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ORIGINAL ARTICLE

Temporomandibular joint degenerative changes following mandibular fracture: a computed tomography-based study on the role of condylar involvement

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Abstract

Objectives This study assessed the incidence of postfracture radiological temporomandibular joint (TMJ) degeneration in patients with different types of mandibular fractures, focusing on the impact of condylar fractures.

Methods This retrospective review included patients diagnosed as having mandibular fractures from 2016 to 2020 who had undergone initial computed tomography (CT) and a follow-up CT scan at least 1-month postfracture. Patient demographics, fracture details, treatment methods, and radiological signs of TMJ degeneration on CT were analyzed to identify risk factors for postfracture TMJ degeneration, with a focus on condylar head fracture and non-head (condylar neck or base) fractures.

Results The study included 85 patients (mean age: 38.95 ± 17.64 years). The per-patient analysis indicated that the incidence of new radiologic TMJ degeneration on CT was significantly the highest ($p < 0.001$) in patients with condylar head fractures (90.91%), followed by those with non-head condylar fractures (57.14%), and those without condylar involvement (24.49%). The per-joint analysis indicated nearly inevitable degeneration (93.94%) in 33 TMJs with ipsilateral condylar head fractures. For the remaining 137 TMJs, multivariate logistic regression revealed that other patterns (ipsilateral non-head, contralateral, or both) of condylar fractures (odds ratio (OR) = 3.811, $p = 0.007$) and the need for open reduction and internal fixation (OR = 5.804, $p = 0.005$) significantly increased the risk of TMJ degeneration.

Conclusions Ipsilateral non-head condylar fractures and contralateral condylar fractures are associated with a high risk of postfracture TMJ degeneration. Indirect trauma plays a vital role in postfracture TMJ degeneration.

Keywords Temporomandibular joint disorders · Mandibular fractures · Computed tomography · Intracapsular fractures · Extracapsular fractures

Introduction

Mandibular fractures are a common type of craniofacial injury [1]. Their epidemiology and etiology vary across regions, being influenced largely by economic, social, cultural, and traffic conditions [1–3]. They are most commonly noted in people aged 20–30 years, with a male-to-female ratio of 1.25:1–6.1:1 [4–8]. In some areas, assault injuries are the primary cause of mandibular fractures, most commonly at the mandibular angle [4, 5]. Motorcycle accidents have also been cited as a major cause, with the symphysis/parasymphysis and condyle being the most frequently involved sites [2, 3, 8–10]. Computed tomography (CT) is routinely employed for the diagnosis of mandibular fractures because it can clearly detect both bony destruction and concurrent head and neck injuries [11]. The management of mandibular fractures primarily depends on the fracture pattern; the two prevalent approaches are closed reduction and surgical reduction with internal fixation [12]. Complications associated with mandibular fractures include wound infection, nonunion, malocclusion, temporomandibular joint (TMJ) dysfunction, and TMJ degeneration [13–15].

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TMJ degeneration is characterized by chronic degenerative changes, including osteophyte formation, subchondral sclerosis, and joint space narrowing [16, 17]. Its etiology is multifactorial, with prominent risk factors including age; sex; genetics; and mechanical stress, such as parafunction, joint overload, and trauma [18]. Mandibular fractures are often considered to be associated with the onset of TMJ degeneration [19]. Although many patients with TMJ degeneration remain asymptomatic, chronic pain and joint dysfunction are the two most prevalent symptoms of TMJ degeneration, and they significantly impair the patient's quality of life [7, 20]. Conventional CT or cone-beam CT is often used to assess bone changes in TMJ degeneration, whereas magnetic resonance imaging (MRI) is commonly used to evaluate injuries to soft tissue, such as the articular disc [21–24].

The aetiological mechanisms of TMJ injury following mandibular fracture can be categorized into direct trauma (condylar head fracture or contusion of the TMJ) and indirect trauma (non-head condylar or contralateral mandibular fractures) [25]. The effects of indirect injury, as analyzed in animal models, remain a subject of ongoing debate [26, 27]. As suggested by Ku, degenerative changes can manifest in the TMJ within one month after condylar fractures [28]. Although these degenerative changes have been demonstrated histologically and radiologically in case series, no large clinical study has compared the incidence of radiological TMJ degeneration across the different patterns of mandibular fracture [29, 30].

In this study, we analyzed the effect of mandibular fracture locations on the incidence of TMJ degeneration in post-fracture CT scans, focusing on the different risks of TMJ degeneration caused by condylar head, neck, and base fractures. We also explored correlations between basic patient characteristics and TMJ degeneration.

Material and methods

This retrospective study was conducted at a level 1 trauma center and was approved by our Institutional Review Board (no. 202300954B0). This study was designed and conducted following the Helsinki Declaration. We searched our hospital's radiological reporting system for patients admitted with mandibular fractures between January 1, 2016, and December 31, 2020. The inclusion criteria were as follows: (1) being $\geq$ 18 years of age, (2) having a new diagnosis of mandibular fracture in the study period, (3) having initial craniofacial bone CT images within 24 h of trauma, and (4) having follow-up CT scans including the TMJ taken at least one month after trauma. Patients with mandibular fractures at our hospital underwent CT scans using an Aquilion One 320-row (Toshiba, Tokyo, Japan) and a BrightSpeed 16-row (GE, Milwaukee, USA) scanner. Images were scanned in the axial plane at 120 kVp and 100 mAs, with a field of view of 25×25 cm and a matrix size of 512×512. The slice thickness for axial bone window images was set at 1.0 mm with no inter-slice gapping. Coronal and sagittal reformatting was performed at a slice thickness of 3.0 mm, also without inter-slice gapping. Intravenous contrast medium was not routinely administered. To minimize the confounding of potential condyle remodeling on the assessment of condyle degenerative changes, patients under the age of 18 were excluded. Patients with marked motion or metallic artifacts on CT images that could affect assessments were excluded from subsequent analysis.

We reviewed the patient's electronic medical records and obtained data on their age, sex, treatment methods for mandibular fractures, and follow-up duration. Poor clinical outcome was defined as persistent maximal mouth opening (MMO) < 35 mm in postfracture follow-up. Treatment methods were divided into two categories: conservative treatment (either no treatment or maxillomandibular fixation) and open reduction and internal fixation (ORIF). Images from the initial CT scan obtained at the time of trauma and follow-up CT scans were retrieved from the Picture Archiving and Communication System. The reports and images of the initial CT scans were reviewed to evaluate the fracture pattern, displacement, presence of TMJ dislocation, and any preexisting TMJ degeneration. The fracture sites were categorized into eight regions: symphysis/parasymphysis, body, angle, ramus, coronoid process, condylar base, condylar neck, and condylar head [30–32]. For clarity in statistical presentation, we defined "non-head condylar fractures" as those involving either the neck or the base of the mandibular condyle. Image interpretation for newly identified TMJ degeneration on the follow-up CT scan was conducted independently by a head-neck radiology specialist with 11 years of experience and a fourth-year radiology resident. Discrepancies in interpretation were resolved through discussion. On CT images, the presence of bony cortex erosion, sclerotic changes, osteophyte formation, or subchondral cysts at the condylar head were defined as indications of TMJ degenerative changes [21].

The interrater agreement for TMJ degeneration was assessed using Cohen's kappa statistic. Subsequent analyses were performed at the patient and joint levels, referred to as per-patient and per-joint analyses, respectively. For the per-patient analysis, patients were stratified into three groups: (1) Patients with mandibular fractures that do not involve the condyle, (2) patients with mandibular fractures including non-head condylar fractures but not the condylar head, and (3) patients with any mandibular fractures involving either a unilateral or bilateral condylar head. The prevalence of post-mandibular fracture TMJ degeneration was assessed using a chi-square test. For the per-joint analysis, TMJs with ipsilateral condylar head fractures were excluded from subsequent analyses because they almost inevitably developed degenerative changes and showed potential remodeling in our study. This exclusion aimed to prevent class imbalance and separation issues in logistic regression [33, 34]. The association between patient demographic characteristics and the newly developed TMJ degeneration observed on follow-up CT scans was assessed using univariate binary logistic regression, and variables with $p < 0.05$ (which indicated significance in this study) were included in a multivariate binary logistic regression model. For the per-patient and per-joint analyses, we employed ANOVA and the independent t-test to examine any differences in CT follow-up durations between groups. Additionally, we used the chi-square test to assess the relationship between postfracture TMJ degeneration on CT and poor clinical outcomes (MMO < 35 mm). All statistical analyses were conducted using RStudio version 2023.06.0 (Boston, MA, USA).

Results

Between 2016 and 2020, 832 patients were identified as having mandibular fractures on CT scans, 197 of whom were diagnosed as having new-onset mandibular fractures. After excluding 79 patients without follow-up CT scans, 6 with previously healed mandibular fractures, 10 who were under 18 years of age at the time of the fracture, and 17 with inadequate baseline or follow-up CT scans for evaluation of TMJ, 85 patients (mean age at the time of trauma: 38.95 ± 17.64 years) were included in this study. The male-to-female ratio was 1.66:1. The average follow-up interval for CT scans was 12.79 ± 12.24 months. On the initial CT images, 57 (67.06%) patients had displacement of the mandibular fractures, 33 (38.82%) had TMJ dislocation, and 14 (16.47%) had preexisting TMJ degenerative changes. In all, 51 (60.00%) patients underwent ORIF for mandibular fractures. ORIF was utilized for the fixation of non-condylar mandibular fractures in 34 patients, condylar fractures in 3 patients, and both condylar and non-condylar mandibular fractures in 14 patients. The patients' demographic characteristics and details of the mandibular fractures are summarized in Table 1. The Cohen's kappa values were 0.835 for the per-patient analysis and 0.873 for the per-joint analysis, indicating strong interobserver agreement.

Per-patient analysis

Of the 85 patients, 49 (57.65%) had mandibular fractures not involving the condyle (Group 1), 14 (16.47%) had mandibular fractures involving non-head condylar fractures but not the condylar head (Group 2), and 22 (25.88%) had mandibular fractures involving either a unilateral or bilateral condylar head (Group 3). We identified new radiological signs

Table 1 Demographics of 85 enrolled patients

Characteristics	Number (%) or mean ± SD		
	Right	Left	Total
Gender (Male/Female)			53 (62.35) / 32 (37.65)
Age (years)			38.95 ± 17.64
Duration of CT follow-up (months)			12.79 ± 12.24
Fracture site displacement			57 (67.06)
ORIF[&] for mandible fracture			51 (60.00)
Pre-existing TMJ[#] degeneration	10 (11.76)	8 (9.41)	14 (16.47)
TMJ dislocation	26 (30.59)	25 (29.41)	33 (38.82)
Fracture site			
Symphysis/parasymphysis			52 (61.18)
Body	12 (14.12)	14 (16.47)	23 (27.06)
Angle	7 (8.24)	5 (5.88)	10 (11.76)
Ramus	4 (4.71)	4 (4.71)	8 (9.41)
Coronoid	8 (9.41)	7 (8.24)	17 (17.65)
Condylar base	7 (8.24)	13 (15.29)	16 (18.82)
Condylar neck	8 (9.41)	7 (8.24)	13 (15.29)
Condylar head	19 (22.35)	14 (16.47)	22 (25.88)
New TMJ degeneration post fracture	33 (38.82)	27 (31.76)	40 (47.06)
Poor clinical outcome (MMO[$] < 35 mm)			17 (20.00)

[#] *TMJ* temporomandibular joint

[$] *MMO* maximal mouth opening

[&] *ORIF* open reduction and internal fixation of TMJ degeneration on follow-up CT scans in 40 patients (47.06%). These included bony cortex erosion in 30 patients, osteophyte formation in 29 patients, subchondral cysts in 15 patients, and sclerotic changes in 11 patients. The per-patient analysis revealed a nonrandom distribution of new TMJ degeneration among the three groups, with the risk being lowest in Group 1 (24.49%) and highest in Group 3 (90.91%). Among the 22 patients in Group 3, all 11 patients with bilateral condylar head fractures and 9 of 11 patients with unilateral condylar head fractures had new TMJ degeneration. In Group 2, new TMJ degeneration was observed in 8 of 14 patients (57.14%), which was higher than in Group 1 (Table 2). The chi-square test results revealed significant differences among the groups ($p < 0.001$). Among the 51 patients who received ORIF treatment, 30 (58.82%) were found to have postfracture TMJ degeneration. In contrast, among the 34 patients who underwent conservative treatment, only 10 (29.41%) exhibited such degeneration. For the CT follow-up duration, there was no significant difference among the three patient groups as determined by ANOVA ($p = 0.405$). For the clinical outcome, postfracture new TMJ degeneration on CT was significantly correlated with persistent MMO < 35 mm ($p = 0.001$).

Per-joint analysis

As many as 31 of 33 TMJs (93.94%) with ipsilateral condylar head fracture exhibited TMJ degeneration on the follow-up CT scan. Because of this high risk, these 33 TMJs were excluded from the subsequent per-joint regression analysis. Of the remaining 137 sides of TMJs, 10 were associated with ipsilateral non-head condylar fractures, 19 with any (base, neck, or head) contralateral condylar fractures, and another 10 sides were associated with both ipsilateral non-head condylar fracture and any contralateral condylar fractures. In total, 39 (28.47%) TMJs were associated with ipsilateral and/or contralateral condylar fractures, whereas 98 (71.53%) TMJs did not have a coexisting condylar fracture. The results of the per-joint analysis, which investigated the association between demographic characteristics, condylar fracture, fracture instability, treatment methods, and the risk of ensuing TMJ degenerative changes on follow-up CT scans, are presented in Table 3.

Univariate logistic regression analysis revealed that ipsilateral and/or contralateral condylar fractures [odds ratio (OR) = 3.458, $p = 0.004$], displacement at the fracture site (OR = 2.673, $p = 0.038$), TMJ dislocation on the initial CT (OR = 3.174, $p = 0.027$), and the need for ORIF for mandibular fractures (OR = 6.145, $p = 0.001$) were significantly associated with new postfracture TMJ degeneration. The patients' age (OR = 0.966, $p = 0.022$) and the duration of CT follow-up (OR = 0.905, $p = 0.005$) were other significant factors; however, their ORs were very close to 1, indicating a relatively small effect size. By contrast, sex ($p = 0.179$) and preexisting TMJ degeneration ($p = 0.972$) were not significant in the univariate analysis. Subsequently, we conducted a multivariate logistic regression analysis using 4 significant factors noted in the prior univariate analysis: patients' age, the duration of CT follow-up, the presence of ipsilateral and/or contralateral condylar fractures, and the need for ORIF. Because of the association between displacement at the fracture site, TMJ dislocation on initial CT images, and the need for ORIF, we only selected the necessity for ORIF, which exhibited the highest OR and smallest *p*-value among these three factors, in the multivariate analysis. All these 4 factors remained significant, with the adjusted ORs for ipsilateral and/or contralateral condylar fracture (OR = 3.811, $p = 0.007$) and ORIF (OR = 5.804, $p = 0.005$) suggesting a significant increase in the risk of new radiologic TMJ degeneration when these factors were present. However, the patients' age (OR = 0.962, $p = 0.036$) and the duration of follow-up (OR = 0.925, $p = 0.021$) remained associated with borderline significance (ORs close to 1) after adjustment. Regarding the CT follow-up duration between the TMJs with and without associated condylar fracture, the *t*-test showed no significant difference ($p = 0.462$). Additionally, postfracture TMJ degeneration on CT was also correlated with poor clinical outcomes in the per-joint analysis ($p = 0.005$).

Table 2 Facture types and their association with temporomandibular joint (TMJ) degeneration in per-patient analysis

Condylar involvement in mandible fracture	Total	Postfracture TMJ degeneration		*p*-value
		(+)	(−)	
Not involving condyle	49 (57.65)	12 (30.00)	37 (82.22)	< 0.001*
With non-head condylar fracture$	14 (16.47)	8 (20.00)	6 (13.33)	
With condylar head fracture#	22 (25.88)	20 (50.00)	2 (4.44)	
Total	85	40	45	

Data was presented as number (%)

$ "Non-head condylar fractures" were defined as fractures involving either condylar neck or condylar base

Patients with both head and non-head condylar fractures were categorized in the third group

* Indicating *p*-value < 0.005

Table 3 Per-joint analysis of univariate and multivariate logistic regression of 137 temporomandibular joints (TMJ) after excluding ipsilateral condylar head fracture

	All TMJ	Postfracture TMJ degeneration		Univariate analysis	p-value	Multivariate analysis	p-value
		(+)	(−)	Odds ratio (95% CI)		Odds ratio (95% CI)	
Age (years)	37.84 ± 17.18	31.30 ± 14.06	39.67 ± 17.58	0.966 (0.938–0.995)	0.022*	0.962 (0.924–0.995)	0.036*
CT follow-up (months)	12.14 ± 11.54	6.80 ± 6.48	13.64 ± 12.21	0.905 (0.838–0.963)	0.005**	0.925 (0.859–0.982)	0.021*
Male patients	83	15	68	0.574 (0.253–1.298)	0.179		
Condylar fracture	39	15	24	3.458 (1.482–8.072)	0.004**	3.811 (1.463–10.301)	0.007*
Contralateral condyle	19	3	16				
Ipsilateral condyle	10	3	7				
Bilateral condyle	10	9	1				
Old TMJ degeneration	18	4	14	1.022 (0.310–3.370)	0.972		
Fracture site displacement	82	24	58	2.673 (1.057–6.761)	0.038*		
TMJ dislocation	19	8	11	3.174 (1.142–8.817)	0.027*		
ORIF treatment	81	26	55	6.145 (2.007–18.813)	0.001**	5.804 (1.887–22.697)	0.005**
Total	137	30	107				

Data was presented as mean ± SD or number

* Indicating p-value < 0.05

** Indicating p-value < 0.005

Discussion

In our cohort of patients with mandibular fractures, most were men and young adults. Moreover, the most frequent fracture site was the symphysis/parasymphysis, followed by the condyle. Despite this being a retrospective single-center study including only patients with both initial and follow-up CT images, our cohort is comparable to those in previous studies [2, 7–9]. Therefore, we believe that our results can be representative of general patients with mandibular fractures.

Estimating the incidence of TMJ degeneration following mandibular fractures is challenging due to its complex and multifactorial etiology [35]. A study involving 165 patients revealed histological TMJ degeneration in 38.3% of patients with a history of mandibular trauma [36]. Another study involving 99 patients with mandibular fractures reported a > 10% incidence of TMJ pain and clicking [25]. Instead of assessing TMJ degeneration based on patients' symptoms, we focused on radiologically indicated changes in TMJ degeneration in follow-up CT images. We identified new TMJ degeneration in 47.06% of patients after mandibular fracture, which was higher than the incidence reported in the other studies. The discrepancy between the clinical and radiological incidences of TMJ degeneration might be due to the presence of asymptomatic TMJ degeneration. In asymptomatic sides of the temporomandibular joint (TMJ), the proportion of abnormal condyle morphology on CT scans can reach up to 24.9%, while the proportion of abnormal disc position on MRI scans can be as high as 58.2% [37]. Although radiological findings correlate with symptoms, whether patients with asymptomatic TMJ degeneration will eventually develop symptomatic temporomandibular disease remains uncertain. Further studies should explore the relationships between radiological findings and symptoms of TMJ postfracture TMJ degeneration.

The incidence of TMJ degeneration in our patients with condylar head fractures (Fig. 1) was significantly higher than in those without condylar involvement (Fig. 2). Several case series have also suggested the development of TMJ degeneration following condylar head fracture; however, in-depth investigation into this phenomenon with radiological images has been lacking [38, 39]. Our findings support the claim that direct trauma caused by condylar head fractures can precipitate joint degeneration, with a high incidence (90.91% in our per-patient analysis and 93.94% in our per-joint analysis). Soft tissue injury induced by condylar head fractures, such as disc perforation or displacement, can allow the condylar head to be in direct contact with the glenoid fossa; moreover, the fragmented condylar head can lead to the formation of an irregular joint surface [19, 40–42]. These changes can exacerbate intra-articular friction, subsequently leading to TMJ degeneration.

The per-joint analysis, in which we excluded TMJs with ipsilateral condylar head fractures, still indicated other condylar involvement as a significant risk factor for TMJ degeneration in patients with mandibular fractures (Fig. 3). These findings suggest that an ipsilateral non-head condylar fracture, regardless of the presence of a simultaneous contralateral condylar fracture, can increase the likelihood of new TMJ degenerative changes on follow-up CT scans.

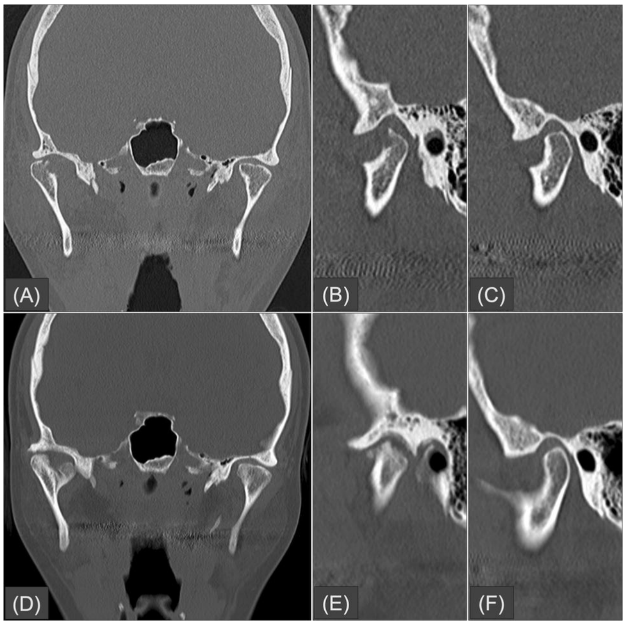

Fig. 1 Initial CT scans in coronal (**A**) and sagittal (**B**) planes of a 49-year-old woman revealed a right mandibular condylar head fracture with fracture site displacement and right temporomandibular joint (TMJ) subluxation. No apparent fracture in the left mandibular condyle is shown in (**C**). Coronal (**D**) and sagittal (**E**) reformatted images of the follow-up CT scan, taken 10 months after conservative treatment, showed condylar deformity, marked osteophyte formation, and potential remodeling. In contrast, no degenerative changes were observed in the left TMJ on the follow-up CT (**F**)

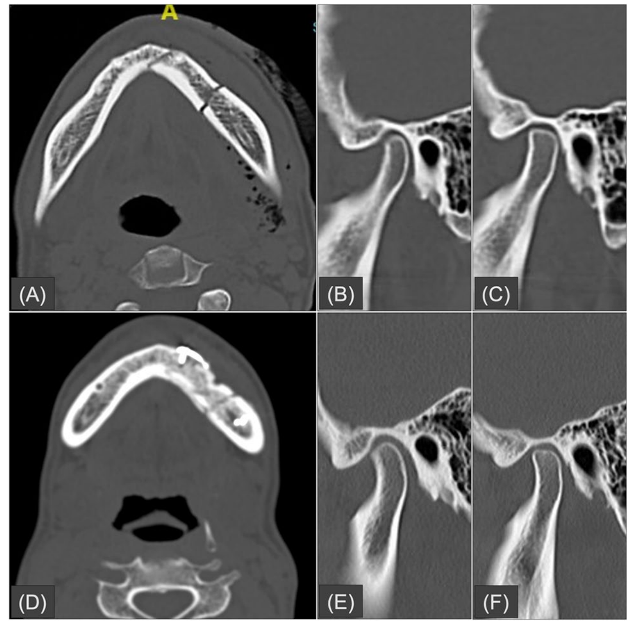

Fig. 2 Initial CT images of a 38-year-old man showed mandibular symphysis and left body fracture in the axial plane (**A**). No fracture, dislocation, or pre-existing degeneration was noted in the right (**B**) and left (**C**) temporomandibular joints (TMJ) on sagittal reformation of the initial CT. The patient underwent surgical fixation for the mandible fracture (**D**). Follow-up CT images 9 months after the fracture showed no apparent degenerative changes in the right (**E**) and left (**F**) TMJ

Studies have investigated the effect of indirect trauma on the pathogenesis of subsequent TMJ degeneration. In a case series involving arthroscopy examination of 20 patients with new condylar neck fractures, 38 of 40 TMJs exhibited intra-articular damage, such as hemarthrosis or disc shredding [43]. Such damage can precipitate biochemical changes within the TMJ, leading to disc degeneration and joint adhesion, consistent with the findings of animal studies [26]. The present study focused on the detection of TMJ degenerative changes on CT images and provides radiological evidence of TMJ degeneration following indirect trauma. Because of the small study sample, we did not perform subgroup analyses comparing the incidences of TMJ degeneration among TMJs associated with contralateral, ipsilateral, and bilateral condylar fractures. However, the incidence was highest in TMJs associated with bilateral condylar fractures, followed by those associated with ipsilateral non-head condylar involvement (Table 3).

Although we did not assess soft tissue injuries within the TMJ, MRI studies may offer some insight in this regard. Although MRI is not as effective as CT for detecting bony degenerative changes of the mandibular condyle, it is more sensitive in examining intra-articular soft tissues, particularly for identifying injuries and degeneration of the disc, as demonstrated in Fig. 4 [44]. A study including 19 patients with different degrees of condylar trauma with and without fractures reported that patients with condylar head fractures or TMJ dislocations had a higher incidence of capsular tear and hemarthrosis [45]. These findings emphasize that direct and indirect trauma exert different effects on the TMJ, potentially leading to differences in the degree of degenerative changes. Another study that focused on TMJ disc changes recruited 100 patients with mandibular fractures and performed initial and follow-up MRIs 5 years after the fracture. The results revealed anterior disc displacement in all 20 patients with bilateral condylar fractures but only in 2 of 20 patients without condylar involvement. Moreover, 7 of 20 patients with unilateral condylar fractures exhibited anterior disc displacement over contralateral TMJ involvement [30]. Although anterior disc displacement is generally considered to precede TMJ degeneration, TMJ degeneration can also occur without disc displacement [19]. Combining the findings from these MRI studies with those from our study, we speculate that non-head condylar fractures, despite not causing direct osseous damage within the TMJ, may pose a risk of subsequent joint degeneration through indirect injuries to the intra-articular soft tissues, such as the disc or ligament.

In our study, univariate logistic regression analyses revealed that displacement at the fracture site, TMJ

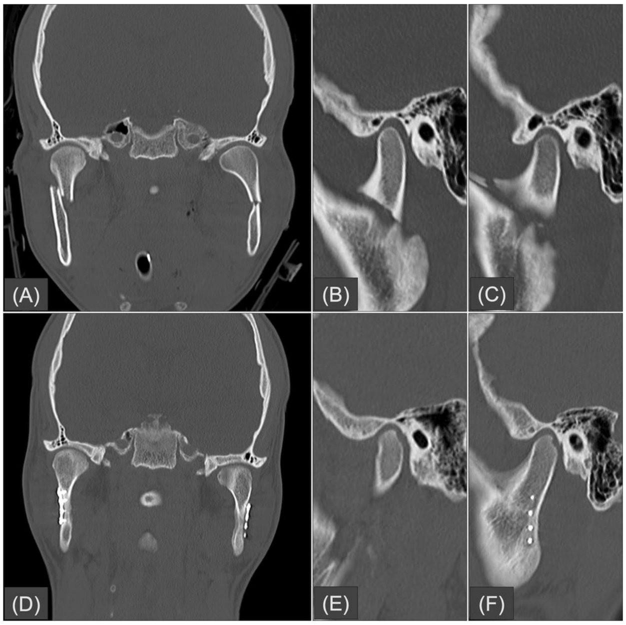

Fig. 3 A 21-year-old man had mandibular symphysis (not shown), right condylar base (**B**), and left (**C**) condylar base fractures. The coronal reformatted image of the initial CT showed displacement at the right condylar fracture site and angulation at the left condylar fracture site (**A**). However, no condylar head fracture or pre-existing condylar degeneration was detected on the initial CT scan. The patient underwent surgical treatment for his bilateral mandibular fractures (**D**). A follow-up CT scan 4 months later revealed newly developed postfracture condylar degeneration with bony cortex erosion on the sagittal planes of the right (**E**) and left (**F**) temporomandibular joints

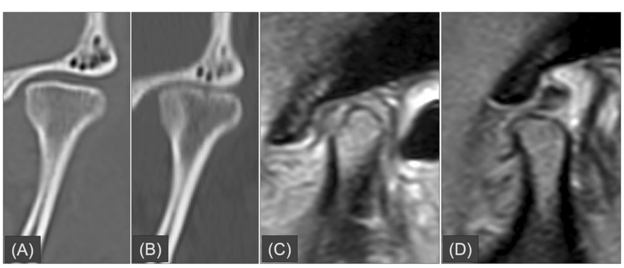

Fig. 4 **A** The initial CT of a 35-year-old female with mandibular fractures at the right condylar base and left parasymphysis showed no evident bony deformity in the left TMJ. **B** The 12-month follow-up CT revealed left condylar head bony cortex erosion. A 9-month follow-up TMJ MRI showed significant thinning and suspected perforation in the intermediate zone of the left TMJ disc, as well as anterior disc displacement with reduction on closed-mouth (**C**) and open-mouth (**D**) sagittal proton density-weighted images

dislocation on initial CT images, and the need for ORIF were significantly associated with an increased risk of TMJ degeneration. Displacement at the fracture site and TMJ dislocation may suggest a relatively high-energy and complex fracture mechanism, postfracture skeletal instability, impaired masticatory function, and a need for ORIF [1, 7].

During the surgical treatment of non-head condylar fractures, it's also possible to alter the TMJ disc position, leading to disc displacement and subsequently causing TMJ degeneration [45]. For example, CT images of the patient in Fig. 3 show that the joint space in both TMJs became narrower on follow-up CT, which might be due to disc displacement following the operation. To avoid confounding effects, we selected the necessity for ORIF, which exhibited the highest OR and smallest p-value among these three factors in the multivariate analysis. We found that it was a significant independent risk factor for TMJ degeneration.

This study has several limitations. First, this was a single-center retrospective study. Future large-scale prospective studies are warranted to mitigate selection bias and validate our findings. Second, we did not control for differences in CT scan protocols, which might have introduced bias due to inconsistent imaging parameters. However, this inherent drawback of a retrospective study may have been somewhat mitigated by having two dedicated readers reviewing the CT images, thus offering a degree of reliability in the results. Third, the timing of CT follow-up for enrolled patients was inconsistent, representing another intrinsic limitation of a retrospective study. Patients with more complex diseases or complications may have been examined more often. Indeed, our study results indicate a relatively small and negative OR regarding the effect of the duration of CT follow-up on postfracture TMJ degeneration. Fourth, we did not exclude patients with preexisting TMJ degeneration because we aimed to investigate whether a preexisting condition can exacerbate postfracture TMJ degeneration. The results indicated that it did not. Finally, we relied solely on CT for detecting radiological TMJ degenerative changes, which is limited in distinguishing soft tissue changes such as disc degeneration and ligament injury. Further research that involves a larger patient population and incorporating both standardized CT and MRI evaluations can provide better sensitivity for clarifying the mechanism of indirect trauma in the TMJ following mandibular fracture.

Conclusion

Our data indicated that ipsilateral condylar head fractures are associated with a near-certain onset of radiologic TMJ degeneration. This risk is also higher with other patterns of condylar fractures and the need for ORIF. These findings jointly suggest that both direct and indirect trauma following fracture play a vital role in TMJ degeneration. Clinicians should carefully evaluate patients with mandibular fractures displaying symptoms of TMJ degeneration during follow-up, and timely and appropriate treatment should be initiated to mitigate the subsequent joint degeneration and its effects on masticatory function.

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Author contributions CLS: Conceptualization; Data curation; Formal analysis; Methodology; Resources; Software; Visualization; Writing—original draft. ACS: Data curation; Formal analysis; Methodology; Software; Supervision; Writing—review & editing. CCC: Conceptualization; Methodology; Resources; Supervision; Validation; Writing—review & editing. AYL: Conceptualization; Methodology; Resources; Supervision; Validation; Writing—review & editing. CHY: Conceptualization; Formal analysis; Investigation; Methodology; Project administration; Resources; Software; Supervision; Validation; Writing—review & editing.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest

Ethics approval All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008. Approval was granted by the Institutional Review Board (IRB) of the Chang Gung Medical foundation (IRB No.: 202300954B0). The IRB reviewed and determined that it is expedited review according to case research or cases treated or diagnosed by clinical routines.

Informed consent The IRB approves the waiver of the participants' consent.

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