Dentomaxillofacial Radiology (2022) 51, 20210148

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RESEARCH ARTICLE

Acute soft tissue injury to the temporomandibular joint and posttraumatic assessment after mandibular condyle fractures: a longitudinal prospective MRI study

[1]Özlem Akkemik, [2]Harald Kugel and [3]Roman Fischbach

[1]Yeni Yuzyil University, Istanbul, Turkey; [2]University Clinic for Radiology, University of Münster, Münster, Germany; [3]Department of Radiology, Asklepios Hospital Hamburg-Altona, Hamburg, Germany

Objective: Evaluation of acute soft tissue injury of the temporomandibular joint (TMJ) with type I–VI fractures immediately after trauma and investigation of the longitudinal evolution including response to conservative treatment using MRI.
Methods: The joints of 24 patients with 33 condylar fractures (15 unilateral, nine bilateral) were imaged on a 1 Tesla MR system within the first 24 h post-trauma. 12 of these patients with 16 condylar fractures (eight unilateral, four bilateral) were clinically re-evaluated using MRI after 3 months of closed treatment. The position, morphology, and signal intensities of the disc, capsule, retrodiscal tissue, and osseous structures were documented.
Results: In the acute phase, disc displacements (DDs) were diagnosed in 8 out of 33 joints with fracture, including posterior DDs in two joints and tears of the inferior retrodiscal lamina in 11 joints. The follow-up MRI in 12 patients revealed new DD in four joints on the fractured side (FS) including a posterior DD and an increased degree of displacement, and new DDs in two joints in the non-fractured side (NFS).
Conclusion: Preexisting and traumatic DD and soft tissue injuries are frequent findings in patients with condylar fracture. Independent of the degree of trauma, condylar fractures may determine the subsequent development of DD on both FS and NFS. Early MR imaging may help initiate well-directed specific measures for better outcomes in the acutely injured TMJ.
Dentomaxillofacial Radiology (2022) **51**, 20210148. doi: 10.1259/dmfr.20210148

Cite this article as: Akkemik Ö, Kugel H, Fischbach R. Acute soft tissue injury to the temporomandibular joint and posttraumatic assessment after mandibular condyle fractures: a longitudinal prospective MRI study. *Dentomaxillofac Radiol* 2022; **51**: 20210148.

Keywords: Magnetic resonance imaging; Mandibular fracture; Conservative therapy; Temporomandibular joint

Introduction

Trauma to the temporomandibular joint (TMJ) can cause both bone and soft tissue injuries. Variable acute soft tissue damages to the TMJ have been reported in the literature (Table 1).[1–11] However, the extent of injury in the entire affected joint structure was not addressed in the previously published studies. To our knowledge, to date, only one study has assessed TMJ soft tissues using magnetic resonance imaging (MRI) on the affected and unaffected sides after condylar fracture.[7] Furthermore, the short-term longitudinal course of an acutely injured TMJ has not been conclusively described in the literature. Distinctive types of fractures in the TMJ may have different long-term consequences. Evaluation of longitudinal evolution including response to treatment is therefore justified and necessary for condylar injuries. MRI is a well-accepted non-invasive technique with high contrast and spatial resolution for the diagnosis of disorders of the TMJ and has proven to be an effective method for evaluating a fractured TMJ including soft tissue status.

Correspondence to: Özlem Akkemik, E-mail: akkemik@yahoo.com

Received 31 March 2021; revised 01 October 2021; accepted 09 October 2021

Table 1 Compilation of studies: condylar fracture types, MRI sequences, and MRI diagnoses in the acute phase

Diagnoses	*Patients, Fracture types*	*MRI sequences*	*MRI*
Sullivan et al[1] 1995	13 patients	SE, T1w and T2w Slice thickness 3 mm or less	Disc avulsion n=10 Lateral capsular tears n=2
Takaku et al[2] 1996	12 TMJs in 10 patients	FISP-3D SE, T1w and T2w Slice thickness 2 mm	Capsule tears n=8 RDT tears n=6 All discs displaced anteromedially
Gerhard et al[3] 2007	38 TMJs in 19 patients	TSE, PDw TIRM DESS-3D Slice thickness 3 mm	Capsular tear n=17 (44.7%) Disc displacement n=7 (18.4%) Hemarthrosis n=22
Emshoff et al[4] 2007	Type V (n = 6) Type VI (n = 11)	TSE, PDw TIRM DESS-3D Slice thickness 3 mm	Capsular tear n=13 (76.5%) Disc disruption n=1 (5.9%) RDT tears n=12 (70.6%) Hemarthrosis in JC n=17 (100%)
Wang et al[5] 2009	108 TMJs w dislocation 10 TMJs w/o dislocation	FSE, PDw and T2w Slice thickness 1.5 or 2 mm	Disc displacement n=105 (97.2%) Disc perforation n=9 (8.3%) Abnormal SPA n=42 (38.9%) Abnormal IPA n=96 (88.9%) Abnormal SI of RDT n=98 (88.3%) Abnormal joint capsule n=94 (87%)
Dwivedi et al[6] 2012	17 TMJs	SE, T1 Slice thickness 5 mm	Disc displacement n=8 Hemarthrosis n=8 Capsular tear n=3
Yu et al[7] 2013	19 TMJs in 18 patients	FSE, T1w and PDw GRE, T2w Slice thickness 2 mm	Disc displacement n=15 Capsule tears n= 9 RDT tears n=16 Effusion n=119
Kim et al[8] 2016	47 joints in 34 patients	SE, T2w and PDw Slice thickness 3 mm	RDT tears n=6
Senthilvelmurugan et al[9] 2017	20 patients, unilateral fractures	SE, T1w, T2w and PDw Slice thickness 3 mm	Anterior disc displacement n=8 Posterior displacement n=3 RDT tears n=20

3D, three-dimensional acquisition; DESS, Double Echo in Steady State sequence; FISP, Fast Imaging with Steady State Precession (a gradient-echo sequence); FSE, Fast Spin-Echo sequence (same as TSE); GRE, Gradient Recalled Echo sequence; IPA, inferoposterior attachment of disc; PDw, Proton Density-weighted sequence; RDT, retrodiscal tissue, SE, Spin-Echo sequence; SPA, superoposterior attachment of disc; T1w, T_1-weighted sequence; T2w, T_2-weighted sequence; TIRM, Turbo Inversion Recovery Magnitude sequence (similar to T1w); TSE, Turbo Spin Echo sequence (same as FSE).

We hypothesized that dislocated condylar fractures may enhance the severity of tissue injuries compared to displaced fractures. Follow-up (FU) of traumatic injury of soft tissues is likely to show progressive changes. Thus, the objective of the current study was to assess the relationship between fracture type, disc position, and soft tissue injuries in patients with condylar fractures and to assess the extent of trauma or therapy associated changes at the 3-month FU to the affected and unaffected joints. The current study thus aims to contribute toward future studies on patient-specific therapeutic interventions prior to the occurrence of any morphological degeneration in the fractured joint.

Methods and patients

Patients

24 patients (6 females, 18 males, mean age 32.7 years; range, 14–55 years) with 33 acute condylar fractures of the mandible were referred to MRI examination within 24 h of acute trauma during the period of 1998 to 1999 at the Department of Diagnostic Radiology, University of Cologne. Initial diagnoses of the patients were carried out on the basis of conventional radiographs including orthopantomogram and postero-anterior views. Inclusion criteria were as follows: the presence of a uni- or bilateral condylar fracture, derangement of occlusion, suspicion of an intracapsular fracture, or a mechanism of injury that would most likely predispose soft tissue damage of the TMJ. All fractures were classified

Table 2 Study collective and condylar fracture type according to the classification by Spiessl and Schroll[12]

Patients	(18 males, 6 females)	24
Fractures	(15 unilateral, 9 bilateral)	33
Type I:	Undisplaced condylar fracture	4
Type II:	Low-neck condylar fracture with displacement	6
Type III:	High-neck condylar fracture with displacement	6
Type IV:	Low-neck condylar fracture with dislocation	3
Type V:	High-neck condylar fracture with dislocation	12
Type VI:	Condylar head fracture (intracapsular)	2

according to Spiessl and Schroll[12] (Table 2). Fracture localization was unilateral in 15 patients and bilateral in 9 patients. The patients were treated conservatively with intermaxillary fixation for 7 to 15 days followed by subsequent active jaw exercises.

Twelve of the 24 patients recruited to the study could not be evaluated at FU as four patients did not respond to contact by telephone or postal mail and eight patients refused further participation in the study. Thus, only 12 patients with 16 condylar fractures including eight unilateral and four bilateral fractures [Type I (n = 3), Type II (n = 3), Type III (n = 2), Type IV (n = 2), Type V (n = 4), and Type VI (n = 2)] could be followed-up prospectively 3 months after the trauma. The study was conducted in accordance with the Declaration of Helsinki. The study design was reviewed and approved by our institutional review board. All patients provided informed consent to the diagnostic procedure and subsequent scientific evaluation, including publication of anonymized results.

Magnetic Resonance Imaging (MRI)

MRI at baseline and at FU were performed in the same setting to avoid any variations in data collection. MRI was carried out with a 1.0 T scanner (Philips Gyroscan T10 NT) using bilateral surface coils, designed for TMJ examinations. Both joints were imaged simultaneously in a closed mouth position with T1w spin-echo images (TR/TE 565 ms/20 ms, six slices, slice thickness 3 mm) and with T2w gradient echo images (FFE; TR/TE/FA 90 ms/21 ms/15°, slice thickness 2 mm acquired, overlapping slices reconstructed to 1 mm, 20 slices per joint) in the sagittal plane for tissue characterization and in the coronal plane for assessment of sideways displacement of the disc and evaluation of the fractured condylar head. The FU examination used the same imaging parameters and additional imaging using the T2w FFE sequence in an open mouth position using an incrementally adjustable bite block to assess joint function.

Evaluation of MR images:

MR images were analyzed by a medical radiologist and an oral and maxillofacial radiologist using a standardized evaluation form. In cases of disagreement, the final diagnosis was obtained by consensus. The main criteria assessed were position, morphology and signal intensity (SI) of the disc, continuity of the posterior attachments, integrity of the joint capsule, tissue reactions in the joint space and retrodiscal area, visible attachments of the ligaments, and fracture morphology. In addition, for patients who were followed-up, osseous structures were recorded for the longitudinal evaluation of joints.

Signals from the TMJ disc on the MR images were described in three categories: homogeneous, non-homogeneous (increased SI), and low signal. Based on the available descriptions of the common types of disc deformations, morphology of the disc was assigned to one of five categories comprising normal, moderately deformed, thickening of the posterior band of disc, compressed, and folded. Disc dislocation was assigned with the finding of a disc being displaced from the confines of the glenoid fossa. Thickening and increased SI of the retrodiscal lamina were considered to indicate injury of the disc attachments. A tear was suspected in case of discontinuity of posterior attachments of the disc or the joint capsule. On T2w images, joint effusion (JE) was identified as an area of high SI in the superior or inferior joint space (JS). If present, JE was observationally recorded according to its extent in the joint space in at least two consecutive slices (0 = none; 1 = minor; 2 = moderate; 3 = marked). The morphology of osseous joint structures (condyle, articular fossa and articular eminence) was recorded on the basis of the most frequently observed alterations (normal, moderate, flattened, irregular, sclerosis, and cyst) in patients with internal derangement (ID).

At the FU MRI evaluations 3 months after trauma in 12 patients, the joints were reassessed in closed- and open-mouth position using the same imaging protocol. Additionally, position and degree of motion of the disc, reduction of the displaced disc and position/translation degree of the fractured condyle in the open-mouth position were assessed.

Statistical analyses

The statistics analysis of the data was performed with SPSS v.25.0 (SPSS Inc., Chicago, IL, USA). The distribution of MRI findings between the groups and the relationship between trauma severity and soft tissue injury was analyzed by chi-square test or Fisher's exact test, when appropriate, among the subtypes of disc positions to determine association between disc position and fracture types.[13] The G*Power program[14] has been used for Power Analysis. According to calculation, the experimental group consisting of a minimum of 12 people was sufficient to perform the chi-square test. Statistical significance was evaluated as $p < 0.05$.

Clinical functional analysis:

The patients were clinically examined by two dental surgeons at the time of FU MRI to determine the functional status of the stomatognathic system based on the form of the 'Arbeitsgemeinschaft für Funktionsdiagnostik und -therapie' (Functional Diagnostic and Therapy Working Group) of the German Society for Oral and Maxillofacial Surgery.[15]

Results

Soft tissue damage

Damage of the retrodiscal lamina was observed mainly in the dislocated fractures. A significant association was identified between the degree of condylar injury and MRI diagnosis of tear of inferior retrodiscal lamina ($p < 0.05$). Discontinuity of the inferior bilaminar zone was observed in 1 out of 6 Type III and 10 out of 12 Type V-fractures. However, an MRI finding of capsular tear or damage of superior retrodiscal lamina was not significantly associated with the degree of condylar injury ($p > 0.05$). In 16 joints, the superior retrodiscal lamina showed thickening and increased SI, indicating the presence of injury (10 Type V, 2 Type IV, 2 Type III, and 2 Type II fractures). In one joint with a Type III fracture (Patient 9), lateral capsular damage was noted. In one joint with Type V fracture (Patient 1), lipohemorrhage caused by intra- articular extension of the fracture line of the mandibular condyle was found. In this case, coronal scans showed considerable edema of the capsule in the medial area and an irregular contour of the joint capsule. Furthermore, blood in the fossa in two joints with Type V fracture (Patients 4 and 5) was observed as additional signs of soft tissue injury. Upon re-examination at the FU after 3 months, increased intensity in the disc attachments as sign of traumatic injury disappeared. Only one joint with a Type V fracture showed new hypointense tissue formation in T1w and T2w MR images in the retrodiscal region of the bilaminar zone, close to the fracture area.

Joint effusion

The relationship between the occurrence of JE and fracture type in 24 patients did not reach statistical significance ($p > 0.05$); however, the presence of effusion increased with the severity of trauma. With the exception of two joints with Type I fractures, minor effusion was recorded in 20 [41.7%; $n = 15$, Fractured Side (FS)], moderate in 15 (31.3%; $n = 15$, FS), while marked effusion was recorded in one joint (FS). Effusion was observed in both JS in 20 joints, followed by the upper JS and then the lower JS. No significant difference in JE was observed with both acute and FU (for those patients who were followed up) findings on the basis of fracture types ($p > 0.05$).

Disc position

MRI scans at the acute stage showed the physiological disc position in 25 joints and displaced disc in eight joints on FS, whereas the normal disc position in 3 TMJs and disc displacement (DD) in five were observed on the non-fractured side (NFS). When the acute findings of 24 patients and both acute and FU findings of the 12 FU patients were evaluated, no significant association between the degree of condylar injury and the MRI diagnosis of disc displacement could be observed ($p > 0.05$) (Tables 3 and 4). With the exception of two joints (posterior disc displacement, PDD), the disc remained in its anatomical position in relation to the condylar head despite fracture dislocation in all patients with type V fractures.

Disc position in 12 patients with FU, with closed mouth, at initial, and follow-up examination

Three out of 16 fractured joints showed DDs, whereas 5 out of 8 joints indicated the presence of DDs on the NFS. FU MRI scans after 3 months revealed an increased degree of DD in one patient with Type I fracture and new DDs in four fractured joints on FS. On the NFS, one new partial anterior DD (PADD) and one new partial medial DD (PMDD) were observed. A partial lateral DD (PLDD) on NFS (Patient 18) from the acute phase was no longer observed at FU (Table 5). Except for PDD, no significant correlation between the development of DD and fracture type could be demonstrated ($p > 0.05$).

Disc position with open mouth at follow-up examination

Differences in disc reduction in the open mouth position on the basis of the fracture type did not reach statistical significance ($p > 0.05$) (Table 6). Normal disc movement during mouth opening was present in 13 out of 16 fractured condyles. However, the change in position of the disc was difficult to identify in one joint with a Type VI fracture (Patient 20) due to restricted translational movement. Furthermore, movement of the

Table 3 Disc position in 12 patients without follow-up

Unilateral fracture					*Bilateral fracture*					
		FS (n = 7)		*NFS (n = 7)*			*FS R (n = 5)*		*FS L (n = 5)*	
P	*A*	*FT*	*DP*	*DP*	*P*	*A*	*FT*	*DP*	*FT*	*DP*
3	23	II	Proper	Proper	11	51	I	PADD	III	PMDD
10	23	II	PMDD, PADD	PADD	9	55	III	Proper	III	Proper
12	14	II	Proper	PADD	8	33	III	Proper	V	Proper
1	31	V	Proper	Proper	7	24	V	Proper	V	Posterior
5	37	V	Proper	PADD	6	28	V	Proper	V	Proper
4	20	V	Proper	Proper						
2	53	V	Posterior	PMDD						

A, Patient age; CADD, Complete anterior disc displacement; DP, Disc position; FS, Fracture side; FT, Fracture type (Spiessl and Schroll)[12]; L, left; NFS, Non-fracture side;P, Patient; PADD, Partial anterior disc displacement; PLDD, Partial lateral disc displacement; PMDD, Partial medial disc displacement; R, right; underlined, displacements.

Table 4 Disc position in 12 patients with follow-up at the initial examination

Unilateral fracture					*Bilateral fracture*					
		FS (n = 8)		*NFS (n = 8)*			*FS R (n = 4)*		*FS L (n = 4)*	
P	*A*	*FT*	*DP*	*DP*	*P*	*A*	*FT*	*DP*	*FT*	*DP*
13	19	I	Proper	PMDD	21	43	II	Proper	II	Proper
14	16	I	Proper	Proper	22	18	III	PMDD	III	Proper
15	25	I	PADD	CADD, PLDD	23	51	V	Proper	V	Proper
16	45	II	Proper	CADD	24	51	VI	CADD	IV	Proper
17	38	IV	Proper	Proper						
18	40	V	Proper	PADD,PLDD						
19	20	V	Proper	Proper						
20	33	VI	Proper	PMDD						

A, Patient age; CADD, Complete anterior disc displacement; DP, Disc position; FS, Fracture side; FT, Fracture type (Spiessl and Schroll)[12]; L, left; NFS, Non-fracture side;P, Patient; PADD, Partial anterior disc displacement; PLDD, Partial lateral disc displacement; PMDD, Partial medial disc displacement; R, right; underlined, displacements.

physiologically positioned disc in the joint with bilateral Type V fracture (Patient 23) could not be reliably assessed with the open mouth position; therefore, the presence of disc adhesion was suspected. On the other FS of this joint, only sufficient movement of the disc with limited condyle translation was observed.

Disc morphology

The disc had a biconcave shape in 37 (70.8%; $n = 27$, FS) of the 48 TMJs evaluated, moderately deformed in two joints (4.2%, NFS), thick posterior band was observed in three joints (8.3%; $n = 2$, FS), while the disc was compressed in four joints (12.5%; $n = 2$, FS) and folded in two joints (4.2%; FS). No statistically significant difference could be identified between morphological changes of the disc on the basis of fracture classification ($p > 0.05$). At the baseline evaluation of the 12 patients with FU, disc shape was biconcave in 15 (62.5%) of the 24 TMJs evaluated, moderately deformed in two joints (NFS), a thick posterior band was observed in three joints (12.6%; $n = 2$, FS), while the disc was compressed in two joints (8.3%; $n = 1$, FS), and folded in two joints (8.3%; FS). A statistically significant difference in disc morphology was noted in 12 patients when reassessed in FU after 3 months ($p < 0.05$), although there was no statistically significant difference for a given morphological change.

Signal intensity of the disc

Of the 48 TMJs evaluated, homogeneous, non-homogeneous and reduced signal were observed in 26 (54.2%; $n = 19$, FS), 20 (41.7%; $n = 12$, FS) and 2 (4.2%; FS) TMJs, respectively. No statistically significant difference in the disc signal with relation to the fracture types could be observed ($p > 0.05$). In addition, differences in disc signal between fractured and non-fractured joints did not reach statistical significance ($p > 0.05$). However, the distribution of the homogeneity of the disc signal according to the disc position reached statistical significance. In this regard, a significant difference in the disc signal in the event of completely anteriorly displaced disc ($p < 0.05$) could be identified. The increased disc

Table 5 Disc position in 12 patients at the follow-up examination

Unilateral fracture					*Bilateral fracture*					
		FS (n = 8)		*NFS (n = 8)*			*FS R (n = 4)*		*FS L (n = 4)*	
P	*A*	*FT*	*DP*		*P*	*A*	*FT*	*DP*	*FT*	*DP*
13	19	I	Proper	PMDD	21	43	II	Proper	II	Proper
14	16	I	Proper	Proper	22	18	III	CADD*	III	PMDD*
15	25	I	CADD*	CADD, PLDD	23	51	V	Proper	V	Proper
16	45	II	Proper	CADD	24	51	VI	CADD	IV	Proper
17	38	IV	Proper	PMDD*						
18	40	V	Proper	PADD						
19	20	V	Posterior*	Proper						
20	33	VI	PADD*	PMDD, PADD*						

* changes in disc position at follow-up. A, Patient age; CADD, Complete anterior disc displacement; DP, Disc position; FS, Fracture side; FT, Fracture type (Spiessl and Schroll)[12]; L, left; NFS, Non-fracture side;P, Patient; PADD, Partial anterior disc displacement; PLDD, Partial lateral disc displacement; PMDD, Partial medial disc displacement; R, right; underlined, displacements.

Table 6 Disc position in closed and open-mouth position on fractured and non-fractured side in 12 patients at follow-up MRI examination and clinical findings in relation to trauma type and disc position

		Follow-up MRI examination		*Follow-up clinical examination*	
Patient	*Fracture type per side*	*Disk position closed mouth*	*Disk position open mouth*	*TMJ sound*	*Clinic*
14	Type I	Proper	Proper	—	—
	NFS	Proper	Proper	—	—
16	Type II	Proper	Proper	+	—
	NFS	Completely anterior	Without reduction	—	—
24	Type VI	Completely anterior	Without reduction	+	—
	Type IV	Proper	Proper	+	—
*20	Type VI	*Partially anterior	Reduction	—	—
	NFS	*Partially anteriomedial	Reduction	—	—
13	Type I	Proper	Proper	+	Deviation
	NFS	Partially medial	Reposition	+	
18	Type V	Proper	Proper	—	Deviation
	NFS	Partially anterior	With reduction.	—	
*15	Type I	*Completely anterior	Without reduction	+	Deviation
	NFS	Completely anterior, Partially lateral	Without reduction	—	
21	Type II	Proper	Proper	+	Restriction in laterotrusion
	Type II	Proper	Proper	+	
*22	Type III	*Completely anterior	Without reduction	+	Deviation
	Type III	*Partially medial	With reduction	+	Malocclusion
*17	Type IV	Proper	Proper	+	Deviation, malocclusion
	NFS	*Partially medial	With reduction	—	Restriction in laterotrusion Restriction in protrusion Pain
*19	Type V	*Posterior	Without reduction	+	Deviation, malocclusion
	NFS	Proper	Proper	—	Restriction in laterotrusion Restriction in protrusion Pain
23	Type V	Proper	Proper	+	Restriction in mouth opening
	Type V	Proper	Proper	+	Pain

NFS, Non-fracture side.
(in the order of increasing severity of clinical symptoms; lower three patients: unsatisfactory clinical results)
— = not present; + = present; *newly developed changes in joints.

signal was located at the posterior band in 17 out of 48 joints ($n = 11$, FS; $n = 6$, NFS), but this relationship did not reach statistical significance ($p > 0.05$). The normally located discs appeared non-homogeneous after trauma in five joints ($n = 4$ on the FS) and in nine joints at FU ($n = 7$ on the FS).

At the baseline evaluation of the patients with FU, signal intensity of the disc was homogeneous in 15 discs (62.5%; $n = 10$, FS) and non-homogeneous in 9 discs (37.5%; $n = 6$, FS) in 24 joints. At the 3 months FU of 12 patients, the disc appeared homogeneous in 9 (37.5 %; $n = 7$, FS) and non-homogeneous in 15 discs (62.5%; $n = 9$, FS). A statistically significant change in disc signal, particularly in the event of completely anteriorly displaced disc, was identified ($p < 0.05$). Although the increased SI was observed more frequently in the posterior disc band [7 out of 16, FS; 1 out of 8, NFS (immediately after trauma); 10 out of 16, FS; 4 out of 8, NFS (at FU)], the difference was not statistically significant ($p > 0.05$).

Condyle position immediately after trauma

The condylar head was severely dislocated in the anterior direction in each case with dislocated fractures. Additionally, 20 condyles showed a medial deviation. Upon re-evaluation at 3 months, the condyle position with regard to the ascending ramus of the mandible did not show any marked change. Movement of the condyle and disc could be barely evaluated because of the dislocated position in six fractured joints. Morphological deformations of the completely displaced discs prevented movement of the condyle. As secondary findings, a bone contusion of the contralateral condyle in a Type VI fracture, a separated fracture fragment in the glenoid fossa in a Type V fracture and deformations of the condylar head of 3 joints in two Type VI and one Type V fracture were recorded.

Condyle morphology

None of the condylar fragments showed any resorption upon re-evaluation of the 12 patients at FU. Comparison of the morphology at the acute phase and FU indicated a statistically significant difference ($p < 0.05$). Significant shortening of the ascending ramus indicating regressive remodeling in seven joints (n = 2 with DD) ($p < 0.05$) and condylar hyperplasia indicating post-trauma hyperplastic remodeling in 11 joints (n = 5 with DD) ($p < 0.05$) were observed. When the relationship between the occurrence of degenerative changes and post-trauma disc position was evaluated, alterations in condyle morphology were observed especially in DD joints on both sides; however, this difference did not reach statistical significance ($p > 0.05$). Evaluation of the simultaneous effect of trauma on the NFS suggested that a non-fractured joint (right Type I fracture) showed barely noticeable irregularities at the posterior condyle convexity after trauma; nonetheless, it exhibited a pronounced concavity as a sign of regressive remodeling upon re-examination at the FU.

Morphology of adjacent osseous structures at FU

No statistically significant difference was observed in the morphology between examinations at the acute phase and at the FU ($p > 0.05$). The fossa was found to be flattened on the FS in two joints at the baseline and eight joints at the FU examination, whereas the fossa remained unchanged on the NFS. No remarkable change in the articular eminence and its inclination were detected at the FU ($p > 0.05$). Exophytic bone changes were predominantly observed on the posterior surface of the eminence in 12 cases with the ventral/dorsal ratio of 3/3 at the first examination and 6/12 at the FU. No significant correlation was observed between the disc position and the occurrence of secondary exophytic bone ($p > 0.05$).

Relation of clinical findings and MRI findings

Clinical functional analysis at the FU 3 months after trauma indicated the presence of physiological occlusion in all except three patients. Frontally open bite and asymmetry were not detected in any of the cases (Table 5). MRI findings correlated well with the clinical findings except for three patients. Restricted mouth opening in one patient with bilateral fractures (Patient 23) may be explained by a combination of several factors including healing of the condyles in a dislocated position, reduced translation of the fractured condyle on one side and soft tissue changes resembling adhesions between the fractured condyle and the articular tubercle on the other FS. For the three patients (Patients 17, 18, 19) with clinically determined deviation, MR images showed healing of the condyles in the dislocated position (Figures 1 and 2 for Patient 19). In four patients with deviation (Patients

Figure 1 Patient 19, unilateral condylar fracture (type V). Parasagittal T_2-weighted gradient-echo image of the left TMJ in the first examination; closed-mouth view: Fracture associated with cortical disruption (arrow), leading to a lipohemarthrosis in both joint spaces. A physiological disc position relative to anteromedially dislocated condyle. The condyle is situated under the articular eminence. The inferior disc attachment shows discontinuity with increased signal intensity suggesting the presence of a tear (T). The superior disc attachment shows thickening with a higher intensity of the signal, indicative of injury

15, 18, 19, 22), displacement of the disc was also evident (Figures 3–5 for Patient 22). Furthermore, the deviation and malocclusion in these patients could be explained by loss of the condylar height. The joint sound in two joints was correlated by MRI with a disc displacement with reduction (DDWR) (Patients 17, 22). In three cases with a physiological disc position (Patients 17, 21, 23) and in three cases with disc displacement without reduction (DDWOR) (Patients 15, 22, 24), fracture-related changes in the condyle were identified as a possible cause of joint sound. Subluxation of the condyles in front of the articular eminence in three joints with physiological disc position and the slipping of the condyle from the anterior band of the eccentric posteriorly displaced disc in one joint (Patient 19) were considered as explanatory for terminal joint sound in the mouth opening.

Discrepancies between MRI and clinical findings were found in three patients. In two cases (Patients 18 and 20) with MR-evidence of DD, a reduction of the articular disc could not be determined clinically. In a patient (20) with MR-evidence of reduced translational motion, increased rotation of the condyle to compensate for the decreased translation may provide an explanation for the absence of clinical signs of restricted mouth

Figure 2 Patient 19. Parasagittal T_2-weighted gradient-echo image in the follow-up exam; closed-mouth view of the left TMJ: Posterior disc displacement. The fractured condyle with a shortening of collum height and hyperplasia is observed to have healed under the articular eminence. The disc is situated on the flattened condyle convexity, thereby its posterior band with a thickened appearance (black arrow) and its intermediate zone are observed in the level of the posterior surface of the articular eminence. There is appearance of new tissue on the posterior surface of the condyle (white arrow). Minimal effusion is seen in both joint spaces

Figure 3 Patient 22, bilateral condylar fracture (type III). Parasagittal T_2-weighted gradient-echo image (FFE sequence) of the left TMJ in the first examination; closed-mouth view: physiological disc position in the sagittal plane (arrow). In this patient, coronal images demonstrate medial displacement of the disc. Minimal effusion is seen in both joint spaces

opening. In one case (Patient 16), moderate degenerative changes without clinical signs were considered adaptive bone changes.

Discussion

Several studies have provided insight into soft tissue changes of acutely injured TMJs with MRI. Results of these studies have demonstrated considerable heterogeneity in injury associated changes.[1–11,16–19] Capsular tear was reported to be common in patients with condylar injuries, with an incidence rate ranging from 15 to 67%,[3] while retrodiscal tissue tears were described to vary between 39 and 74%.[1,2,4,7] Consistent with other studies,[5,20] we found that dislocated fractures predisposed an individual to concomitant retrodiscal tissue tear. Thereby, in the current study, the inferior retrodiscal lamina seemed to be more susceptible to injury than the superior lamina.

Contradictory results have been reported in two studies that have evaluated patients by MRI at the acute stage. Sullivan et al[1] reported capsular tears in only 2 out of 13 cases of dislocated condylar fracture, whereas Takaku et al[2] reported tears in the capsule of eight joints and in the retrodiscal tissue of six joints. In contrast, we found capsular tear in one displaced fracture in the current study. We believe that the low frequency of injury to the joint capsule may be suggestive of its resistance to injury. Differences in the incidence of capsular tear with the previous studies may be related to the severity and direction of the blow to the mandible.

Liu et al[11] suggested that the low frequency of tearing of the retrodiscal attachment in children was a great advantage for recovery of the displaced disc and restoration of function of the TMJ. The present study showed unsatisfactory results in functional analyses of three patients with Type V fractures. Owing to changes in load distribution, the consequences of tears may vary. Following the presumption of Liu et al,[11] we suggest that the unsatisfactory clinical outcomes in the three patients may be suggestive of an unknown clinical relevance of a retrodiscal tissue tear.

Contradictory results are reported in other studies evaluating the prevalence and direction of DD in patients with condylar injury.[1–3,5,7,21,22] In the current study, apart from trauma-related posterior displacement in two joints with Type V fractures, disc displacement was following the fractured condylar head. Goss and Bosanquet[18] arthroscopically examined 40 TMJs in 20 patients with mandibular trauma. In contrast to the MRI findings of Gerhard et al,[3] but in support of the findings of Dwivedi et al,[6] a relationship between the degree of dislocation and damage to the disc was reported. In the current study, no specific association was identified between the degree of condylar injury and MRI diagnosis of the displaced disc ($p > 0.05$). The disc is attached firmly to the medial and lateral poles of the mandibular condyle with its ligaments. We believe that this helps to maintain a normal relationship with the condyle on both sides, suggesting that the disc displacements detected may have existed independently of the trauma.

In the 12 out of 24 patients for whom a FU was carried out at 3 months, regardless of the severity of the trauma, new DDs developed in four joints. In addition, an increased degree of DD on the affected side - and the occurrence of new DDs in two joints on the unaffected side - were observed. A trauma-related loss of backward directed elastic strength of the bilaminar zone may explain the development of new DDs, particularly in cases with severe dislocation of fragments. Senthilvelmurugan et al[9] evaluated 11 displacements in 20 patients with unilateral condylar fractures by MRI and contrary to the current findings, reported discs with a normal appearance in 16 patients at FU after 3 months.

Among the different directions of displacement, posterior displacement is considered to be the most uncommon.[23] Corroborating the findings of the current study, two studies have reported posterior discal displacement in patients with condylar injuries[8,9]; however, these authors did not give any specific explanations for their findings. We surmised that the development of posterior DD in relation to the condyle may occur due to trauma-induced elongation of the collateral and anterior capsular ligament while the condyle moves forward out of the fossa leaving the disc behind. DD has been reported to be one of the most prevalent contributive factors of post-traumatic ankylosis.[24] Considering the data reported in the current study, early knowledge of aberrant relationships in the joint may be useful to regain full functionality. Diverse results in data reported in various studies might be related to differences in the diagnostic criteria of condylar injuries and types of condylar fractures.

We have demonstrated MRI-based evidence of joint effusion in approximately 75.1% of the cases after condylar fractures, in line with previous studies.[4,7,8,11,25] However, in contrast to Wang et al,[5] we found no statistically significant difference in JE between patients with dislocated and non-dislocated joints. Furthermore, in contrast to the study by Dwidevi et al,[6] we could not identify any association between JE and the position of the disc. Emshoff et al[4] reported that effusion was more frequently observed in the superior joint cavity than the inferior cavity. These data were supported by the findings of Yu et al[7] and Kim et al.[8] Conversely, Takahashi et al[25] reported the presence of effusion more often in the inferior space and more frequently in TMJs after high condylar fractures. Additionally, in contrast

Figure 4 Patient 22. Parasagittal T_2-weighted gradient-echo image in the follow-up exam; closed-mouth view of the left TMJ: Complete anterior displacement of the disc beyond the condyle. The disc has a folded appearance (arrow). The posterior band of the disc shows higher signal intensity. Moderate effusion is seen in the superior joint space. Irregular margins of the condyle can also be seen

to the current study, none of the TMJs on the unfractured sides showed any evidence of joint effusion. We found increased signal in 31 out of 33 fractured joints and hemarthrosis in one joint. In line with the study by Takaku et al,[2] both upper and lower effusions were often observed in the current study. Larheim et al[26] suggested to grade the amount of TMJ fluid to find the significance of TMJ fluid in TMJ disorders. While a limited amount of joint fluid may be found in normal or in previously damaged joints, we believe that future studies should address a grading system of joint fluid in relation to condyle fractures to define the clinical significance of the effusion in these injuries.

Neuronal mediators are known to participate in local bone formation and bone remodeling, and have been identified in fracture hematomas.[27] Accumulating evidence from experimental studies suggest that peripheral nerve fibers are not only important in normal bone homeostasis and skeletal growth but can also influence the repair mechanism after bone trauma (*e.g.,* fracture healing) and may be involved in the pathogenesis of degenerative joint diseases.[28] At the FU examination of one joint with a Type V fracture, we observed a new hypointense tissue formation in T1w and T2w MR images on the posterior surface of the condyle, close to the fracture area. We evaluated these data as suggestive of neurofibrous tissue development in a hematoma.

Figure 5 Patient 22. Parasagittal T_2-weighted gradient-echo image in the follow-up exam; open-mouth view of the left TMJ: Complete anterior displacement of the DDWOR. The disc remained anteriorly displaced beyond the condyle with increased deformation (arrow)

Unfortunately, we were unable to confirm our hypothesis with further studies of the relevant patient.

Several studies have reported the histological features of a TMJ disc in asymptomatic and symptomatic patients.[29] MRI scans can detect changes in the SI of TMJ disc. In this regard, blood vessels and connective tissue at the posterior band were reported to be the cause for increased SI of the posterior band. Thereby, the density of blood vessels was reported to be significantly higher in patients than in controls.[30] In the current study, the high SI observed in the physiologically positioned disc immediately after the trauma did not conform to the criteria for a tear or a degeneration of the TMJ disc. We suggest that the increased signal of the discs in their physiological position could be an indication of a contused disc structure in relation to severe trauma. Similar focal signal abnormalities of the meniscus in the knee have been described in patients with a history of acute trauma.[31] These authors suggested that the signal alteration may be due to a contusion of the meniscus and the signal may resolve over time in some patients. However, further studies need to be conducted to clarify this in the future.

We could not find a statistically significant difference in disc signals from the different types of condylar TMJ fractures in the 24 patients recruited to the current study. However, there was a statistically significant association between the disc position and disc signal. We found this relation particularly in cases with total disc displacement, suggestive of progressive disc degeneration.

Kim et al[8] examined 47 joints in 34 patients with condylar fracture. These authors estimated the degree of displacement in the fractured condylar segments to be closely related to the position and shape of the disc. At the baseline examination of 24 patients, we found no association between the trauma type and configuration of the disc, other than a marked traumatic compression in four joints with non-dislocated fractures. Comparison of the baseline data with that of the 12 FU patients suggested the presence of a statistically significant difference in disc morphology. Previous studies have demonstrated that the highest stress appeared in the posterior band of displaced discs, while the intermediate zone and anterior band remained almost unloaded.[32] The current study corroborated this finding. The posterior band was seen to be predominantly deformed by thickening following trauma, although we did not find a statistically significant difference for specific morphological changes of the disc. We observed enhanced morphological alterations of the deformed discs after trauma. This suggests an effect of the trauma on disc morphology, which may lead to subsequent degenerative changes.

In agreement with other studies, we also found severe displacement of fragments in the medial or anteromedial direction out of the fossa in the dislocated fractures. This tendency for a more medial angulation of fragments may be attributed to a thickening of the joint capsule with tissue fibers called the lateral ligament in the lateral joint side and the weakness of ligaments in the medial joint side. Anterior displacement of the fractured segment may be attributed to the function of the lateral pterygoid muscle.

In the current study, the fractured fragments remained displaced or dislocated at the FU. Remodeling of the condyles, which can be influenced by physiological and pathological factors such as trauma was often observed in joints with high condylar fractures.[28] However, when morphology changes of the condyles were considered, no clear relationship with different trauma types could be found in the short-term FU.

Comparative studies on therapeutic options after condylar fractures suggest the presence of a flat glenoid fossa in nonsurgical patients.[33,34] The morphological changes of articular eminence and disc have been suggested to contribute to the appearance of disc displacement without reduction.[35] We could not establish statistically significant changes in the articular eminence, its posterior aspect, or fossa articularis at the short-term FU examination of the small study population of the current study.

Dysfunction and condylar degeneration can occur not only on FS but also on the NFS.[36] To our knowledge, there is only one MRI study by Yu et al,[7] who reported the alterations of both sides after condylar fractures. In the current study, we were able to record simultaneous effects of the trauma on the NFS. The uniform action of both joints underlines the response of the NFS. Compensatory activation of the unaffected side may lead to an increase in the load; this may be considered as a possible explanation for the subsequent development of degenerative changes in this joint, especially if there is pre-existing internal disorder.

To our knowledge, except for one study[6] bone bruise has not been reported in patients with condylar fractures. Bone bruise, characterized by bone marrow edema and/or hemorrhage or compression of trabecular zones, is a secondary sign of trauma based on CT or MR images, but is not indicative of fracture.[37] In the present study, bone bruise was detected in one joint in the form of a compression zone, suggesting damage of the NFS.

Regarding the clinical outcomes of 12 patients with FU in the present study, dislocated fractures caused the greatest dysfunction, in agreement with the literature.[36] Irrespective of treatment choice, complications may occur after the treatment of condylar fractures. However, there is dearth of studies that have evaluated response to treatment after acute TMJ injury by simultaneously performing long-term imaging studies to assess soft tissue structures.

The results of the above mentioned studies show the spectrum of articular damage after condylar injuries. Posttraumatic osteoarthritis (PTOA) is a rapidly progressive type of OA that occurs in individuals with a history of an acute joint injury. Disc injury or disc displacement accompanying condylar fracture is a contributing factor for adverse consequences on longer-term joint health. Therefore, a long-term detrimental effect of not treating malpositioned discs may result in osteoarthrosis, facial asymmetry, and occlusal disturbance.[38] Developing early intervention and strategies to reduce or prevent posttraumatic arthritis after condylar injuries before joint degeneration begins rather than prioritizing long-term results should be in critical priority of clinicians. Awareness of the relationship between TMJ disorder and jaw injury can support the clinicians' decisions and improve patients' optimal first-line care which may include dental care, self-management instructions, splint therapy or physical therapy and be modulated with the symptom severity.

Conventional plain films and CT scans are used frequently as a primary diagnostic method in case of condyle fractures. However, the extent of soft tissue injury cannot be assessed with these imaging modalities. MRI offers a better understanding of discoligamenteous injuries and can influence treatment decisions, resulting in improved outcomes in patients with condylar fractures. MRI data in the present study were obtained at a field strength of 1 T with T1w spin-echo and T2w gradient echo (FFE) imaging. A variety of MRI sequences are available for different clinical applications with different contrast techniques, resolution and speed of acquisition. These variables should be used in the correct combination to best answer the clinical query. In general, spin-echo sequences offer better resolution at the cost of time of acquisition and potential motion artifacts, while gradient echo sequences offer speed.[39] T1w sagittal images are best for the detection of the anatomy of the TMJ. T2w images are useful for detecting degenerative changes in the joint and the presence of JE. However, limited availability of MRI may impair its routine clinical use.

The main limitation of this study is the small size of the study population that may preclude generalization of the study results. Despite our best efforts, the FU sample represented 50% of the patients that were approached for participation in the current study. In addition, the follow-up period was relatively short in consideration of the natural course of disc displacement. A larger sample size should be warranted to obtain more detailed follow-up outcomes. Another limitation is the lack of complementary diagnostic procedures.

Conclusion

Preexisting and traumatic disc displacement and soft tissue injuries are frequent findings in patients with condylar fracture. In acutely injured TMJs, the joint capsule appeared to be more resistant to injury whereas tear of inferior retrodiscal lamina was associated with high-grade injury. No association between displacements of the discs and type of fracture could be detected. However, the degree of condylar injury appeared to be related to the development of posterior disc displacement. Disc displacement was found to be associated with non-homogenous disc signal. There was no significant relation between joint effusion and fracture types. Short-term FU suggested that acute injury resulted in the development of new displacements irrespective of trauma type. Trauma affected both the bony structures and soft tissues simultaneously. Significant differences in disc morphology were seen after trauma, suggestive of post-traumatic disc degeneration. Early MR imaging may help to initiate well-directed specific therapeutic interventions for better outcomes. If further diagnostic support is needed, we suggest the use of MRI after some months. However, further studies with larger sample sizes are warranted.

Funding

Open Access funding enabled and organized by Projekt DEAL.

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