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REVIEW ARTICLE / ПРЕГЛЕД ЛИТЕРАТУРЕ

Imaging of the temporomandibular joint – contemporary clinical and radiological implications

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SUMMARY
The temporomandibular joint (TMJ) represents a biomechanically and morphologically complex structure, tightly connected with the development and growth of mandible and craniofacial complex.
The aim of this article is to comprehensively present contemporary diagnostic modalities and clinical implications for imaging of the TMJ.
Contemporary imaging modalities, if used properly and according to adequate clinical implications and criteria, are able to depict different pathological processes and play a crucial role in establishing the right diagnosis and monitoring therapeutic effect. The key to right diagnosis, however, still lies in good knowledge of the TMJ developmental and functional anatomy, as well as the TMJ dysfunction related to the jaws, surrounding muscles, teeth, and cranial base.
Keywords: temporomandibular joint; temporomandibular joint disorders; magnetic resonance imaging; craniomandibular disorders

INTRODUCTION

The temporomandibular joint (TMJ) represents a biomechanically and morphologically complex structure, tightly connected with the development and growth of mandible and craniofacial complex [1]. The superior part of the joint is formed by articular eminence (part of the temporal bone), while the inferior part is formed by the mandibular condyle [2, 3]. The understanding of growth and development of the TMJ is necessary for understanding complex pathophysiological fundaments of the TMJ dysfunction [4]. Furthermore, it is essential for comprehensive radiological evaluation of the joint and establishing a clinically valuable diagnosis based on the imaging.

One of the most common symptoms that induce the patient to seek the treatment is pain. Chronic pain is associated with some psychological disorders such as depression and somatization, which makes the evaluation and treatment even more complicated [5]. Chronic pain in the TMJ is considered to be the part of central sensitization syndrome (CSS), meaning that even subtle anatomical derangements can lead to the chronic regional pain [6]. There is a clinical instrument used as screening for CSS, considered to be a useful tool in the hands of an experienced clinician [7, 8, 9].

Imaging of the TMJ was initially performed using methods of conventional radiography, such as panoramic, transcranial radiography, and cephalometry [10, 11, 12]. Conventional radiography is of limited use since the anatomy the TMJ requires three-plane imaging [13]. These methods are limited, due to distortions, superimpositions of tissues, and poor tissue contrast. Disadvantages of these two-dimensional radiologic methods opened the door for three-dimensional imaging modalities in the TMJ evaluation. Computed tomography (CT) is an imaging method that provides useful information about osseous morphology of the joint, but high radiation dose and high cost make it unfavorable for the TMJ evaluation [14]. Cone-beam computed tomography (CBCT) is a recently developed imaging modality and has already become a method of choice for evaluation of the TMJ osseous morphology [15]. It enables obtaining submillimeter slices in all three planes, with shorter scanning time, lower radiation dose, and at lower cost than CT [16]. However, soft tissue imaging remains a problem for CBCT, making space for magnetic resonance imaging (MRI), which is the imaging modality of choice for assessment of disc and soft tissue pathology [17, 18].

Imaging of the TMJ requires a dedicated patient posturing. Adequate mandible positioning is essential both for soft tissue and osseous imaging. It is necessary to obtain images both in positions of the closed jaw and fully-opened jaw. Fully-opened jaw position is essential for evaluating condyle position and disc status. If the position of fully-opened jaw is suboptimally

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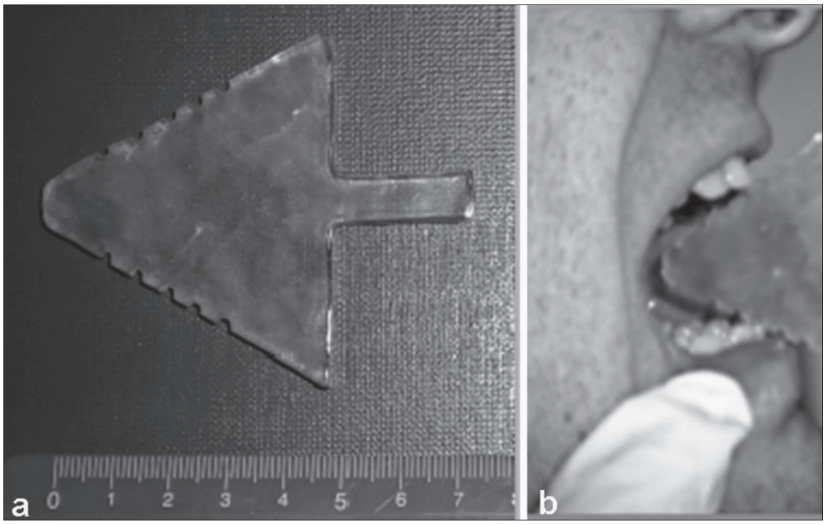

Figure 1. (a) Applicator – mouth opener; (b) the position of the applicator during the opening of the jaw in the middle position

Figure 2. The position of parasagittal images of temporomandibular joint that follow the axis of the mandibular body

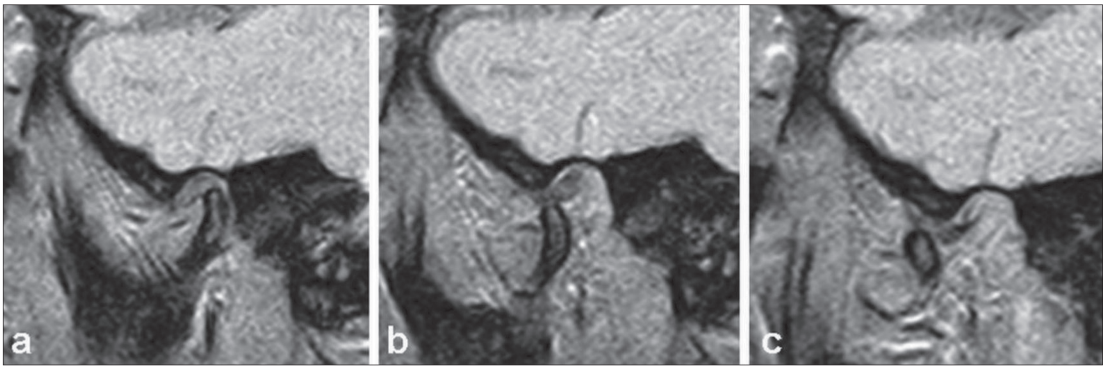

Figure 3. Parasagittal magnetic resonance images of the temporomandibular joint in the closed jaw (a), semiopened jaw (b), and fully opened jaw (c) positions with the use of the applicator; the translation of the mandibular condyle and the disc movements can be observed in the 12 o'clock position

accomplished, spatial relationships in the TMJ cannot be reliably examined and the proposed diagnosis is not accurate [1]. However, a number of patients are not able to remain adequately positioned during the time of scanning (especially with MRI), so prefabricated mouth openers (applicators) are commonly used to maintain the position of opened jaw (Figure 1). Also, sometimes, a scan with a splint placed between the teeth is necessary to evaluate the effect of the splint on the position of the condyle.

Clinical implications for the imaging of the TMJ are various, covering a broad span of possible etiologies, including developmental (hemifacial microsomia, hypoplasia, hyperplasia) [19], traumatic (fractures) [20], inflammatory (juvenile idiopathic arthritis, rheumatoid arthritis, pigmented villonodular synovitis) [13], degenerative [21, 22], neoplastic (benign and malignant tumors) [23], or vascular disorders [24, 25].

The aim of this article is to comprehensively present contemporary diagnostic modalities and clinical implications for the imaging of the TMJ.

IMAGING MODALITIES

Magnetic resonance imaging

MRI of the TMJ is established as an internationally recognized standard for the evaluation of position, shape, and mobility of the disc and condyle, as well as for the evaluation of soft tissues surrounding the joint [26]. The advantage of MRI is free choice of the plane in which the images are obtained. Classical planes used for the TMJ assessment are corrected sagittal oblique and coronal oblique, through the axis of the mandibular body (Figure 2). These planes are used in order to detect correct spatial relationship between the disc and the condyle, as well as between the condyle and the glenoid fossa. MRI offers a palette of different sequences enabling different tissue contrasts, necessary for detecting pathological processes of different structures. Conventional MRI protocol of the TMJ consists of T1-weighted (T1W), T2-weighted (T2W), and proton density-weighted (PDW) tomograms both in opened- and closed-jaw positions (Figure 3). T1W and PDW tomograms depict anatomical relationships and morphology of structures, while T2W tomograms depict the presence of abnormal fluid collections and bone marrow edema.

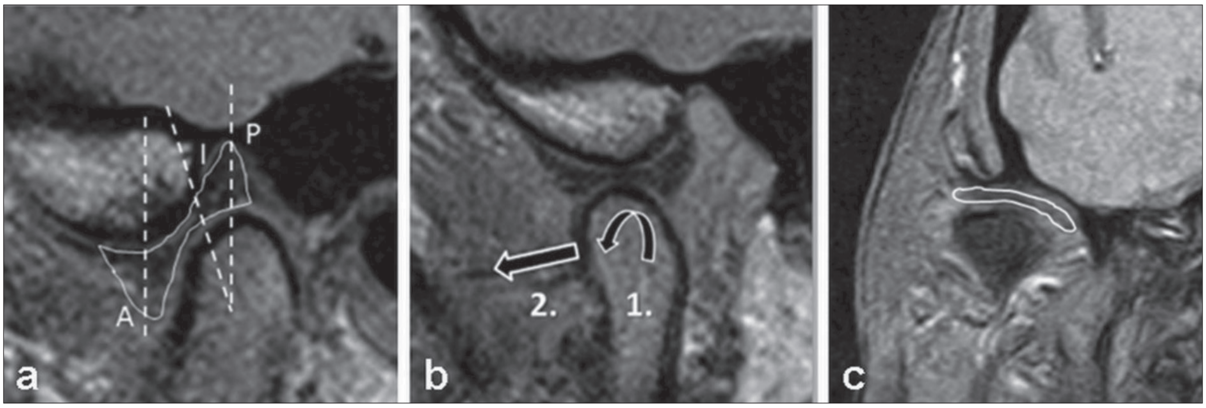

Figure 4. The disc at the 12 o'clock position in the closed jaw position in the sagittal view; (a) the anterior zone (A) is below the articular eminence, the intermediate zone (I) is between the condyle and the posterior slope of the articular eminence, and the posterior zone (P) is above the tip of the condyle; (b) in the opened jaw position, the condyle (1) performs rotation and then translation anteriorly (2); (c) in the coronal view, the disc is situated on the condylar head without medial or lateral dislocation

Postcontrast imaging is performed by injecting intravenous paramagnetic contrast agent (GdTPA) and obtaining T1W tomograms, preferably suppressing the fat signals. Postcontrast imaging is indicated when there is clinical suspicion of inflammatory or neoplastic disorder [3].

MRI represents a non-invasive diagnostic module that does not imply the use of ionizing radiation and therefore carries little or no risk for the patient's long-term well-being. However, the examination is time-consuming (over 30 minutes), not widely available, and expensive. Furthermore, there are absolute (cochlear implants, pacemakers, presence of metal foreign bodies, obesity) and relative (pregnancy, claustrophobia) contraindications for MRI that prevent a substantial group of patients from undergoing this examination. Finally, MRI is superior in evaluation of soft tissue pathology, while the evaluation of osseous structures and the presence of fracture is rather limited. However, clinical implications regarding the status of bone marrow (edema, infiltration) should be examined using MRI, since it is able to clearly and reliably depict these pathological processes [13, 20].

Cone-beam computed tomography

CBCT is a diagnostic modality mostly used for imaging in dentistry. Imaging protocol using CBCT includes images axially corrected perpendicular to and along the long axis of the mandibular condyle. These images are obtained as three-dimensional volume format and can be reformatted in the sagittal oblique and coronal oblique planes using postprocessing on digital workstations. Furthermore, curvilinear reconstructions along the curve of the mandible (panoramic reformation) and three-dimensional surface renderings in frontal and lateral views can be obtained. This enables the visualization of the maxillofacial complex and the evaluation of the effect of the TMJ disorders on the mandible and the teeth [15]. CBCT provides useful information about osseous morphology of the TMJ by obtaining submillimeter slices in all three planes. The scanning time is short and radiation dose is lower than that of helical CT, so CBCT has been established as the method of choice for the assessment of osseous structures and the TMJ morphology [16].

Computed tomography

CT has a small role in the imaging of the TMJ. Although it has a superior spatial resolution and short scanning time, it implies a high radiation dose and excessive cost, so it is not considered a standard imaging tool for evaluating the TMJ pathology [15, 16].

CBCT and CT both represent fast-performance diagnostic modules that obtain high-quality images of the TMJ. Nevertheless, both modalities imply ionizing radiation and therefore should be used carefully and with clear clinical implications and questions [16]. Finally, those imaging modalities are superior for examining osseous pathology and anatomical disorders, while the utility for evaluating soft tissue processes remains limited [27].

IMAGING EVALUATION OF NORMAL ANATOMY

The examination should start from the position of the condyle contour in relation to the glenoid fossa. Cortex of the condyle is thinner on the curvature (above the neck) both on posterior and anterior surfaces. In a normal condyle, the posterior height of the contour is inferiorly positioned compared to the anterior one and this distance grows with growing of the patient (until reaching the adult size). Equator of the condyle can be observed on coronal oblique views as the line that passes through medial and lateral heights of the condyle contour. Loss of bone tissue in the articular surfaces (above the equator) indicates a degenerative or inflammatory disorder, and can be key differential diagnosis between condylar hypoplasia and degenerative joint disease [10, 28].

Articular surfaces of the condyle and the glenoid fossa are not congruent. The disc is a fibrocartilaginous structure used for amortizing this incongruency. The normal shape of the disc is biconcave, with rounded surfaces, normally positioned between the anterior aspect of the condylar curvature and the posterior slope of the articular eminence. The irregularity of the disc shape, length, or position speaks for dysfunction of the TMJ as a structural unit. The normal posterior zone of the disc (the thickest part) is situated at the 12 o'clock position on the sagittal oblique view (with the anterior aspect on the left-hand side) (Figure 4). Thin intermediate zone is positioned above the maximum height of the condyle curvature. The anterior zone is positioned on the superior head of the lateral pterygoid muscle at the point of insertion in the pterygoid fovea. In the opened jaw position, a normal condyle translates forward to the point inferior to the eminence crest (1–3 mm anteriorly or posteriorly) but always remaining below the eminence, with enough space for the intermediate zone of the disc between the articular surfaces (Figure 4b) [10, 11]. CBCT is not able to depict the disc itself, contrary to MRI. On MRI, the disc is a low-to-intermediate signal intensity biconcave structure both on T1W and T2W, due to high amount of fiber tissue. A small, laminar amount of free joint fluid surrounding the disc is considered normal [11].

The articular surface cortex should be eggshell-thin and continuous (in children, the cortex is often invisible), presented as high-density line on CBCT/CT. On MRI, the articular cortex is hypointense and slightly thicker (compared to CBCT) due to the presence of low-signal fibrocartilaginous cap indistinguishable from bony cortex [27]. Thickening of the cortex is observed in degenerative joint diseases, while the absence of continuity is observed most commonly in fractures. Increased bone density on CBCT/CT and T1W and T2W low signal intensity indicates bone sclerosis, while T1W low and T2W high signal intensity indicates the presence of excess fluid in the form of bone marrow edema or cystic fluid collections. The presence of calcifications can reliably be detected only by using CBCT/CT, since MRI is not specific enough for the presence of calcium (at least conventional MRI) [28].

TRAUMATIC CHANGES

Neonatal fractures

Neonatal fractures occur seldomly, specifically with forceps delivery. The fracture is located in the condylar neck, with anterior dislocation of the fragment resulting in acute mandibular notch with a classical pair-of-scissors appearance. This dislocation of the condyle results in suboptimal pressure on the fibrocartilage of the eminence. The articular eminence consequently remains flat, due to the lack of stimulating pressure from the condyle. Mild to moderate mandibular asymmetry is always additionally present, since the normal growth of mandible is also compromised [29].

Bifid condyle

Bifid condyle represents a rare condition presented with partial division of the mandibular condyle. The etiology is unclear, possibly due to congenital, developmental, or traumatic reasons. The condyle shape is changed, ranging from a heart-shaped condyle, over vertical depression of the curvature, to the duplication of the condyle observed on sagittal oblique views [29].

Ankylosis

Ankylosis of the TMJ is most often a consequence of a trauma (hemarthrosis) and can be both bony or fibrous. Secondly, it can be due to inflammatory processes and previous surgery or major infection (osteomyelitis). Bony ankylosis presents with completely fused bony structures of the joint, resulting in severely compromised joint function and movement. Fibrous ankylosis is presented with low-density joint space and irregular articular surfaces [29, 30].

IMAGING OF INFLAMMATORY CONDITIONS

Rheumatoid arthritis

Rheumatoid arthritis (RA) is a chronic inflammatory disorder affecting various synovial joints, including the TMJ. Inflammation of the capsular synovia in the TMJ results in forming granulomatous pannus that further erodes articular fibrocartilage cap and underlying bone structures of the joint. The process is often unilateral or bilateral with one-side predominance. The beginning of the process is characterized by joint effusions and synovial proliferation, followed by osteopenia and resorption of the articular surface of the bones. Anterior and posterior aspects of the condyle flatten (sharpened-pencil appearance). MRI is a modality of choice in depicting changes connected to RA (Figure 5). Pannus is observed as an intermediate signal intensity structure displacing the temporal posterior attachment inferiorly and the condylar posterior attachment posteriorly. Condylar height is reduced, mandible rotates and

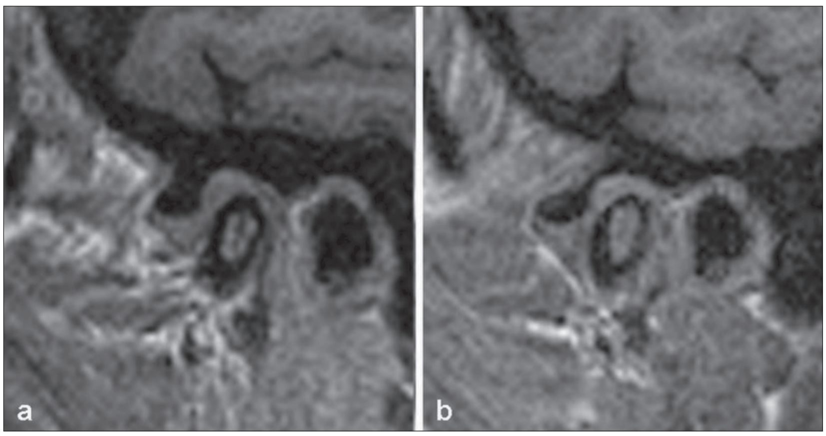

Figure 5. The contrast enhancement of the synovial thickening (a), due to synovial proliferation, is observed inside the articular fossa in a patient with rheumatoid arthritis (b)

the patient presents with anterior open bite. The advanced phase of the disease is represented with severely limited function and movements of the TMJ, as well as fibrous or bony ankylosis [31].

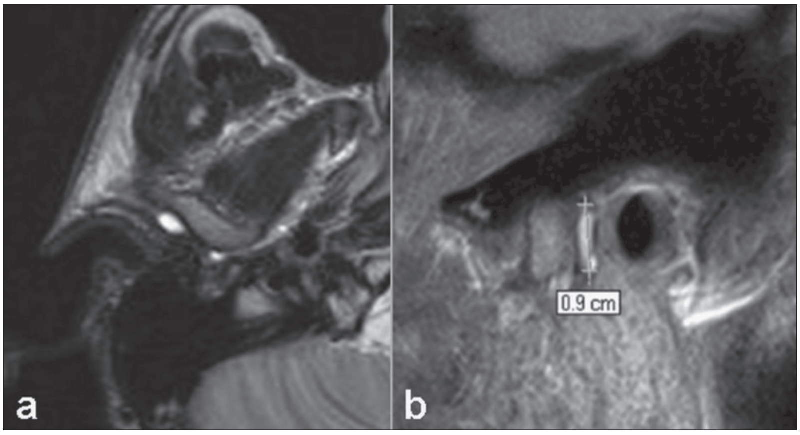

Figure 6. Incidental synovial cyst of the left temporomandibular joint observed in a 40-year-old female patient

Juvenile idiopathic arthritis

Juvenile idiopathic arthritis (JIA) is an autoimmune inflammatory disorder presenting primarily in large joints, during the childhood. Rarely it can also affect the TMJ. The imaging modality of choice is contrast-enhanced MRI. Inflammation usually affects the condyle, resulting in a flat and wide glenoid fossa. The condyle is displaced anteriorly and superiorly. When there is an active inflammatory process present, the contrast enhancement is present in joint compartments on MRI preceding radiographically (and tomographically) visible bone destruction [32].

Pigmented villonodular synovitis

Pigmented villonodular synovitis (PVNS) is an inflammatory, locally aggressive tumefactive disorder seldomly affecting the TMJ. The imaging modality of choice is contrast-enhanced MRI, since this condition has a radiologically aggressive appearance with destroying of the condyle and invasion of the middle cranial fossa. Low signal intensity on T1W and T2W sequences with peripheral no-signal intensity is observed in the lesion, representing pigmented portions of the inflammatory proliferating tissue. After contrast injection, some portions of the mass may enhance mildly [33].

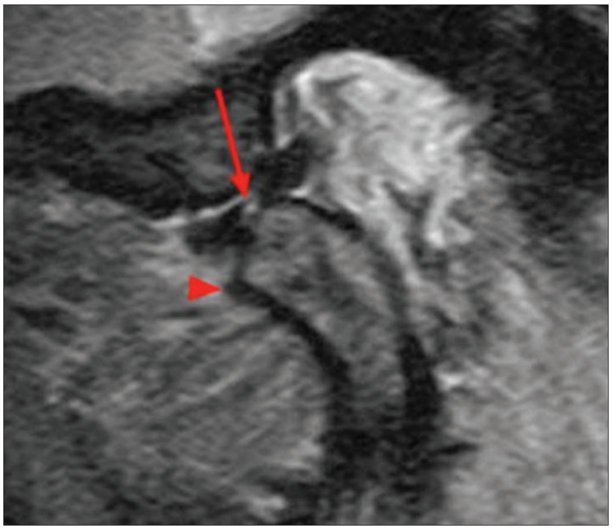

Figure 7. Perforation of the disc in the parasagittal view, proton density-weighted sequence, in the fully opened jaw position; the perforation of the intermediate zone (long arrow) is observed along with the condyle deformation and osteophytes in the anterior part (arrow tip)

Cysts

Cyst of the TMJ represents a very rare condition that can be observed in two forms: ganglion cyst and synovial cyst. Ganglion cyst is a pseudocyst, covered by fibrous tissue, while synovial cyst is a real cyst, with synovial cysts constituting the inner membrane (Figure 6). Most often it is found in female population, 20–40 years old. The etiology remains unclear, potentially traumatic or congenital [34].

IMAGING OF DEGENERATIVE DISORDERS

The TMJ is an anatomically and functionally complex joint, designed to withstand high multidirectional mechanical forces. At the point when those forces exceed the biomechanical threshold of the disc, the derangement of disc integrity and attachments occur [35]. Disc displacement from its normal anatomical position is a consequence of gradual translation of the posterior zone from its normal 12 o'clock position. Disc dislocation can occur in two planes: sagittal and transversal. Disc dislocations in the sagittal plane are termed anterior and posterior, while in the transversal one they can be lateral or medial [26]. Posterior dislocation is somewhat disputable, since it might also represent pseudodisc due to the thickening and fibrosis of the posterior attachment (retrodiscal fibrosis due to inappropriate loading of the bilaminar zone), having the same or even lower signal intensity as that of a disc [27, 33]. Rupture or perforation of the disc represents a subgroup of the posterior dislocation, according to Westesson et al. [36] (Figure 7). Anterior disc dislocation is present if the posterior zone of the disc can be observed on MRI anterior to the normal 12 o'clock position [37, 38]. Due to clinical implications, it is important to assess disc mobility during jaw movements. If the normal disc–condyle relationship is restored in the opened jaw position, this type is called disc dislocation with reduction (DDWR) (Figure 8); if not, it is called disc dislocation without reduction (DDWOR) (Figure 9) [39, 40]. DDWOR may result in a locked joint, with complete restriction of movement [39]. The imaging modality of choice in establishing diagnosis of disc dislocation is native MRI in closed and fully opened jaw positions. Osseous changes occur consequently to soft tissue changes [41]. The morphology of the condyles at the end-stage of a degenerative

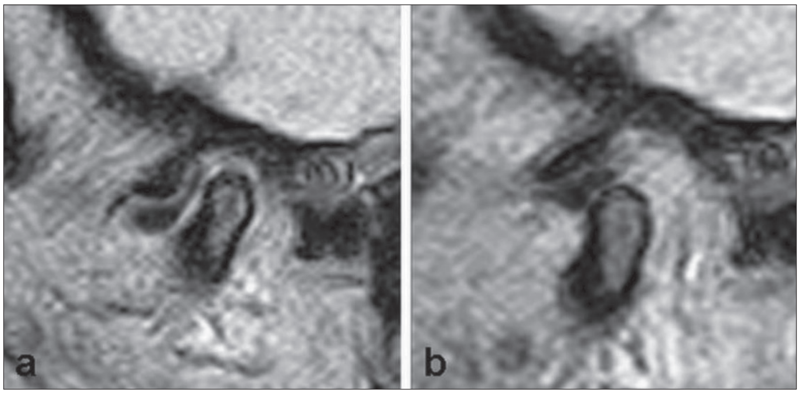

Figure 8. Disc dislocation with reduction in the closed (a) and fully opened jaw position (b); in the fully opened jaw position, the disc is dislocated anteriorly, and in the closed jaw position it returns to its normal position

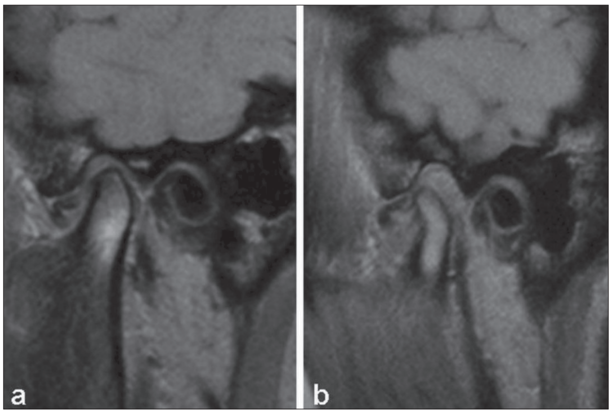

Figure 9. Disc dislocation without reduction in the closed (a) and fully opened jaw position (b); in the fully opened jaw position, the deformed disc is dislocated anteriorly and it does not return to its normal position during the closing of the jaw

process is different in children (this form of joint disorder is called progressive or idiopathic condylar resorption) and adults. However, the process of osseous destruction is similar. When biomechanical stress exceeds the threshold of fibrocartilage and articular surfaces, cortical thickening and subchondral sclerosis of the articular bone surfaces occur as a response to stress distribution. With further biomechanical stress, erosions of the cortical bone occur, destroying the articular surface and reducing its volume. The condylar height is reduced and the relationship with glenoid fossa is disturbed. Repair process in adults consists of forming marginal osteophytes as an attempt to increase the surface area for load distribution. The imaging modality of choice for depicting osseous changes is CBCT [15, 18].

According to the motion range of the condyle, the TMJ can be of normal mobility, hypermobile, or hypomobile (Figure 10). Hypermobility of the condyle is defined as the condyle motion of more than 120° anterior and superior to the eminence crest [42]. This condition occurs with the elongation of the posterior attachments, sphenomandibular and stylomandibular ligaments, in early cases of internal derangement of the TMJ or in Ehlers–Danlos syndrome [43]. If the condyle returns to the anatomical position with closed jaw, it is manifested as subluxation, but if it remains in the pathological place, it is considered dislocation (open lock). Condylar restriction represents the state where the condyle is located posteriorly and superiorly to the eminence crest. DDWR usually presents with normal motion range, while DDWOR presents with open lock in its acute phase. With entering the chronic phase, the normal range of motion could be restored. Hypomobility of the condyle usually appears as the consequence of disc adhesions secondary to trauma or disc dislocation, or synovitis, as well as in the end-stage phase of inflammatory conditions (such as RA, JIA, etc.) [31, 32].

Temporomandibular disorders (TMD) consist of several conditions related to pain and dysfunction in the TMJ and masticatory muscles. The two most common types of TMD are TMJ-associated disorders (disc dislocations and degenerative processes) and pain-related disorders (myalgia, TMD-associated headache, and arthralgia). This condition is associated with impaired general health, psychological disorders, and chronic pain, representing an important cause of reduced quality of life [44, 45, 46].

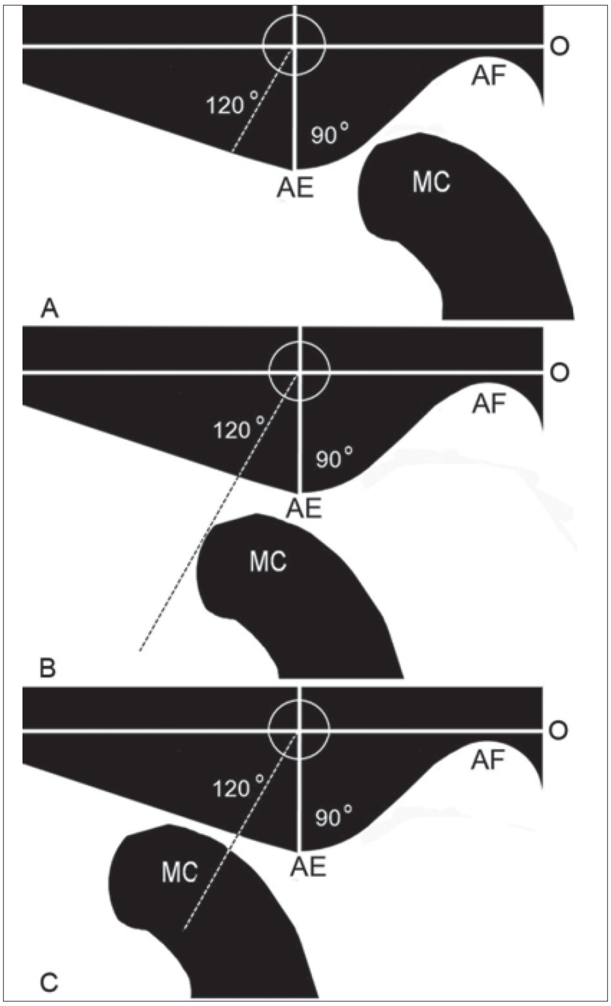

Figure 10. Scheme of hypomobility (a), normal mobility (b), and hypermobility (c) of the condyle

IMAGING OF BENIGN NEOPLASTIC PROCESSES

Osteochondroma

Osteochondroma is a benign exophytic bony lesion with a cartilaginous cap, arising from the side of the bone. It can arise either from the condyle or from the coronoid process [47]. On the imaging, it presents as a pedunculated mass attached to the condyle, often extending from the anterior surface of the condyle in the direction if the fibers of the lateral pterygoid muscle. When it grows large, it is able to displace the mandible contralaterally, resulting in contralateral posterior crossbite and ipsilateral posterior open bite [48].

Osteoma

Osteoma is a benign bone tumor characterized with slow growth and proliferation of compact or cancellous bone. Usually it originates from the non-articular surface of the condyle, which is covered with periosteum. On imaging, it appears as pedunculated, well-defined bone density mass with homogenous structure and normal bone pattern. It can also cause mandibular displacement if the dimensions are large enough [35].

IMAGING OF MALIGNANT NEOPLASTIC PROCESSES

Chondrosarcoma

Chondrosarcoma is a malignant cartilaginous tumor located centrally in the temporal bone or the condyle, parosteally or in soft tissues of the TMJ. A non-enhancing, lobulated, low-density mass with flocculent calcifications is observed in the condyle, temporal bone, or in the widened joint space. The condyle may also appear enlarged or remodeled. Periosteal reaction is variable. On MRI, the mass is of high signal intensity on T2W with hypointense foci representing calcifications. Postcontrast enhancement is heterogeneous [49].

Metastases

Metastases to bone structures of the TMJ are rare, reported as single case reports in the literature. Most commonly, the origin of metastases to the bones is breast, followed by lungs, prostate, colon, and kidneys [49, 50]. Symptoms at presentation include pain, swelling, and trismus. Although a rare condition, one must bear in mind the possibility of metastatic lesion in differential diagnosis [50].

CONCLUSION

The TMJ is anatomically, embryologically, and physiologically a complex structure, functionally tightly connected to the rest of the craniomandibular complex. Contemporary imaging modalities, if used properly and according to adequate clinical implications and criteria, are able to depict different pathological processes and play the crucial role in establishing the right diagnosis and monitoring therapeutic effect. The key to the right diagnosis, however, still lies in thorough familiarity with the TMJ developmental and functional anatomy, as well as with the TMJ dysfunction related to the jaws, teeth, and cranial base.

Conflict of interest: None declared.

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Снимање темпоромандибуларног зглоба – савремене клиничке и радиолошке импликације

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САЖЕТАК
Темпоромандибуларни зглоб представља биомеханички и морфолошки сложену структуру, која је уско повезана са растом и развојем мандибуларног и краниофацијалног комплекса.
Циљ овог рада је да се свеобухватно прикажу савремени дијагностички модалитети и клиничке импликације дијагностике сликом темпоромандибуларног зглоба.
Савремени начини снимања, ако се правилно користе и према адекватним клиничким импликацијама и критеријумима, могу да прикажу различите патолошке процесе и играју кључну улогу у успостављању адекватне дијагнозе и праћења терапијског ефекта, уз адекватан клинички протокол. Кључ за исправну дијагнозу, међутим, и даље лежи у добром познавању функционалне анатомије темпоромандибуларног зглоба, као и дисфункција темпоромандибуларног зглоба које су повезане са максилом, мандибулом, околним мишићима, зубима и базом кранијума.

Кључне речи: темпоромандибуларни зглоб; обољења темпоромандибуларног зглоба; магнетна резонанца; краниомандибуларне дисфункције