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Diagnostic value of dynamic magnetic resonance imaging of temporomandibular joint dysfunction

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HIGHLIGHTS

- Dynamic MRI sequences allow direct observation of the joint`s movements.
- Patients with known or suspected disc displacement benefit the most.
- Dynamic MRI is a sensible addition to solely static images.

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ABSTRACT

Background: To estimate the diagnostic value of dynamic magnetic resonance imaging (MRI) for the assessment of the temporomandibular joint (TMJ) compared to standard static MRI sequences in patients with TMJ dysfunction (TMD).
Methods and materials: This retrospective study included 71 patients with clinical diagnose of TMD. We acquired 5 static T1- and T2-weighted sequences in parasagittal and paracoronal views and one dynamic sequence (trueFISP) in parasagittal view for each TMJ. Image analysis included evaluation of morphology and function of intra-articular structures and rating of the dynamic images as more, equally, or less informative compared to static MRI sequences.
Results: Mean age was 35.0 ± 14.7 years and 50/71 (70.4%) were female. 127/142 (89.4%) TMJs were of diagnostic quality. 42/127 (33.1%) TMJs showed no disc displacement (DD), 56 (44.1%) had DD with disc reduction (DDwR), and 29 (22.8%) had DD without disc reduction (DDwoR). In 38/127 (29.9%) TMJs, dynamic images were rated “more informative”, in 84/127 (66.2%) “equally informative”, and in 5/127 (3.9%) “less informative” compared to solely static images. Overall, 27/71 (38.0%) patients benefited from additional dynamic sequences compared to solely static images. Dynamic images were “more informative” in TMJs with DDwR (23/56 [41.1%], $p < 0.001$) and in TMJs with DDwoR (13/29 [44.8%], $p = 0.007$), while it had no beneficial value for TMJ without DD. For evaluation of joint effusion, static T2-weighted images were rated better in 102/127 (80.3%) TMJs compared to dynamic images (<0.001).
Conclusion: Dynamic MRI sequences are beneficial for the evaluation of morphology and function of the TMJ compared to static sequences, especially in patients with temporomandibular disc displacement.

1. Introduction

Magnetic resonance imaging (MRI) of the temporomandibular joint (TMJ) is an established diagnostic imaging technique and provides detailed information of the anatomy [1–3]. It is routinely used in patients with suspected or known temporomandibular joint dysfunction

Abbreviations: TMJ, Temporomandibular joint; TMD, Temporomandibular joint dysfunction; ID, Internal Derangement; HASTE, Half-Fourier Acquisition Single-shot Turbo spin Echo; trueFISP, true fast imaging with steady state precession; FLASH, Fast Low-Angle Shot; DDwR, disc displacement with reduction; DDwoR, disc displacement without reduction.

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Table 1
Baseline characteristics.

Parameter	Subjects N = 71
Age, y	35.0 ± 14.7
Female	50 (70.4)
Clinical parameter	
Mouth opening, mm	33.0 ± 5.4
Male	36.0 ± 4.1
Female	31.8 ± 5.4
Indication for MRI	
Discopathy	30 (42.3)
Arthralgia	16 (22.5)
Arthrosis	7 (9.9)
Joint effusion	3 (4.2)
Eagle syndrome	1 (1.4)
Preoperative before osteotomy	11 (15.5)
Evaluation during TMD treatment	3 (4.2)

Note. Values are mean±standard deviation or n (%).
MRI = magnetic resonance imaging, TMD = temporomandibular joint dysfunction.

(TMD) [4–7]. Typical symptoms of TMD are pain, clicking, crepitation, and limitation or alteration of the mandible when opening the mouth. These symptoms are caused by deranged or degenerated articular surfaces, disc, and ligaments of the TMJ. The Internal Derangement (ID) Grades have been established by Wilkes for symptomatic TMD [8,9] and evolves from changes in form, position, and structure of the intra-articular components.

The TMJ is usually examined using static MRI sequences in the two maximum positions, which are closed mouth position (=physiologic rest position) and open mouth position. Thus, those images do not depict the complexity of TMJ movement including rotation and translation of the condyle and disc. In patients with TMD, interaction and coordination between the articular surfaces, disc, ligaments, and muscles are impaired. Dynamic high-resolution visualization of the TMJ is beneficial. Cine-MRI sequences lack of spatial resolution and are not able to visualize the disc clearly [11,12] or provide more information than static sequences [13,14]. The upcoming use of Half-Fourier Acquisition Single-shot Turbo spin Echo (HASTE) pulse sequences [15], true fast imaging with steady state precession (trueFISP) sequences [16,17] and Fast Low-Angle Shot (FLASH) sequences [18] allowed to renounce a jaw opener, which commonly results in better visualization of intraarticular structures during their natural movement [19–21].

The principle of jaw openers is to open and close the mouth in exactly defined steps and, in addition, to provide motion-free images [19]. However, this technique is vulnerable for motion artefacts and could depict movement differing from the natural jaw movement [22].

The aim of our study was to evaluate the diagnostic value of a novel dynamic MRI sequence in addition to standard static MRI sequences of the TMJ in patients with TMD.

2. Materials and methods

This retrospective, single-center study was approved by the institutional review board with a waiver for informed consent. In total, 71 individuals underwent an MRI exam of the TMJs between 08/2015 and 07/2017. All individuals were examined by a maxillofacial surgeon prior to the MRI and had symptomatic TMD. Patients with contraindications to MRI were excluded.

2.1. Image acquisition

All exams were performed on a 1.5 Tesla MRI scanner (Magnetom Aera, Siemens Healthineers, Forchheim, Germany). For static image sequences, a coil solely developed for TMJ imaging (CPC Multipurpose Coil, NORAS MRI products, Hoechberg, Germany) was used and provided a small field of view with imaging of both TMJs during one sequence. For dynamic image sequences, a standard head and neck coil (Head/Neck 20 MR Coil, Siemens Healthineers) was used. Acquisition of the static images required 28 min and included patient positioning and acquisition of two localizers and five sequences. Acquisition of the dynamic sequences required an additional 5 min and included changing of the coil and acquisition of one localizer and two sequences. For the dynamic sequences, patients were told to open and close their mouth in 14 steps. Each step was hold for 5 s from closed mouth (Step 1) to maximum mouth opening (Step 7) to closed mouth position (Step 14). The acquired images can be visualized in a movie sequence. A jaw opener was not required. The MRI protocol is listed in Table 2 and had a scan time of 33 min.

2.2. Image evaluation

Image evaluations were performed jointly by a radiologist (XX [anonymized]) with 30 years of experience in head and neck imaging and a dentist (XX [anonymized]). Static and dynamic image series were analyzed qualitatively with sagittal T1-weighted images (static) and trueFISP (dynamic) to evaluate the morphology of condyle, fossa and tuberculum (classified in: physiological, degenerated) and disc (classified in: biconcave, biplane/flattened, degenerated). For the classification of the disc position in static and dynamic image series, the most superior point of the condyle corresponds to 12 o′clock, the most anterior point to 9 o′clock. Positions of the posterior end of the disc between 11 and 12 o′clock were seen as physiological, between 9 and 11 o′clock as slightly anterior, below 9′ o clock as total anterior and above 12 o′clock as posterior disc displacement (Fig. 5). In static image series, the comparison between closed and open mouth position allowed a classification in anterior disc displacement with reduction (DDwR) or without reduction (DDwoR). In static T2-weighted images and the dynamic trueFISP images, possible signals of fluid were depicted and classified into no signals, signals of fluid and joint effusion. All TMJ were categorized into Internal Derangement Grades I-V [8,23].

For the dynamic MRI, a metric/quantitative analysis was made

Table 2
MRI protocol for imaging of the temporomandibular joint. Sequence 2 was performed twice (closed and open mouth position). Sequence 9 was performed twice (each side separately).

	Static sequences						Dynamic sequences	
No.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Plane	Localizer transversal	parasagittal	parasagittal	parasagittal	Localizer coronal	para-coronal	Localizer transversal	parasagittal
Sequence type	SE	SE	TSE	TSE	SE	SE	FISP	TrueFISP
TR/TE	200/13	597/15	3610/15	4020/90	230/13	593/15	7.0/2.95	4.09/2.05
weighting	T1	T1	T2	FS	T1	T1	T2/T1	T2/T1
matrix	256 × 256	256 × 256	384 × 384	256 × 256	256 × 256	256 × 256	384 × 384	192 × 192
FOV	128	128	128	128	128	128	260	223
Slice thickness, mm	5	3	3	3	5	3	8	8
Mouth position		closed and open	closed	closed		closed		14 steps
Time, min	0:55	4:52 (x2)	5:41	5:42	1:02	6:23	0:26	1:11 (x2)

Table 3
Assessment of static MRI sequences.

Parameter	TMJ N = 127
Morphology	
Fossa/Tuberculum	
physiological	112 (88.2)
degenerated	15 (11.8)
Condyle	
physiological	71 (55.9)
degenerated	56 (44.1)
Disc	
physiological/biconcave	9 (7.1)
Biplane/flattened	51 (40.1)
degenerated	67 (52.8)
Disc position; closed mouth	
Physiological (11–12 h)	22 (17.3)
Slightly anterior (9–11 h)	77 (60.6)
Anterior (<9 h)	28 (22.1)
Disc displacement	
No disc displacement (NDD)	42 (33.1)
Disc displacement with reduction (DDWR)	56 (44.1)
Disc displacement without reduction (DDWOR)	29 (22.8)
Signals of fluid	
No signal of fluid	25 (19.7)
Signals of fluid	97 (76.4)
Joint effusion	5 (3.9)

Note. Values are n (%).
TMJ = temporomandibular joint.

Table 4
Diagnostic value of dynamic MRI findings in comparison to static MRI findings for different diagnoses.

Diagnose	TMJ N = 127	Comparison of dynamic vs. static MRI sequences		
Disc Displacement		more information	equal information	less information
All	127 (100)	38 (29.9)	84 (66.2)	5 (3.9)
NDD	42 (33.1)	2 (4.8)	39 (92.8)	1 (2.4)
DDWR	56 (44.1)	23 (41.1)	31 (55.3)	2 (3.6)
DDWOR	29 (22.8)	13 (44.8)	14 (48.3)	2 (6.9)
Signal of fluid		0 (0.0)	25 (19.7)	102 (80.3)

Note. Values are n (%).

including the distance of the most cranial point of the fossa to the most caudal point of the tuberculum, the maximum distance of the movement of the posterior part of the disc and the posterior part of the condyle. It was also evaluated whether the condyle rotated or not.

To compare the diagnostic value of static and dynamic MRI, we evaluated each examination on the quality of the depiction of the morphology of the intra-articular structures and the movement of condyle and disc. A diagnosis concerning discopathies was made and we judged the dynamic images on the added value into “more informative” when dynamic images allowed a more precise diagnosis or led to a clear diagnosis, when static images did not allow a clear diagnosis. Dynamic images were rated as “less informative” when the depiction of morphology, position or movement of condyle or disc were of worse quality compared to static images or “equal informative” when no added value was detected in dynamic MRI compared to the static images. In a second step, we compared the diagnostic value of static and dynamic MRI concerning signals of fluid.

2.3. Statistical analysis

Statistical analysis was performed by BiAS 11.06 (epsilon-Verlag, Frankfurt/M., Germany). We determined possible correlations between age, disc and condyle movement, length of the condyle track and mouth opening with Pearson`s correlation coefficient. Using Wilcoxon-Mann-Whitney-Test and Spearman`s correlation coefficient, we analyzed morphology of disc, condyle and fossa, joint effusion, ID, disc displacement, disc position and rotation.

3. Results

The study included 71 patients with a mean age of 35.0 ± 14.7 years and 50 females (70.4%). Indications for MRI were discopathies (n = 30, 42.3%), arthralgia (n = 16, 22.5%), preoperative control before corrective osteotomy (n = 11, 15.5%), arthrosis (n = 7, 9.9%), re-evaluation during TMJ-therapy (n = 3, 4.2%), joint effusion (n = 3, 4.2%), and further diagnostics in a patient with unspecific facial pain and diagnosed Eagle-Syndrome (n = 1, 1.4%). In the clinical examination prior to the MRI scan, mean mouth opening was 33 ± 5.4 mm with a significant correlation ($r = 0.49$, $p < 0.001$) between mouth opening and gender (male 36.1 ± 4.1 mm; female 31.8 ± 5.4 mm) (Table 1).

3.1. Assessment of static MRI sequences

We examined 142 TMJs in 71 patients, of which we excluded 15 (10.6%) TMJs due to motion artefacts in the dynamic sequences. Therefore, we evaluated 127 TMJs (left n = 63; right n = 64), of which 85 (66.9%) had disc displacement and 42 (33.1%) had no disc displacement. 56/127 TMJs (44.1%) had DDwR and 29/127 (22.8%) had DDwoR. Fluid was observed in 97 (76.4%) and joint effusion in 5 (3.9%) of the 127 TMJs, while 25 (19.7%) showed no signals of fluid.

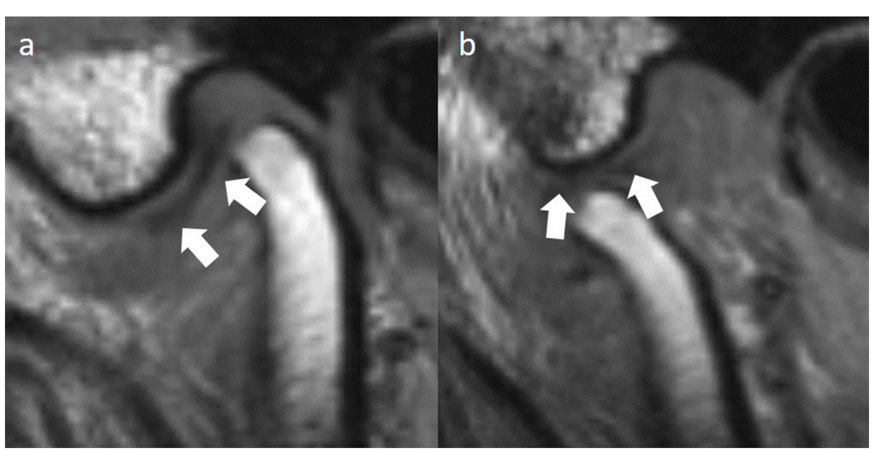

Fig. 1. T1-weighted static images of the left temporomandibular joint of a 52-year-old male patient with anterior displaced disc (arrows). Anteriorly (11`o clock) positioned disc with contact to the condyle in closed mouth position (a). At open mouth position the condyle is located on the disc (b). The translation of the condyle and disc is reduced.

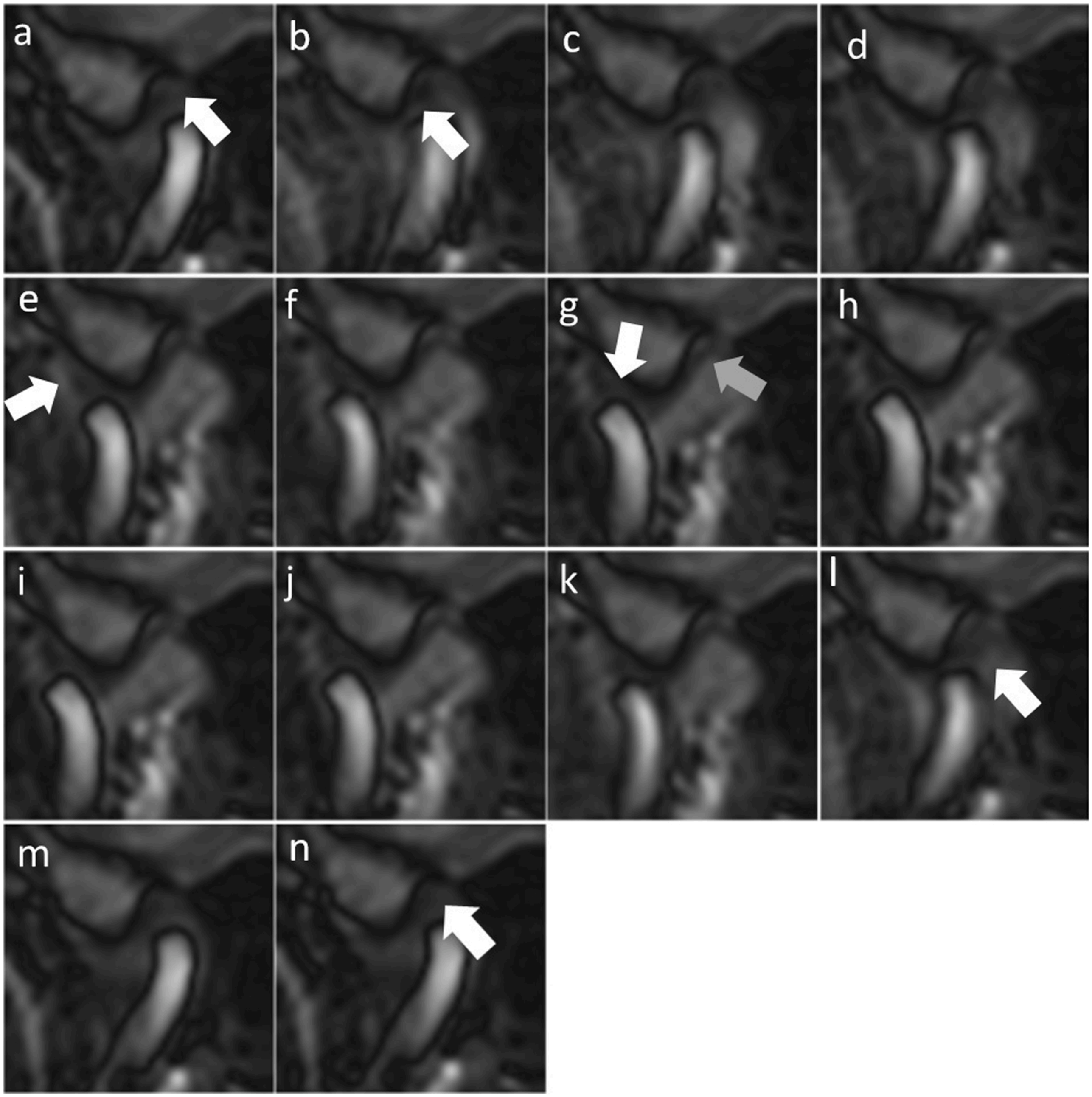

Fig. 2. Dynamic MRI sequences of the patient from Fig. 1. The dynamic sequence starts in closed mouth position and slightly anterior positioned disc (a, white arrow). During mouth opening (a-g) the condyle translates to its physiological position below the disc (b and e, white arrows) until complete open mouth position is reached with the condyle being anterior of the tuberculum (g). The posterior ligament (gray arrow in g) of the disc is attached to the temporal bone, stretched at maximum mouth opening and prevents the disc (white arrow in g) from gliding further anterior. During mouth closing the condyle translates below the disc (white arrows in j and l) back into the fossa (h-m) until closed mouth position is reached and the disc is slightly anterior positioned (n, white arrow).

In closed mouth position, 22 (17.3%) TMJs showed physiological disc position, while 77 (60.6%) TMJs had slightly anterior disc position and 28 (22.1%) TMJs had anterior displaced disc position. Of 127 TMJs, 112 (88.2%) TMJs showed normal morphology of fossa and tuberculum, while in 15 (11.8%) TMJs degenerated fossa/tuberculum morphology was observed. In 71 (55.9%) TMJs, condyle morphology was normal, in 56 (44.1%) TMJs condyles were degenerated. In 9 of 127 (7.1%) TMJs biconcave, in 51 (40.1%) biplane/flattened and in 67 (52.8%) degenerated disc morphology was observed.

Significant correlation was found between condyle morphology and mouth opening ($r = -0.21$, $p = 0.018$; physiological condyle: 33.9 mm, degenerated condyle: 31.6 mm) and between disc displacement and mouth opening ($r = -0.25$, $p = 0.004$; average mouth opening no disc displacement: 34.2 mm, DDwR: 33.6 mm and DDwoR: 29.9 mm). No correlation was found between mouth opening and disc morphology ($p = 0.28$), fossa-/tuberculum morphology ($p = 0.19$), and signal of fluid ($p = 0.096$).

Overall, 116 of 127 (91.3%) TMJs had an ID with 39 (30.7%) classified as Grade I, 28 (22.0%) as Grade II, 25 (19.7%) as Grade III, 22 (17.3%) as Grade IV, and 2 (1.6%) as Grade V. 11 of 127 (8.7%) showed no sign of Internal Derangement.

3.2. Assessment of dynamic MRI sequences

We found a significant positive correlation ($r = 0.69$, $p < 0.001$) between the mobility of condyle (average mobility of 9.8 mm) and disc

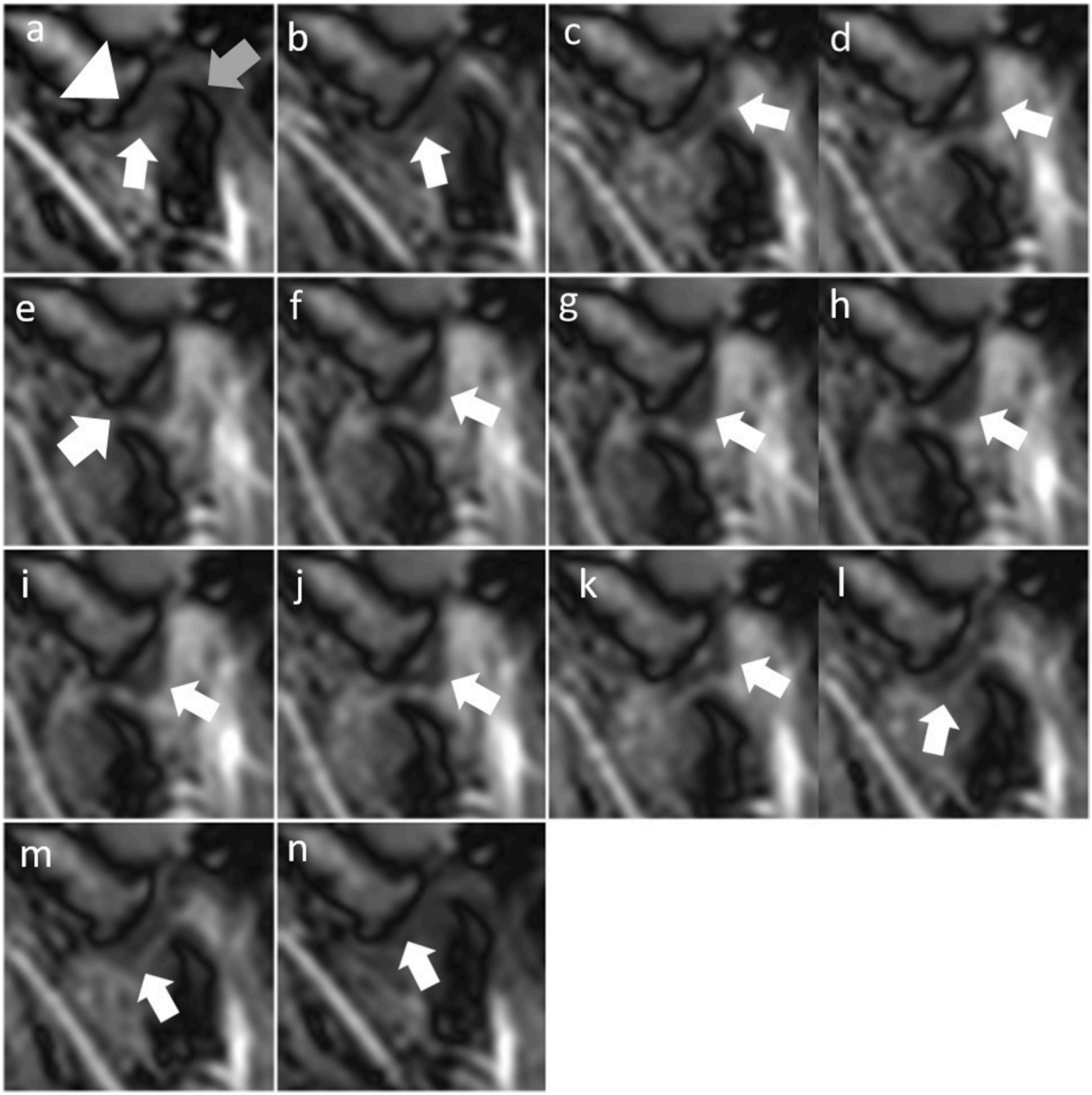

Fig. 3. Left temporomandibular joint of a 21-year-old male patient with disc displacement without reduction (disc adhesion). In closed mouth position (a), the disc (white arrow in a) is displaced anteriorly the degenerated condyle (gray arrow in a) between mandibular fossa and tuberculum mandibulae (arrow-head in a). During mouth opening (b-g), the condyle glides from posterior below the disc (arrow in b), deforms the disc (c), and glides anterior of the disc (arrow in e) until maximal mouth opening position is reached (h). Reversed movement can be observed during mouth closing (arrows in i to n). The disc does not move during mouth opening and closing and stucks on the temporal bone (disc adhesion).

(average mobility of 4.9 mm). The mobility of disc and condyle correlated well with mouth opening ($r = 0.39$, $p < 0.001$ and $r = 0.55$, $p < 0.001$, respectively) as meaning higher disc or condyle mobility allows bigger mouth opening. ID and disc mobility ($r = -0.43$, $p < 0.001$) as well as ID and condyle mobility ($r = -0.24$, $p = 0.006$) correlated with each other. With increasing ID Grade, less disc and condyle mobility was detected. No correlation was found between disc morphology and disc mobility ($p = 0.19$), condyle morphology and condyle mobility ($p = 0.41$), disc mobility and rotation ($p = 0.34$) or condyle mobility and rotation ($p = 0.92$).

In 108 (85.0%) of all 127 TMJ a rotation was detected, in 19 (15.0%) not. No correlations were found between rotation and mouth opening ($p = 0.28$), disc displacement ($p = 0.54$), disc morphology ($p = 0.77$), condyle morphology ($p = 0.42$), joint effusion ($p = 0.66$) or ID ($p = 0.28$) (Table 3).

3.3. Comparison between static and dynamic MRI findings

For disc displacement, in 38 of 127 (29.9%) TMJs, the dynamic sequences added value to the static images, in 84 (66.2%) TMJs value of dynamic was equal to static images and in 5 (3.9%) TMJs dynamic images had less information than static images. For 27 of 71 patients (38.0%) the dynamic sequences were of benefit. For the rest (44/71; 62.0%) the dynamic images were rated equal informative in both joints or equal informative in one joint and less informative in the other joint. There was no patient with unsuccessful static or dynamic examinations

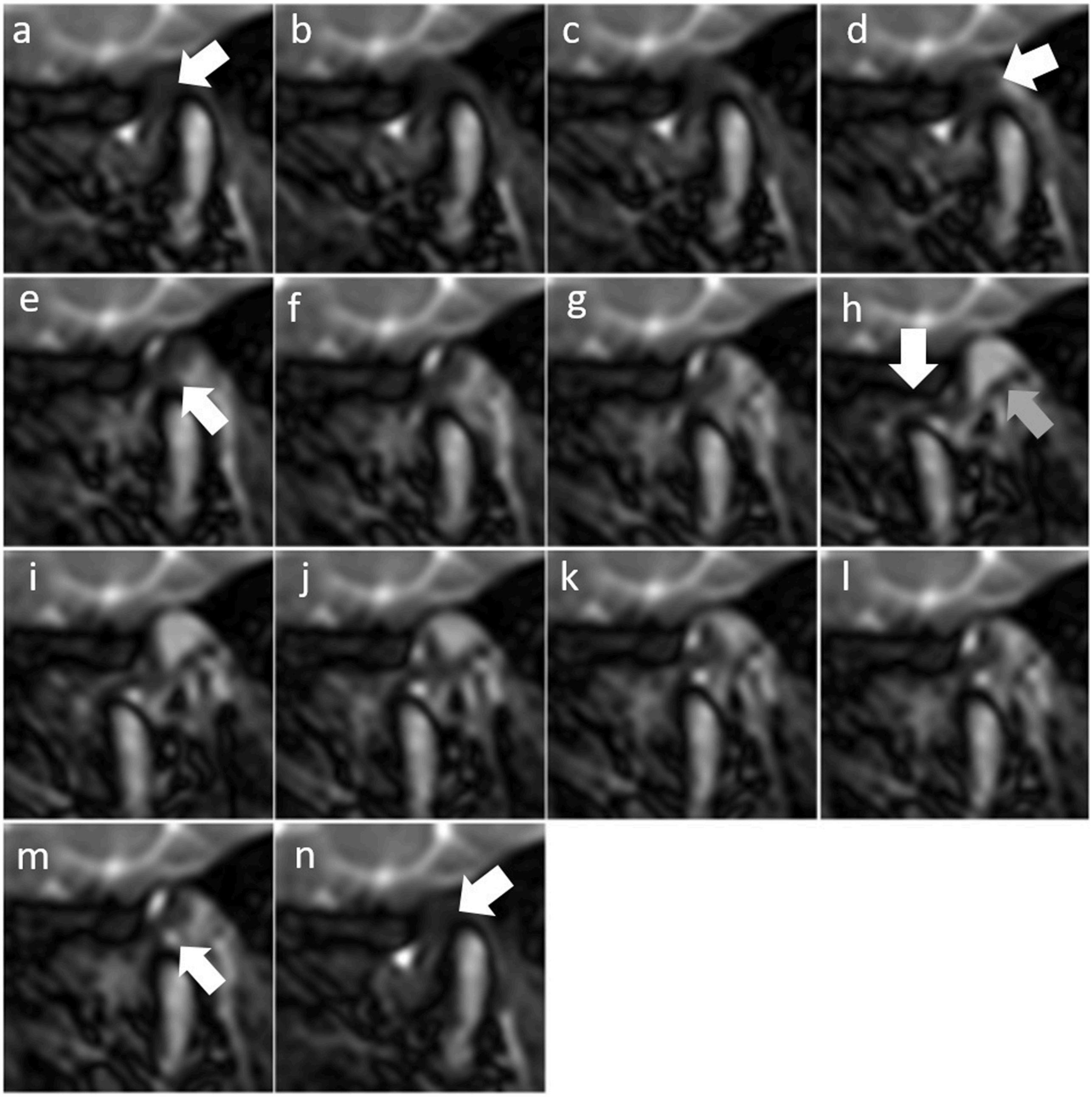

Fig. 4. Right temporomandibular joint of a 31-year-old female patient with disc displacement with reduction. In closed mouth position, the disc is displaced anterior the condyle (arrow in a). During the initial phase of mouth opening, rotation but no translation is observed (b and c). Subsequently, the condyle glides below the disc (arrow in d) until the condyle is repositioned on the disc (arrow in e). Condyle and disc translate (e-h) on the anterior until maximum mouth opening (white arrow in h). Mouth opening is naturally limited by the posterior ligament of the disc (gray arrow in h). Dynamic sequences provide detailed visualization of condyle and disc movements during mouth closing (i to m). In the last part of mouth closing, the condyle glides down from the disc (arrow in m to n).

in both joints. While dynamic images had added value to static images in 23 of 56 cases of TMJs with DDwR ($p < 0.001$) and 13 of 29 TMJs with DDwoR ($p = 0.007$), in cases with NDD ($p = 1.00$) there was no significant added value (Table 4).

Comparing static and dynamic images for depiction of signal of fluid, static images were rated as significantly better than dynamic images ($p < 0.001$) in 102 (80.3%) of 127 TMJs and equal depiction of signal of fluid in 25 (19.7%) TMJs. In no cases, dynamic images were better for depiction of signal of fluid (Table 4). Figs. 1 and 2 and Video 1 show the temporomandibular joint of a patient without DD. Fig. 3 and Video 2 show a case of DDwoR and Fig. 4 and Video 3 show an example of DDwR.

Supplementary material related to this article can be found online at doi:10.1016/j.jhazmat.2020.124016.

4. Discussion

In this retrospective study, we showed that adding dynamic MRI sequences to static MRI sequences is beneficial for the assessment of morphology and function of the TMJ in patients with TMD compared to solely static sequences.

So far, studies showed that the depiction of the disc's morphology and function was the weakness of dynamic sequences of the TMJ [11,15,16,24]. As the disc is in the focus of interest, it is essential to visualize it clearly [22,25]. By using trueFISP dynamic sequences, we were able to achieve high spatial resolution and an image quality comparable to

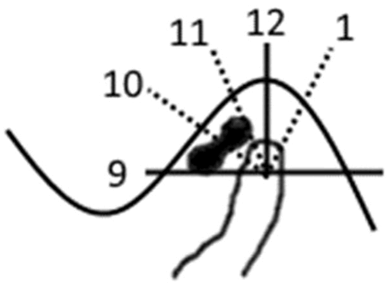

Fig. 5. Scheme of the physiologic anatomy in closed mouth position: The posterior border of the disc is located at 11'o clock. Positions of the posterior border of the disc between 11 and 12 o′clock were seen as physiological, while positions between 9 and 11 o′clock are defined as slightly anterior, below 9′ o clock as total anterior, and above 12 o′clock as posterior disc displacement.

static images in the majority of exams. However, it has to be mentioned, that in cases of less informative dynamic sequences, blurred disc was the main reason.

Several studies showed positive correlations between pain and disc displacement and that disc displacement was one of the main indications for a MRI of the TMJ [4–6,26,27]. Especially in cases of DDwR and DDwoR, we observed an added diagnostic value of dynamic images compared to static images. The further developed dynamic MRI provided compared to static images a better understanding of morphology, position and movement of intraarticular structures of the TMJ during their natural movement including rotation and translation. Thus, dynamic sequences provided a better and more detailed diagnosis of disc displacement and we saw a benefit for patients with disc adhesion, total or partial anterior disc displacement with reduction and total anterior displacement without reduction. Patients without disc displacement did not benefit from the additional dynamic sequences, but in most of these cases, the dynamic sequences were of equal value. For imaging of fluid in the TMJ, dynamic sequences were in general less informative than static images, due to the better imaging of fluids in T2-weighted and T2-weighted fat saturated static sequences. Thus, static sequences can not be replaced by solely dynamic sequences.

In the development of dynamic imaging of the TMJ, the jaw opener was a compromise to allow motion-free pseudo-dynamic images, but the depicted jaw movement differed from the natural mouth opening [22]. In our study, faster imaging without the help of a jaw opener allowed a direct observation of the natural movement and interaction of the intra-articular structures of the TMJ and, in cases of DDwR, allowed to determine the time point when the condyle glides onto the disc. However, we do not see the exact location where reduction takes place. In our opinion, we get a good approximation of the natural movement by letting the patient open and close the mouth in 14 steps, which leads to a better understanding of the complex movement of the TMJ compared to the interpretation of solely static images. The novel dynamic examination also allowed an examination time for dynamic sequences of only 5 min including coil change and positioning of the patient.

Beer et al. [24] compared cine MRI with static MRI and axiography and observed that the measurements of disc and condyle mobility by using cine MRI are comparable to axiography which is a reliable, but time-consuming non-invasive technique to detect movements of the mandible. Their average results for disc- and condyle mobility were similar to our results (disc mobility 6.2 mm and condyle mobility 11.4 mm in cine MRI).

The rotation of the condyle occurs in the caudal compartment of the joint in the initial phase of the mouth opening respectively in the last part of the closing [3,28]. This rotation can only be visualized in dynamic sequences and adds important information about the interaction of intra-articular structures and their grade of destruction. As we found no correlations between rotation and one of the examined parameters, we assume that the rotation takes place independently from the translation.

It is important to mention, that dynamic MRI sequences required high patients compliance. Due to motion artefacts, we had to exclude 11% of all TMJ from our study. Further, some patients had difficulty to open and close the mouth in 14 steps of approximately the same distance. Developments towards faster data acquisition such as real-time sequences [18] with simultaneously high quality images could eliminate these weaknesses.

There are several limitations of our study which need to be mentioned. Limitations of the examination technique itself were the need for a slowly and stepwise jaw movement and the poor visualization of fluids. Further, it was not possible to detect the jaw movement in both joints simultaneously. The study had a retrospective design and included only a small population with a wide range of symptoms and indications for MRI imaging of the TMJ. Further, we did not evaluate whether the additional information by the dynamic images led to a change in therapy.

5. Conclusion

Dynamic MRI of the temporomandibular joint can not replace static sequences, but is recommended as a sensible addition to the established static MRI examination in patients with known or suspected disc displacement in the TMJ, being worth the additional time that is needed for the dynamic MRI.

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CRediT authorship contribution statement

Vogl, Guenther, Scholtz: Data curation, Formal analysis, Investigation. **Vogl, Guenther, Weigl** : Methodology. **Vogl**: Project administration, Resources. **Vogl, Guenther**: Software. **Vogl**: Supervision. **Vogl, Guenther, Weigl** : Validation. **Guenther, Weigl** : Visualization. **Guenther, Vogl, Scholtz, Weigl** : Roles/Writing – original draft. **Scholtz**: Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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