Dynamic Weight-bearing Magnetic Resonance in the Clinical Diagnosis of Internal Temporomandibular Joint Disorders

Silvana Giannini, MD[1] Giorgio Chiogna, MD[2] Rosario Francesco Balzano, MD[3] Giuseppe Guglielmi, MD[3]

[1] Department of Radiology, Casa di Cura Villa Stuart Sports Clinic, Università degli Studi di Roma "Foro Italico," Rome, Italy
[2] Department of Surgical and Dental Sciences, Fondazione Don Carlo Gnocchi, Rome, Italy
[3] Department of Clinical and Experimental Medicine, University School of Medicine, Foggia, Italy

Address for correspondence Silvana Giannini, MD, Department of Radiology, Casa di Cura Villa Stuart Sports Clinic, 00135 Rome, Italy (e-mail: silvana.giannini@tin.it).

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Abstract

Temporomandibular joint (TMJ) disorders can be painful and cause functional limitations and bone changes. Deeper clinical knowledge of the pathologies related to the TMJ has always been hindered by the difficult identification of the causes that limit its movement. Weight-bearing magnetic resonance imaging (WBMRI) can reproduce the articular movement in orthostasis and allows the evaluation of joint movement. WBMRI, compared with other procedures such as double-type condylography and real-time dynamic ultrasound, helps to better identify tissue characteristics of the articular glenoid-condylar surfaces, articular space, disk position on both the open and closed mouth, and the locoregional musculotendinous area. WBMRI also identifies the true position of the articular disk in orthostasis, emphasizing the different joint positions compared with the study carried out in a clinostatic (supine) position.

Keywords

- temporomandibular joint
- weight-bearing MRI
- functional weight-bearing examination

The evaluation and comprehension of temporomandibular joint (TMJ) movements and its activation are important to determine the causes of motor incoordination and joint lock disorders that are at the basis of the discomfort, complexity, and worsening of symptoms that patients experience.[1–3] Among the diagnostic imaging methods able to evaluate the complex functional unity of the TMJ, high-field magnetic resonance imaging (MRI) scanners (1.5 or 3 T) are certainly the only ones able to define location, extension, and causes of the disease. The panoramic view and high sensitivity in the identification of tissue characteristics make MRI the best method to identify TMJ diseases.[4–6] TMJ is used in every movement of the mouth and modification of the dental lock, such as in chewing, talking, and singing. All these activities are generally carried out in both standing and seated positions.[7,8] These considerations should be taken into account for the evaluation of changes in the TMJ functional unit and locoregional muscle area. A TMJ examination should be performed under functional load, as also reported in the recent literature.[9–12]

In our opinion, great modifications in the muscle and joint area occur when passing from the supine to the orthostatic position or under functional load. Few imaging techniques can currently study TMJ movement through a dynamic evaluation to register the articular damage. Among them, it is worth mentioning double-type condylography (pertaining to the gnatologist), real-time static and dynamic ultrasound, clinostatic (supine) MRI with a pseudo-dynamic study,[5,6] and orthostatic MRI in a functional load position. In dentistry it is important to use the correct investigation to obtain a quantitative and qualitative assessment of the movements and functional capacity of the craniomandibular system. Double-type condylography is a specific investigation that shows the kinematic aspects of the jaw; it works by recording

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and analyzing mandibular movements along the three axes, and it observes and analyzes the position of both condyles and their relationship with the jaw. Condylography also studies the activity of masticatory muscles when the jaw is moving (such as while chewing, grinding the teeth, etc.).[1] Gnathologists also use electromyography to study the masticatory muscles, according to the Dental Instrumental Analysis guidelines.[13]

Weight-bearing static and dynamic ultrasound is a functional examination of TMJ that has been used since 1992 when Stefanoff and colleagues evaluated condylar shifting movement when opening the mouth. Its usefulness has been validated in the international literature for its capability in detecting joint range of motion, the relation of the condyle-disk complex, and the identification of structural changes in different disorders.[14–16] The knowledge of joint dynamics applied to ultrasound functional studies in orthostasis showed good correlation with MRI studies in a supine position[16] and with the joint pseudo-dynamic MRI.[5] The use of WBMRI for the evaluation of TMJ movement has not yet found official validation because it is considered an innovative technique, but it can still provide useful clinical information compared with other functional dynamic techniques, such as condylography and dynamic ultrasound. The clinical expectations of WBMRI are also supported by recent studies on the lumbar spine and other disorders that appear differently on clinostatic investigations.[9,10] Patients with temporomandibular joint disorder (TMD) can be studied on a low-field MRI open scanner in a seated position.[17] In this condition it can reproduce an environment that resembles everyday life and unveil changes in the TMJ unit that may not be evident with supine studies.

TMJ Anatomy

The adult TMJ is a bilateral ginglymoarthrodial joint that articulates the skull to the lower jaw. Several components form the TMJ. There are the bony parts (the mandibular condyle that articulates with the articular eminence and the mandibular fossa of the temporal bone) separated by an articular disk, which is a round or biconcave shaped fibrous tissue and divides the articular space into a superior and inferior compartment. Other important components are the joint capsule, the synovial membrane, and some ligaments.[18–21] In the back is highly vascularized tissue critical for the functional balance of the TMJ, called the bilaminar area[22,23] (►**Fig. 1**).

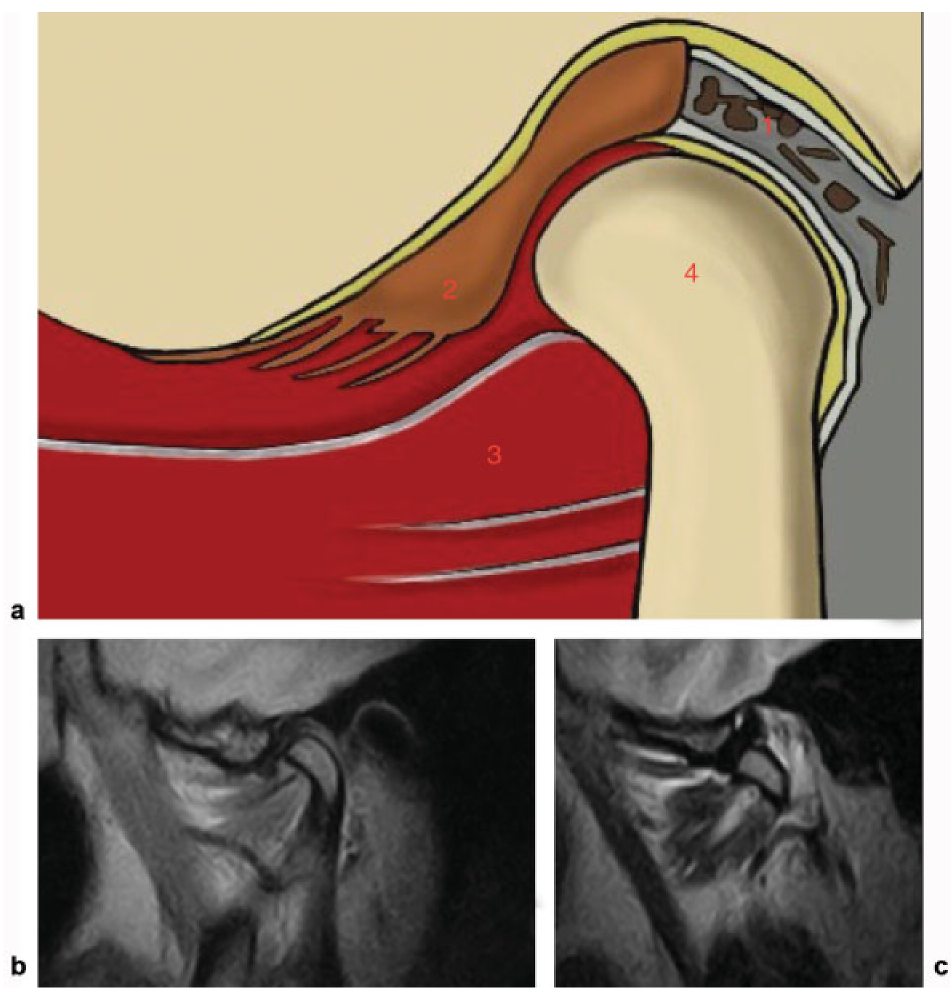

Fig. 1 (**a**) Schematic dawning of temporomandibular joint: 1, bilaminar zone; 2, disk; 3, caput superior lateral pterygoid muscle; 4, mandibular condyle. (**b**) Sagittal plane (mouth closed), (**c**) Sagittal plane (mouth open).

On the frontal plane, the disk is connected to the mesial and lateral condylar poles by two ligaments. During condylar "torsions," there could be a "partial lock" on the *y*-axis. On the sagittal plane, the joint capsule shows a thickening connected to the zygomatic bone, creating a vertical and horizontal connection. Such an anatomical condition allows a so-called carriage roto-translation movement of the condyle-disk unit, so the jaw moves shortly anteroposteriorly, and consequently the mouth opens ~ 5 cm (2 inches) at the interincisal level. The translation movement is enabled by the superior part of the articular space and the rotation movements by the inferior one. In a healthy TMJ, the articular cavity is filled with a small amount of synovial fluid; the presence of higher quantities suggests a functional overload.

Ligaments are other important components of the TMJ and contribute to its movements. They can be intracapsular, such as the medial and lateral ones, or extracapsular, such as the temporomandibular (lateral), sphenomandibular, and stylomandibular ligaments.[21] Some authors recently discussed another intracapsular ligament described for the first time by Terry Tanaka in 1984 and then named for him.[21] This ligament can be considered part of the medial ligament, and its function could be the connection of the articular disk to the mandibular fossa; its endings blend into the insertion fibers of the tensor tympani and the tensor veli tendons. During swallowing, the contraction of the medial pterygoid muscle, which stabilizes the dental arches, occurs along with the contraction of the tensor tympani and internal and external peristaphylin muscles.[22–24] It also produces a positive pressure inside the joint capsule that in turn reacts, expanding the synovial fluid within the joint. But if the isometric tension lasts too long, the resulting vector shifts backward and causes impairment in the posterior dental support that blocks in the front.[24] The two TMJs have their own muscles pertaining to the craniomandibular muscle system (CMS) that have the isometric function of steadiness. These muscles include these parts:

1. Caput superius of the lateral pterygoid muscle that arises from the sphenoid bone and reaches the medial half of the condyle, inserting the joint capsule and the disk
2. Caput superficialis of the masseter muscle that arises from the lower side of the zygomatic bone and reaches the external side of the jaw
3. Frontal part of the temporal muscle that arises from the anterior aspect of the temporal bone and blends into the superior pterygoid
4. Caput profundum of the masseter muscle that inserts on the condylar process, the capsule, and the disk

The synergic contraction of all cranium-mandibular muscles and the condyle and disk positions also play a postural role.[23,25] CMS does not have real antagonists but modulates the muscular tone according to the vectorial result exercised by mastication. The vectorial load on the TMJ depends on the muscular contraction, the inclination on the clenching plane, and the angle of the articular eminence.[26] Masticatory muscles are a kind of abductor muscles; instead, supra- and infrahyoid muscles act as a distractor antagonist on the mandible. All these muscles act synergistically in several functions (such as chewing and talking), and their action is also influenced by paravertebral muscles that work as stabilizers.[5,25] The suprahyoid muscles have a greater impact on the TMJ and are mostly involved in moving the jaw down; among them, the primary ones are as follows:[27]

1. The mylohyoid muscle, which is part of the mouth floor itself, along with the contralateral one, arises in the mylohyoid line of the jaw and inserts on the median raphe of the tongue; it enables the movement of the base of the tongue and swallowing, is involved in the lowering of the jaw when the hyoid bone is steady, while it brings forward the hyoid bone when the jaw is steady.
2. The stylohyoid muscle, innervated by the facial nerve, arises from the styloid process and inserts with the tendon of the digastric muscle on the anterior face of the hyoid bone; when the jaw is steady, it raises the hyoid bone forward. When the hyoid muscle is steady, it has the important function of lowering the jaw, together with the mylohyoid bone. It locks and steadies the hyoid bone.
3. The geniohyoid muscle acts as stabilizer of the hyoid muscle and allows the opening of the mouth; it originates in the spine of the jaw, inserts the hyoid muscle, and is innervated to the hypoglossal nerve; when the jaw is steady, it raises and moves the hyoid bone forward. It lowers the jaw when the hyoid bone is steady.
4. The digastric muscle allows the maximum opening of the mouth and lowers the jaw. It is composed of two muscle bellies: one arises from the digastric groove of the mastoid region of the temporal bone and the other one from the digastric fossa inside the jaw. They both converge on an intermediate tendon that in turn is connected to the hyoid bone by a fibrous ring. When the muscle contracts, if the jaw is steady, the hyoid bone is raised up and backward. On the contrary, if the hyoid bone is steady, the muscle lowers the jaw and allows the retrusion of the jaw when it is protruded.

In addition to the muscles just described are other muscles, such as the hyoglossus, styloglossus, genioglossus, and infrahyoid muscles, that act on the hyoid bone and in turn allow the suprahyoid muscles to lower the jaw. Lastly, the omohyoid and sternocleidomastoid muscles maintain the tension of the neck to help the joint movement of the jaw. Hence taking into consideration the complexity of the TMJ movement and the great number of muscles involved in its functions, it is very important to use the correct technique that can reproduce the same physiologic movement.

Incoordination Pathology

In TMDs, the articular disk dislocation and the breakdown of normal anatomical relations between all TMJ components are responsible for the subtle clinical symptoms we observe in suffering patients. In this complex situation we must remember that the TMJ is adjacent to other important anatomical structures that can also take part in the symptoms of TMD.[18,28]

Lesions in the condyle-disk complex or retrodiskal tissue can cause compression symptoms for the involvement of adjacent nervous structures. The glossopharyngeal nerve is usually involved at the oval foramen (can result in pain at the homolateral nasal wing); vagal nerve involvement can result in paresthesia at the base of the tongue on the same side; finally, headache can be triggered from pressure along the medial meningeal artery course that enters the skull through the foramen rotundum.[1,22–24] The possible multiple lesions of intrinsic or extrinsic TMJ structures can even cause a joint instability-related disease, the otognatic syndrome, that includes several signs and symptoms such as tension headache, facial pain, jaw locking, odontogenic dizziness and fullness, tinnitus, hyperacusis, sleep obstructive apnea, bruxism, cervical headache, and dysphagia. To study TMD, several techniques are commonly used.

Condylography

Condylography is a diagnostic instrument that can noninvasively evaluate mandibular kinematics and determine the hinge axis. Schematically, it consists of an upper face bow and a mandibular bow. The latter is clamped to a para-occlusal clutch that aids in the execution of mandibular movements either assisted or not. To track mandibular movements, some recording styli (or recording sensor in modern instruments) are introduced on the face bow branches. Condylography was proven to detect TMJ degeneration even in early stages and in imbalances of the masticatory system.[29–31]

Ultrasound

The application of ultrasound to the field of gnathology and maxillofacial surgery offers an excellent evaluation of internal disorders of the TMJ.[14] One of the first articles that described this technique stressed the possibility of identifying the position of the articular disk and capsule distension in some disorders,[32] especially in juvenile arthritis.[15] More specifically, ultrasound is a good screening technique to identify lesions of the capsule-ligament and disk-articular units. Furthermore, as stated by different authors, it can identify bone erosions, marginal osteophytes, and condylar deformities.[33]

Ultrasound is usually carried out in a comparative way, with the patient standing (only in some occasions seated), using high-frequency linear probes, considering the shallowness of the condyle-disk complex of the TMJ. The examination is performed with the mouth open and closed on both sagittal and axial planes. The dynamic study consists of a mediotrusion phase on sagittal and axial planes, a laterotrusion phase on sagittal and axial planes, and a protrusion phase on both planes as well.[16,34] The patient must look forward, without turning the head or bending the neck. During the different dynamic phases, the operator must make sure the patient does not change the head position, to ensure the correct repetition of the different phases of the ultrasound study, keeping in the echogram the same orientation of known bones' anatomical references (glenoid and lateral pole of the condyle-mandibular bone). The operator is free to choose the chronological order of the different phases, which however should be similar to the clinical functional phases performed on condylography or axiography examinations.

Magnetic Resonance Imaging

Conventional MRI is usually performed in a recumbent position, but orthostatic acquisitions may provide further information on disk and joint diseases.

Clinostatic MRI

High-field MRI (1.5–3.0 T) is considered the gold standard for the evaluation of TMDs. With its high imaging definition, MRI can overcome some common limits of other imaging techniques and thus play an important role. In fact, MRI can easily detect changes in the articular cartilage, such as subchondral alterations and cartilage delamination.[35] It also provides information on disk structure, location, and morphology, as well as capsule and ligaments.[3–6,28]

MRI shows capsule distension and registers the different positions of the disk in the dynamic study. For assessing the position of the condyle-disk complex, the examination must be performed with the mouth open and closed; if necessary, an oral bite is placed to check if the gnathologic treatment (for recapturing the articular disk and reducing the impingement) is correct. Iwasaki et al[5,6] reported the results obtained using 1.5- and 3.0-T scanners, carrying out a pseudo-dynamic study in the evaluation of the position of the articular disk, considering the site of the frontal and posterior border in patients with different degrees of damage in the TMJ.

The movement analysis along the axis and the trajectory defined by positional assessment points of the anterior and posterior border of the articular disk with opened and closed mouth help identify the regular excursion of the condyle-disk complex and report structural anomalies of joint components.[5,6] Furthermore, MRI plays an important role in the posttreatment follow-up.

Weight-bearing MRI

The correct evaluation of the structures composing the TMJ and working on it implies that their relationship should occur under correct circumstances, also including the action of the neck muscles.[23] Because every articular movement occurs under gravity, whose field lines can change the balance between neck, masticatory muscles, and the TMJ itself, and then the whole movement, patients with TMDs should be studied in a weight-bearing position with a dedicated scanner to reproduce the TMJ movement as in real physiologic conditions. In daily life, TMJ works under gravity while standing or seated. The coordinated movement between the two joints during chewing, talking, and all the other functional movements occurs in such conditions.

Weight-bearing MRI Technique

In our experience, WBMRI has a favorable diagnostic accuracy. Thanks to the open-shape magnet and the tilting table, patient can be studied in a physiologic position and then information can be precisely assured under the weight-bearing examination. WBMRI can better define, in a whole different and innovative way, several disorders whose appearance changes

Fig. 2 Weight-bearing magnetic resonance imaging scanner in the orthostatic position. The patient is seated on the table that is tilted vertically at 81 degrees with a dedicated coil. Both temporomandibular joints are studied simultaneously.

according to the supine or orthostatic position, for either their location or the involvement of different functional units.[9–12] Many pathologies and symptoms tend to worsen in the orthostatic position.

The TMJ study is performed with the patient seated on a table vertically tilted at 81 degrees, and a dedicated coil is used to study both joints simultaneously. The patient is told to keep the position with the head relaxed on the support and placed perpendicular to the table, respecting the Frankfurt plane (►Fig. 2). The patient is then placed carefully into position, strapped in with dedicated and comfortable bands and using side supporting pads that will prevent any rotation of the head. We also use another band to lock the chest into position. Thanks to a proper LCD monitor placed on the magnet unit, real-time acquisition is used to place the joint in the magnet isocenter to optimize image quality (►Fig. 3). In the end, an accurate and comfortable patient placement should be achieved to avoid any motion artifacts.

The MRI study protocol should be set up to arrive at the correct diagnosis in the shortest examination time; it includes two-dimensional fast spin-echo T2-weighted sequences, with a slice thickness of ~ 3 mm, as well as a three-dimensional isotropic gradient-echo T1-weighted sequence. The acquisitions would start using a transversal scan with the mouth closed and the teeth clenched to identify the correct sagittal scan planes that should be obtained perpendicularly to the major axis of the condyle and recreate the condyle-disk complex movement on the sagittal plane. Then a coronal plane is obtained according to the longitudinal axis of the condyle, to identify the exact position of the articular disk and the possible mesial dislocation (►Fig. 3).

Morphological MRI Assessment of the TMJ

In TMD, symptoms can be various and often misleading; they can apparently be referred to other extra-joint sites. Patients may experience aural fullness, headache, cervical instability, and diplopia. The functional balance of TMJ is strictly connected to the action of the cervical muscles. This assumption can explain those changes that occur when passing from the orthostatic to the supine position. Because TMJ works synergistically with the action of the cervical muscles and those muscles also influence the mandibular motion and in turn articular disorders, TMJ should not be evaluated in conditions where the cervical muscular action is not present. In its functional balance and movement, TMJ is influenced by head and neck position,[7,22,23,28,36] and these findings are also supported by WBMRI studies on both the cervical and lumbar spine. This effect is a consequence of how gravity influences

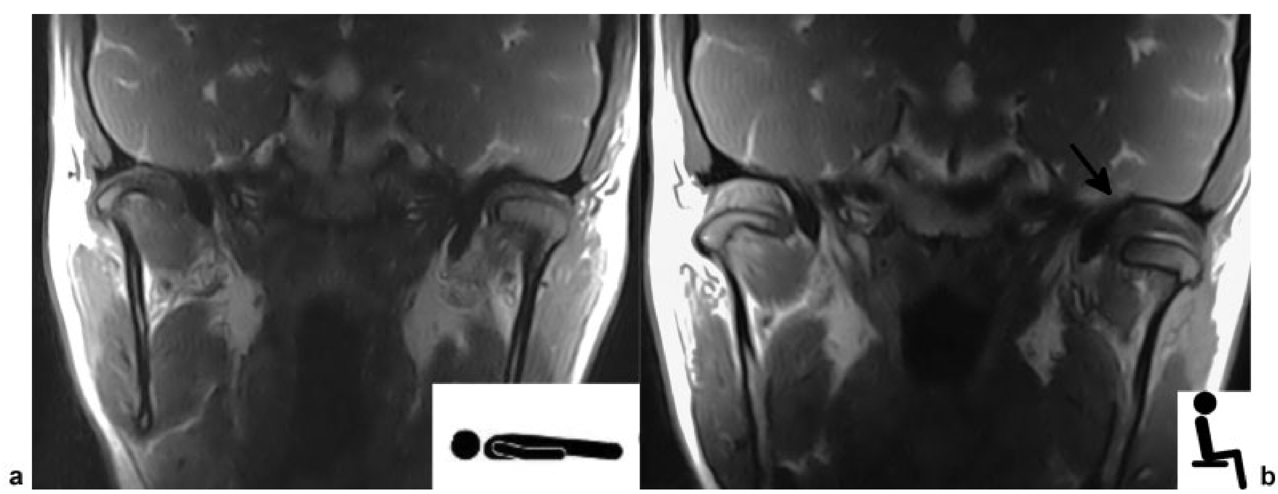

Fig. 3 MRI coronal acquisitions of the temporomandibular joint with the mouth closed. (**a**) The supine examination shows a good left articular congruence. (**b**) Weight-bearing scan of the same patient shows mesial displacement (arrow) of the articular disk.

and modifies the field lines of muscular movements.[10,11,17,23] In orthostatism, the muscular contraction causes variations in the articular disk position, retrodiskal pad, and supra- and infrahyoid muscles. As a ginglymoarthrodial joint, TMJ allows two combined movements: the first one (or first phase) is a hinge-like movement that starts when the mouth opens and plays on the arthrodial gliding motion. The second one (or sliding movement) lets the mouth open completely and consists of a lateral and protrusive motion.[37,38] To evaluate the internal TMD, we generally refer to the definitions of the American Academy of Orofacial Pain that classify TMD in two groups: muscle and joint disorders. Among all the classifications found, we favor the one by Piper that considers disk dislocation with reduction or without reduction.[39]

Piper's classification includes five categories:

1. Regular
2. Cartilage and ligament damage
3a. Partial disk subluxation, with reduction
3b. Partial disk subluxation, nonreducing
4a. Complete disk dislocation, with reduction
4b. Complete disk dislocation, without reduction
5a. No disk, bone to bone: adapting
5b. No disk, bone to bone: adapted

In our experience, when comparing WBMRI and supine MRI examination, some differences can be discerned concerning the evaluation of disk location and dimensions, capsule distention, the amount of synovial fluid, or muscular and ligamentous changes.[2,39,40] The articular disk usually appears as a structure regularly biconcave, made of a tissue with a variable signal according to the number of connective fibers. In the disk we can distinguish a thin anterior portion and an even thinner and homogeneous central part attached to the temporal muscle through a highly vascularized and innervated retrodiskal tissue (the bilaminar zone).[2,39–41] In the front, the caput superior of the pterygoid muscle inserts onto the joint disk.[24,37,38] In nonpathologic conditions and when teeth are in occlusion, on the sagittal plane the articular disk lies above the condyle and its back side adheres to the retrodiskal tissue at the level of the condylar apex (or 12 o'clock position). The sagittal plane is crucial for the evaluation of the anterior, posterior, mesial, or lateral dislocation of the posterior pad, relative to the mandibular condyle.[2,3,39,41] The coronal plane helps detect disk position, whether it was dislocated on the mesial line or laterally.[42] During the examination with the mouth open, the maximum opening possible should be attempted that is still comfortable for the patient, to avoid artifacts caused by movement.

Conclusion

WBMRI can easily detect lesions in the condyle-disk unit and correlate them to the clinical findings. WBMRI is certainly more ergonomic and corresponds to the everyday physiologic condition of the TMJ. It can find lesions in the bilaminar area and muscular injuries; it also can assess progressive and increasing fibrosis in ingrained pathologies (►**Fig. 4**). Moreover, the articular disk can appear displaced on WBMRI compared with a supine examination (►**Figs. 3** and **5**) because it can be appreciated on the coronal plane. The sagittal plane allows a better evaluation of the disk location in open mouth sequences and possible reduction in closed mouth ones (►**Fig. 6a**).

For patients with a joint lock caused by a severe internal disorder, the weight-bearing study can show a different disk position on open mouth acquisitions compared with the supine examination. In the supine position, the disk can be placed on the back but overmount the mandibular condyle at 12 or 1 o'clock. On the contrary, on the WBMRI, the disk can stay locked on the back, at 3 o'clock, inside the glenoid fossa and posterolaterally on the coronal plane (►**Fig. 7**). This evidence can be appreciated only on WBMRI, whereas on conventional supine examination it does not show such displacement, blocking the reduction of the condyle-disk complex, when the mouth is closed. The cause of such evidence in weight-bearing is the inefficiency of the craniomandibular system,[1,24] because in the presence of occlusion disorders, the action of the masseter and posterior temporal muscles brings the jaw forward, for vector forces are direct anteriorly. On the contrary, on clinostatic images, when the craniomandibular system works normally, the caput superior of the lateral pterygoid muscle, the temporal muscle, and the masseter profundum keep the disk on the tubercular eminence thanks to their antigravity action.

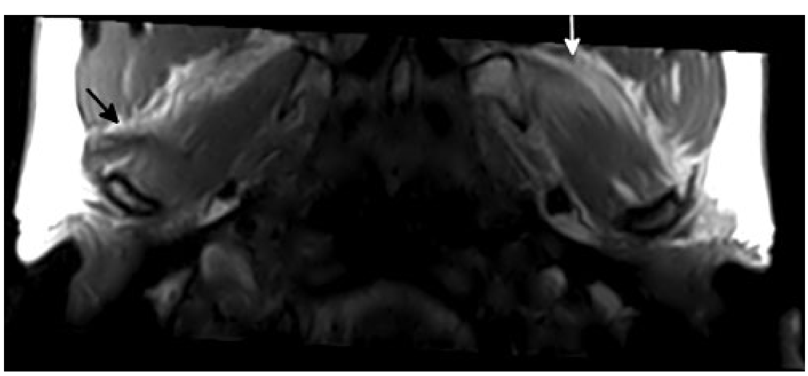

Fig. 4 Weight-bearing magnetic resonance imaging, transversal plane. Inhomogeneous signal intensity of the lateral pterygoid muscles due to fibroadipose involution, which is differently represented between the two sides (closer to the condyle on the right – black arrow – and more distant on the left – white arrow).

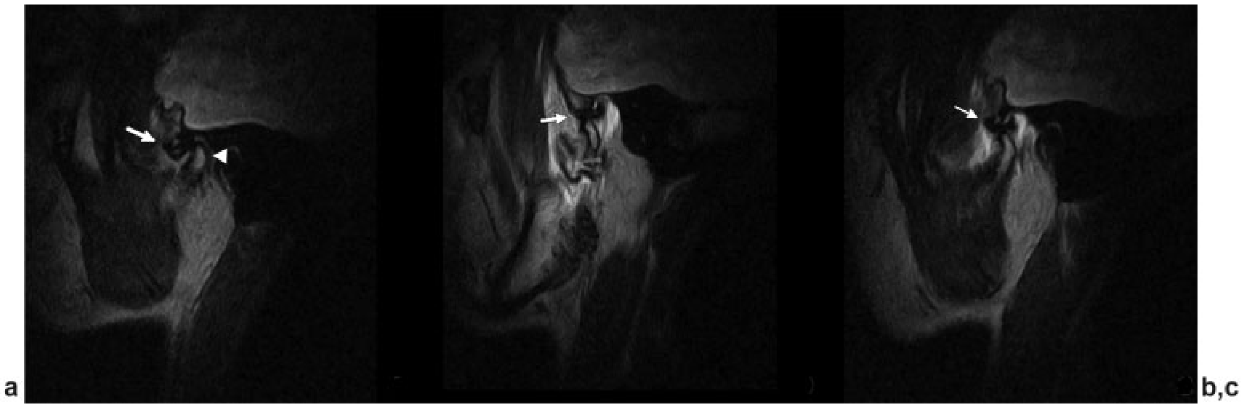

Fig. 5 Left temporomandibular joint examination. (**a**) Supine sagittal T2-weighted imaging sequence with the mouth closed shows anterior displacement of the articular disk (white arrow) while the mandibular condyle is located in the posterior fossa (arrowhead). (**b**) Weight-bearing magnetic resonance imaging sagittal T2-weighted imaging sequence with the open mouth shows the articular disk locked in the glenoid fossa (white arrow). (**c**) Supine sagittal T2-weighted imaging sequence with the mouth open shows anterior displacement of the articular disk that appears dysmorphic and inhomogeneous (white arrow).

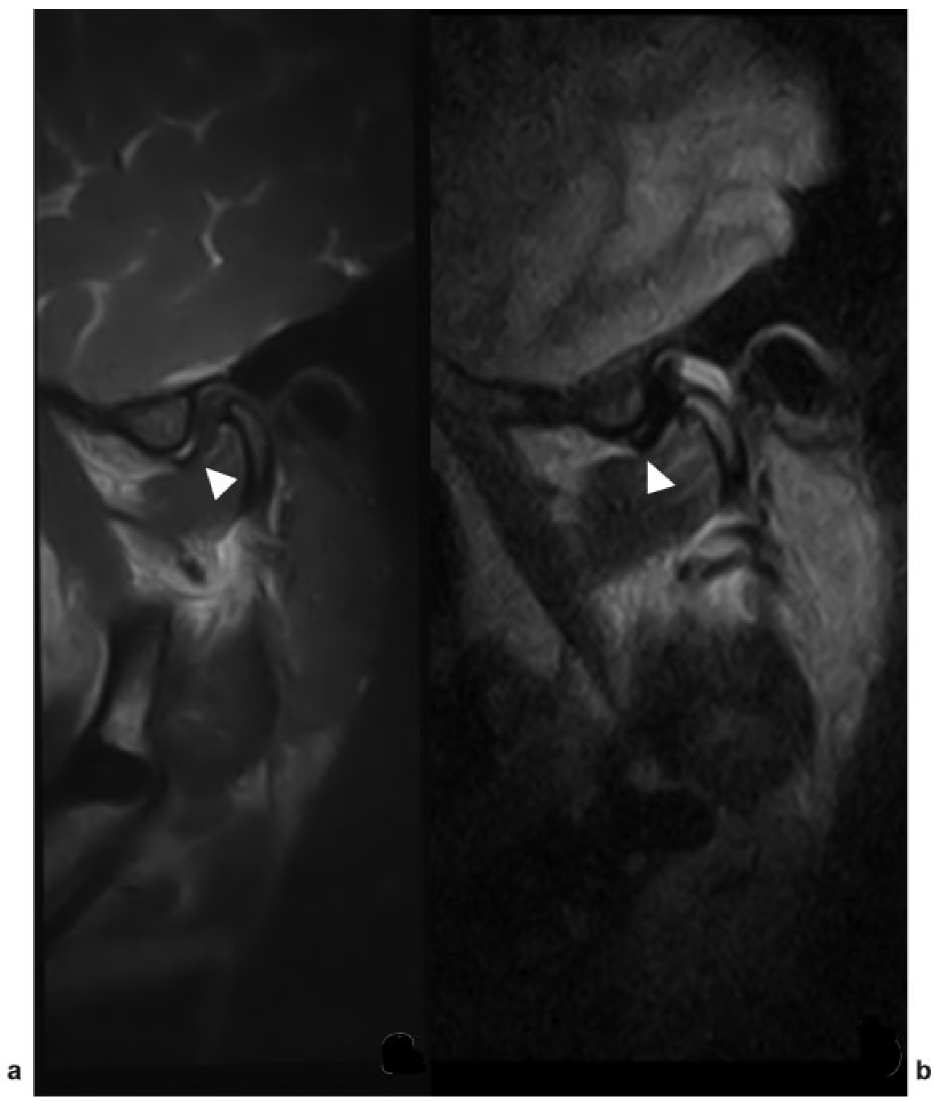

Fig. 6 Right temporomandibular joint examination on weight-bearing magnetic resonance imaging (the table is tilted 81 degrees). (**a**) Sagittal T2-weighted imaging with mouth closed. The articular disk appears displaced anteriorly and mesially (arrowhead). (**b**) Sagittal T2-weighted imaging with mouth open. The articular disk appears displaced anteriorly and mesially (arrowhead) with limitation to open the mouth; higher amount of intra-articular fluid is present.

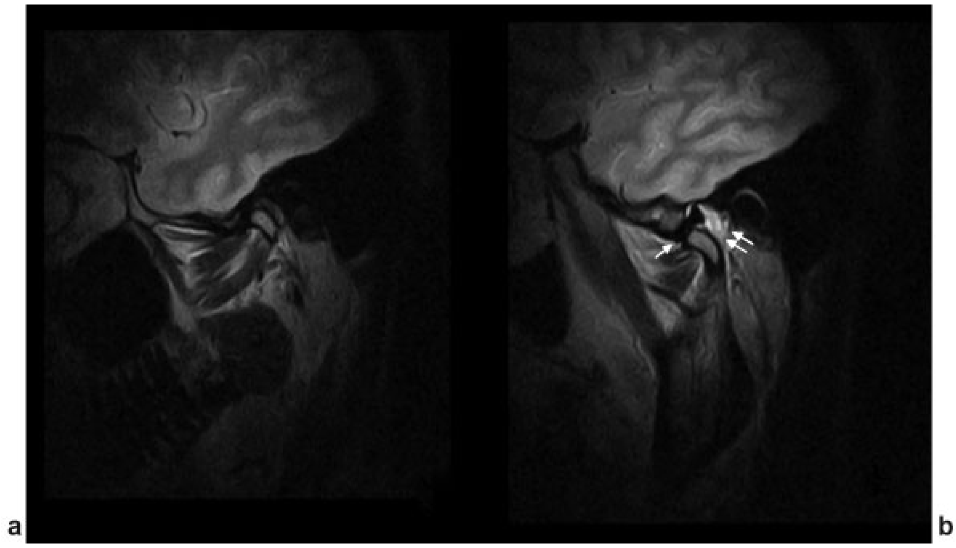

Fig. 7 Left temporomandibular joint examination on weight-bearing magnetic resonance Imaging (the table is tilted 81 degrees). (**a**) Sagittal T2-weighted imaging sequence with the mouth closed shows edema of the caput superior of the lateral pterygoid muscle; the mandibular condyle in located in the glenoid fossa. (**b**) Sagittal T2-weighted imaging sequence with the mouth open of the same patient shows the articular disk locked in the glenoid fossa (arrow); an intra-articular fluid collection is also present (double arrow).

When comparing images acquired with the mouth open and closed, WBMRI shows the real position of the disk-condyle complex and its possible reduction. The comparison with the supine MRI examination may show a different position of the disk, when resting or with the mouth open, thanks to the action of the muscle of the craniomandibular system. As reported in many gnatological studies,[1,7,24,25,28,29] their inefficiency causes greater functional damage of the disk-condyle complex.

Dynamic WBMRI can report the real location and position of the articular disk, its characteristics, the superior and inferior chambers, and the craniomandibular system included in the field of view of the sequence, evidence that changes according to the severity of the functional damage. The lower quality of images compared with the sequences acquired with high-field machinery is widely compensated by the possibility of picturing the real cause of the joint lock in weight-bearing functional conditions. Furthermore, WBMRI is comparable with electronic axiography carried out on seated patients to record joint movements and the ultrasound examination carried out on patients in weight-bearing. Finally, WBMRI can also be used to check if the correctional bite creates the right repositioning of the condyle-disk complex.

Conflict of Interest
None declared.

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