehender Literatur war auf diesen MR-Bildern der Übergang vom Diskus zum retrodiskalen Gewebe gut zu erkennen und es gab keine falsch positiven Diagnosen für anteriore Diskusverlagerungen. Die äussere knöcherne Begrenzung war vor allem in koronalen Schnitten gut zu erkennen. Schwierigkeiten gab es, wenn verschiedene benachbarte Gewebe dasselbe MR-Bild ergaben. Das zentrale Band des M. pterygoideus lateralis kann als Verlängerung des Diskus erscheinen oder als verdrehter oder verlagerter Diskus. Bei anatomischen Schnitten war bei Diskusverlagerung jeweils medial ein Hernienbeutel zu sehen, welcher in den sagittalen und koronalen T1-gewichteten Bildern nicht zu sehen war. Fibrokartilaginöses Remodeling der Gelenksoberfläche, welche in eine Diskusperforation hereinragte, ergab das gleiche Bild wie normales Diskusgewebe. Da der Diskus am lateralen Pol oft verdünnt ist, kann es bei der momentanen Auflösung der MR-Bilder schwierig zu beurteilen sein, ob Diskusgewebe zwischen den Gelenksflächen vorliegt. Subkortikale Knochenräume können als Regionen avaskulärer Nekrose und Osteochondritis dissecans fehlinterpretiert werden. Es wird empfohlen, dass bei der Darstellung des Kiefergelenks mit MRI ein koronales Bild in der Mitte des Kondylus, sowie je ein sagittales laterales, zentrales und mediales Bild des Kondylus angefertigt werden sollen, wobei das laterale am schwierigsten zu interpretieren ist.