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Research Paper
TMJ Disorders

Natural course of severe temporomandibular joint osteoarthrosis evaluated by a novel condylar remodelling scoring system and quantitative volumetric analysis

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Abstract. Temporomandibular joint osteoarthrosis (TMJ-OA) frequently causes mild, moderate, or severe condylar morphological changes. A novel condylar remodelling scoring system (CRSS) based on three-dimensional cone beam computed tomography images is proposed, which is used to grade condylar morphological changes. In the CRSS, the condyle is divided into 10 regions by 11 reference points. For each increase in the number of regions involved in TMJ-OA, one point is subtracted from the full score of 10. The intra-class correlation coefficients for intra- and inter-observer agreement (range 0.656–0.898 and 0.841–0.906, respectively) indicated that the CRSS had good reliability. Cephalometric analysis showed that the condyles with severe morphological changes were prone to present with a retrognathic and clockwise rotating mandible, shorter ramus height, reduced mandibular length, larger mandibular angle, and maxillary retrusion. Qualitative CRSS evaluation and quantitative volumetric analysis were performed to evaluate the stability of severe TMJ-OA in its natural course (343 condyles). The continuous cortex group showed no remarkable changes with an average follow-up of 2 years. In the discontinuous cortex group, most (74.4%) converted into a continuous cortex during follow-up (mean 2 years).

Keywords: Anatomy; Cone-beam computed tomography; Mandibular condyle; Osteoarthritis; Temporomandibular joint.

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The temporomandibular joint (TMJ) is the growth centre of the mandible.[1] Diseases of the TMJ in children and teenagers may lead to condyle hypoplasia, mandibular asymmetry, and retrognathia.[2] Orthodontic treatment or orthognathic surgery is frequently needed to correct the associated dentofacial deformities and improve masticatory function.[3]

Osteoarthrosis refers to a degenerative joint disease involving the articular cartilage and subchondral bone.[4] TMJ osteoarthrosis (TMJ-OA) in teenagers frequently leads to functional impairment and Class II dentofacial deformities.[2,5,6] TMJ-OA could be induced by adaptive responses to excessive forces of the TMJ, or by reducible or non-reducible anterior disc displacement.[7–10] Condylar remodelling processes in TMJ-OA, including erosion, resorption, subchondral cyst formation, osteophyte formation, flattening, and sclerosis, give rise to various degrees of condylar morphological changes.[11]

Functional condylar remodelling is characterized by stable condylar morphological changes, stable ramus height, stable occlusion, and normal growth. Dysfunctional remodelling is characterized by accelerated TMJ morphological changes, decreased ramus height, and mandibular retrusion, and is also known as idiopathic condylar resorption (ICR).[12] However, the distinction between functional condylar remodelling (traditional concepts such as osteoarthritis and osteoarthrosis) and dysfunctional condylar remodelling (progressive/idiopathic condylar resorption) is difficult to make due to the lack of an objective method to grade condylar morphological changes based on routine TMJ imaging.[2,11,13]

The natural course and stability of the condylar morphology and cortical status in TMJ-OA are important considerations in orthodontic and orthognathic treatments.[14–16] Secondary condylar remodelling and resorption subsequent to orthodontic treatment and orthognathic operations are not rare and may lead to recurrence.[15,16] It is not clear whether the recurrence of the TMJ-OA subsequent to the treatment is part of the course of the natural disease or dysfunctional adaptation of the TMJ and the newly established masticatory system. Elucidating the natural course of TMJ-OA, especially cases with severe condylar morphological changes and ICR confusion, will help the clinician to decide the appropriate treatment timing based on TMJ considerations.

The purpose of this study was to propose a novel three-dimensional (3D) condylar remodelling scoring system for condyles based on cone beam computed tomography (CBCT) images, to study the relationship between the degree of condylar remodelling and skeletal patterns, and to evaluate the stability of TMJ-OA with severe condylar morphological changes.

Materials and methods

Subjects

Ethical approval was obtained from the Biomedical Institutional Review Board of Peking University (PKUSS-IRB-202167117). Patients diagnosed with TMJ-OA at Peking University School and Hospital of Stomatology between January 2018 and December 2019 were enrolled in this study.

The inclusion criteria were as follows: patients who had undergone CBCT of the TMJ; TMJ diagnosed with normal condylar or TMJ-OA changes, including condylar abrasion, bone resorption, osteophyte formation, or significant morphological changes; no history of prior surgical treatment of the jaw. Patients who had lateral cephalometric radiographs were recruited for the cephalometric analysis; patients who were diagnosed with asymptomatic TMJ-OA with severe morphological TMJ changes were selected for the follow-up study. The exclusion criteria were as follows: patients diagnosed with TMJ ankylosis or tumour; patients with systemic diseases involving the TMJ; patients with a history of TMJ trauma, infection, or surgery; patients with a history of orthognathic surgery.

Image acquisition and data processing

Details of the CBCT and cephalometric radiograph image acquisition and data processing protocols are presented in the Supplementary Material (File S1).

Condylar remodelling scoring system (CRSS) and validation

The condylar remodelling scoring system (CRSS) was established based on 11 anatomical landmarks (Fig. 1). For each increase in the number of anatomical regions involved in the condylar morphological change, 1 point was subtracted from the full score of 10 points. The CRSS scores for the lateral pole (Lx) and medial pole (My) were recorded in the form of Lx/My. The sum of Lx and My represents the total CRSS score for the condyle. The degree of condylar morphological change was defined as follows: no change, CRSS score = 10; mild change, CRSS score = 8–9; moderate change, CRSS score = 5–7; and severe change, CRSS score = 0–4.

Four oral and maxillofacial radiologists with at least 5 years of experience in CBCT diagnosis of TMJ diseases interpreted all of the images independently on screens. A second-round evaluation was performed after 4 weeks to assess the intra-observer agreement.

The patients were divided into adolescents (10–19 years old) and adults (≥20 years old). The clinical examinations were performed by a specialist doctor to determine the presence of TMJ dysfunction including clicking, noise, pain, opening deviation, and limitations in mandibular movement (unassisted opening < 35 mm).

Cephalometric analysis

Details of the cephalometric measurements are presented in Supplementary Material Fig. S1. Two linear measurements (Ar–Go′, Go′–Pog) and five angular measurements (SNA, SNB, ANB, MP to SN, Ar–Go′–Me) were used to analyse the skeletal pattern.

Evaluation of the stability of severe TMJ-OA

Patients with severe condylar morphological changes in the TMJ-OA (sTMJ-OA) were recruited to evaluate the stability of the condyles during its natural course. The status of the condylar cortex was classified into continuous and discontinuous groups and into hypodense, normal density, and sclerotic groups by two experienced radiologists in consensus (Fig. 2).

The method used for the quantitative measurement of condylar volume is given in the Supplementary Material (File S1). The initial condylar volume (ICV) and the final condylar volume (FCV) were recorded. The condylar volume change rate (CVCR) was calculated as follows: $CVCR = 100\% \times (ICV - FCV)/ICV$. A stable condyle

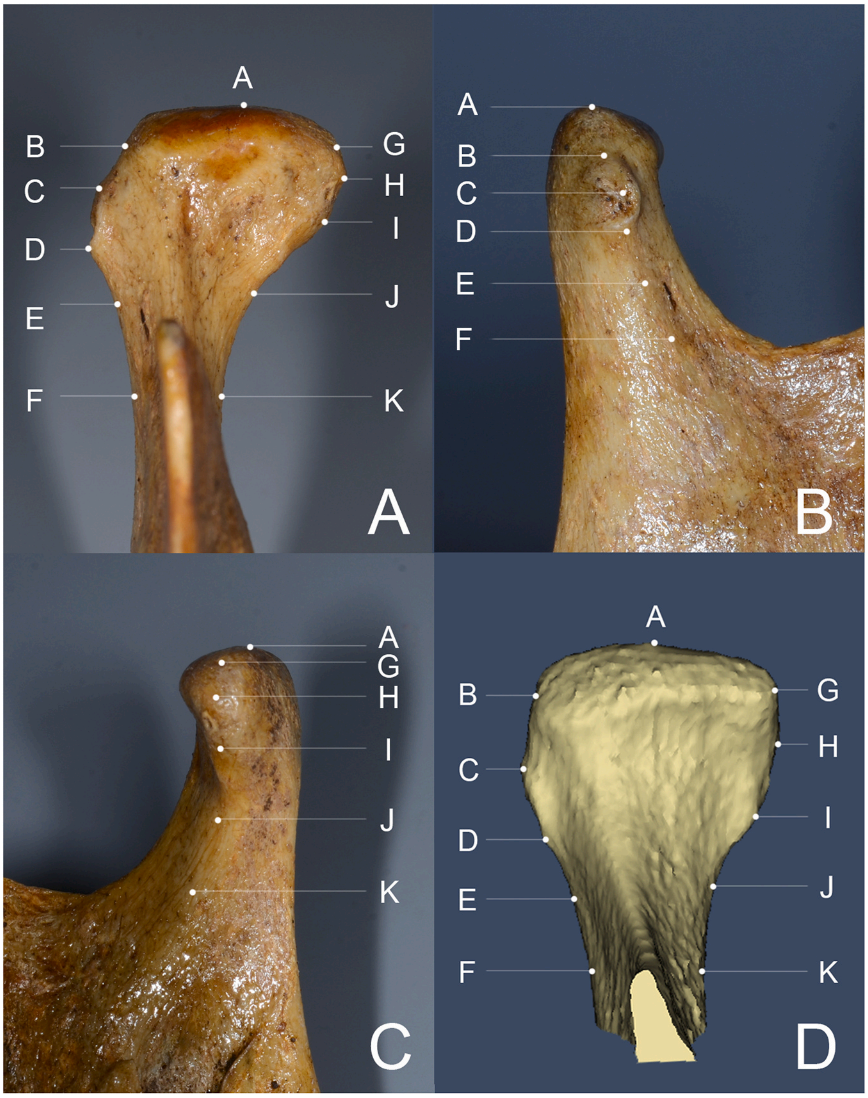

Fig. 1. Specimen of a normal condyle in (A) frontal, (B) lateral, and (C) medial views; and (D) three-dimensional CBCT image of a normal condyle in frontal view. Point A: the midpoint of the transverse crest of the condyle; point B: the outermost edge of the articular surface or the lower joint cavity; point C: the superior point of the bony protuberance of the lateral pole (attachment area of the capsular, disc, and temporomandibular ligaments); point D: the inferior point of the bony protuberance in the lateral pole; point E: the most concave point between point D and point F; point F: the boundary between the condylar neck and the ramus on the lateral side; point G: the innermost edge of the articular surface or the lower joint cavity; point H: the midpoint between point G and point I; point I: the inferior point of the medial pole; point J: the most concave point of the connection curve between point I and point K; point K: the boundary point between the condylar neck and the ramus on the medial side.

was defined as a loss of condylar volume less than 10% (CVCR ≤10%) (Supplementary Material Fig. S2).

The CRSS was also used to evaluate the stability of condylar remodelling. The condylar anatomical loss score (CALS) was defined as the difference obtained from the initial CRSS score minus the follow-up score. If a condyle had a CALS greater than zero, the condyle was considered unstable.

Statistical analysis

The statistical analyses were performed using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA). The significance level was set at 0.05. Intraclass correlation coefficients (ICC) were calculated to assess the intra- and inter-observer agreement based on a single rating (intra-observer agreement)/mean rating (inter-observer agreement), absolute agreement, two-way mixed-effects model. Based on the 95% confidence interval (CI) of the ICC estimate, values greater than 0.75 are indicative of good reliability. Spearman correlation analysis was used to investigate the correlation between the lateral and medial scores. Pearson's χ^2 test with/without post-hoc multiple comparison using a Bonferroni correction was applied to test the association between the CRSS and clinical features, condylar stability, and condylar cortex status. The independent-samples *t*-test was used to analyse the cephalometric results and the paired-samples *t*-test for the analysis of the volume change between the initial and follow-up condyles.

Results

Reliability of the CRSS

A total of 430 TMJ sides (280 symptomatic, 150 asymptomatic) of 215 patients (184 female, 31 male; age range 10.0–67.0 years, mean age 24.1 years, standard deviation (SD) 10.0 years) were included in this analysis. Regarding symptoms for all 430 TMJ sides, these included TMJ clicking (27.7%, 119/430), crepitus (11.4%, 49/430), pain (26.5%, 114/430), mouth opening deviation (14.4%, 62/430), and joint movement limitation (27.4%, 118/430).

The results of the CRSS evaluations of the condyles are given in Supplementary Material Table S1 (Figs. 3–5). There was no significant association between the occurrence of TMJ symptoms and the CRSS result (Supplementary Material Table S1; $\chi^2 = 6.777$, $P = 0.079$).

The intra- and inter-observer agreement of the four observers (mean ICC of 0.788 and 0.874, respectively; range 0.656–0.898 and 0.841–0.906, respectively) showed that the CRSS had good reliability (Supplementary Material Table S2).

The lateral (Lx) and medial (My) CRSS scores were positively correlated with each other ($r_s = 0.887$, $P < 0.001$), indicating that the condylar remodelling of the lateral and medial poles maintained a basically synchronous progress. The Lx (mean 2.73, SD 1.54) was slightly lower than the My (mean 3.14, SD 1.52) ($Z = -10.5$, $P < 0.001$), indicating that the lateral pole had a more advanced involvement in remodelling.

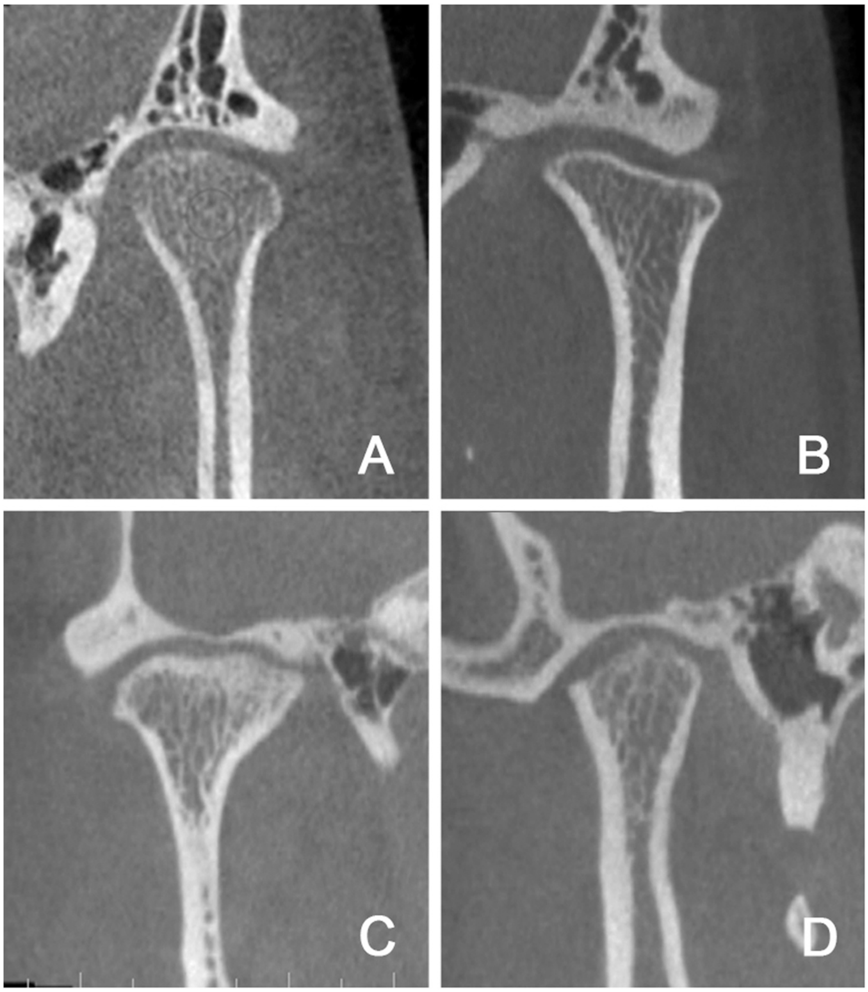

Fig. 2. (A) Coronal image of a condyle with continuous and hypodense cortex. (B) A condyle with continuous and normal density cortex. (C) A condyle with continuous and sclerotic cortex. (D) A condyle with discontinuous cortex.

The adolescents showed higher proportions of condyles with mild and moderate remodelling and the adults showed a higher proportion of severe remodelling (χ^2 = 21.375, P < 0.001). The male patients showed higher proportions of condyles with normal and mild remodelling and the female patients showed a higher proportion of severe remodelling (χ^2 = 13.668, P = 0.003).

The relationship of the CRSS and cephalometric analysis

One hundred and nineteen patients (89 female, 30 male; mean age 25.4 years, SD 8.1 years) were included in this analysis. The condyles presented a normal morphology in 25.2% (60/238); mild morphological changes were observed in 19.7% (47/238), moderate in 23.5% (56/238), and severe in 31.5% (75/238).

The cephalometric comparisons are reported in Table 1. The mild group showed no measurement differences in comparison with the normal group. The moderate and severe groups showed a tendency for mandibular retrognathia and clockwise rotation in comparison with the normal group. In the moderate group, the measurements of SNB and ramus height (Ar–Go′) were significantly reduced, while the measurements of ANB and MP to SN were increased in comparison with the normal and mild groups. In addition, the gonial angle (Ar–Go′–Me) in the moderate group was greater than that in the mild group. In the severe group, the measurements of SNA, SNB, ramus height (Ar–Go′), and mandibular length (Go′–Pog) were significantly reduced, while the measurements of ANB, MP to SN, and the gonial angle (Ar–Go′–Me) were increased in comparison with the normal and mild groups. In comparison with the moderate group, the measurements of SNB and ramus height (Ar–Go′) were significantly reduced, while the measurements of ANB and MP to SN were increased in the severe group.

Stability of sTMJ-OA during its natural course

Three hundred and forty-three TMJ sides of 212 patients with sTMJ-OA (186 female, 26 male; age range 10–30 years, mean age 25.1 years, SD 12.3 years) were included in this analysis. All patients were asymptomatic and received only conservative daily self-care. The follow-up period lasted between 1 and 6 years, with a mean of 2.0 years (SD 1.2 years). Six subtypes were observed: L0/M0 (9/343), L0/M1 (47/343), L1/M1 (157/343), L1/M2 (30/343), L2/M2 (72/343), and L1/M3 (28/343) (Fig. 5).

The overall CVCR ranged from − 37.3–48.3% (mean 3.9%, SD 12.5%). Overall, 73.8% (253/343) showed no volume change (mean −14 mm^3, SD 68 mm^3). Twenty-six percent (90/343) showed reduced volumes (mean 209 mm^3, SD 112 mm^3). The continuous cortex group showed a higher stability rate in comparison with the discontinuous cortex group: 92.5% (173/187) compared to 51.3% (80/156) (χ^2 = 74.7, P < 0.001). The difference in stability rate among the three density type groups (hypodense, normal density, and sclerosis) was found to be highly significant (Pearson's χ^2 test, P < 0.001). The Bonferroni test revealed significant differences in the stability rate between the normal density (82.5%, 141/171) and hypodense groups (42.7%, 38/89) (P < 0.001) and between the sclerosis (89.2%, 74/83) and hypodense groups (P < 0.001). No significant difference was found between the normal density and sclerosis group (P = 0.165). There was no significant difference in stability according to the degree of remodelling using the CVCR index (χ^2 = 5.535, P = 0.347) (Table 2).

Overall, 77.8% (267/343) showed no CALS change; 22.2% (76/343) showed reduced CALS. The majority of the L0/M0 (9/9), L0/M1 (42/47), L1/M1 (134/157), and L1/M2 (25/30) subtypes showed no CALS change. Subtypes of L2/M2 (32/72) and L1/M3 (11/28) showed an increased tendency for CALS reduction (χ^2 = 34.052, P < 0.001) (Fig. 6). The continuous cortex group

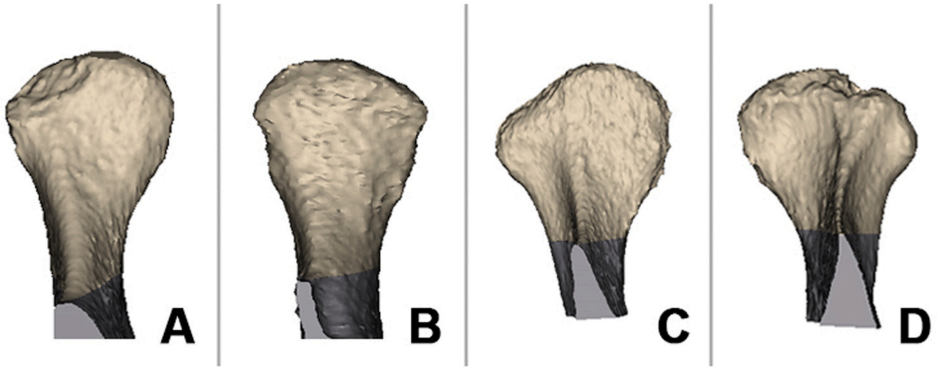

Fig. 3. Three-dimensional images of mild CRSS results: (A) L4/M5 (right condyle); (B) L5/M4 (right condyle); (C) L3/M5 (right condyle); (D) L4/M4 (left condyle).

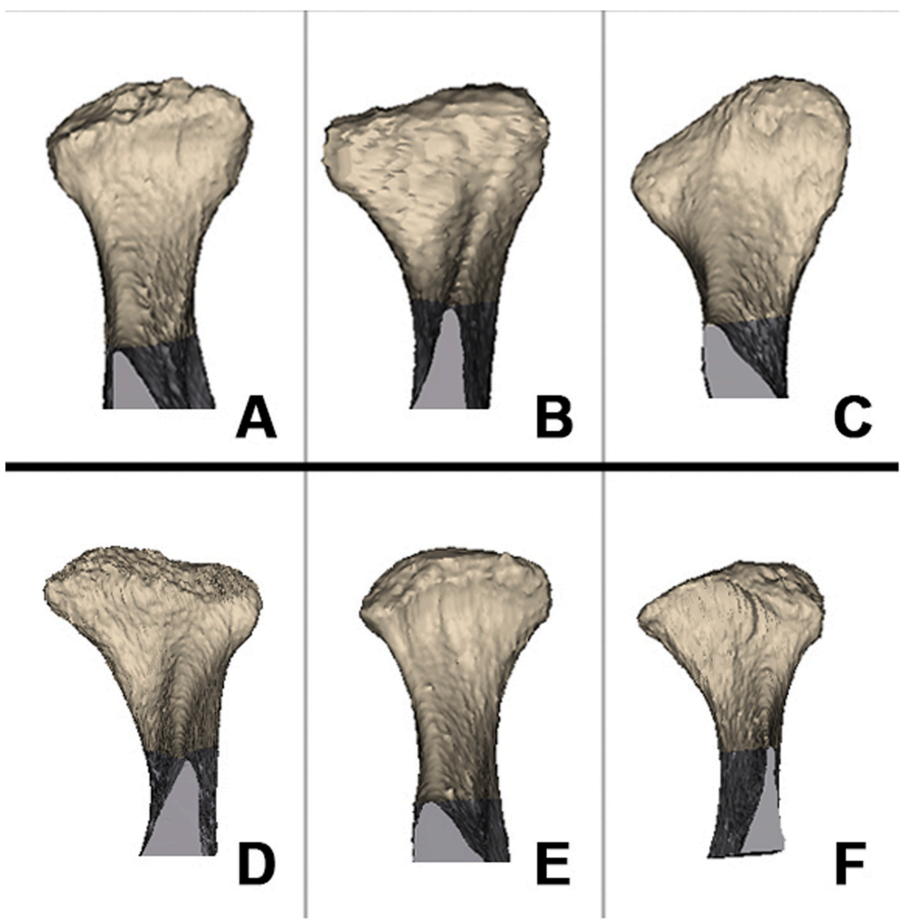

Fig. 4. Three-dimensional images of moderate CRSS results: (A) L3/M4 (right condyle); (B) L4/M3 (left condyle); (C) L2/M4 (right condyle); (D) L3/M3 (left condyle); (E) L2/M3 (right condyle); (F) L3/M2 (left condyle).

showed a higher stability rate than the discontinuous cortex group: 94.1% (176/187) compared to 41.7% (65/156) (χ^2 = 63.142, P < 0.001). The difference in stability rate among the three density type groups (hypodense, normal density, and sclerosis) was found to be highly significant (Pearson's χ^2 test, P < 0.001). According to the Bonferroni test, the stability rate was significantly lower in the hypodense group (60.7%, 54/89) than in the normal density (81.3%, 139/171) (P < 0.001) and sclerosis groups (89.2%, 74/83) (P < 0.001). No significant difference was found between the normal density and sclerosis groups (P = 0.110). In the discontinuous cortex group, the discontinuous cortex transformed into continuous cortex in 74.4% (116/156) of cases during the follow-up period. In the continuous cortex group, the cortex transformed into a discontinuous cortex in 8.0% (15/187) of cases (Fig. 7).

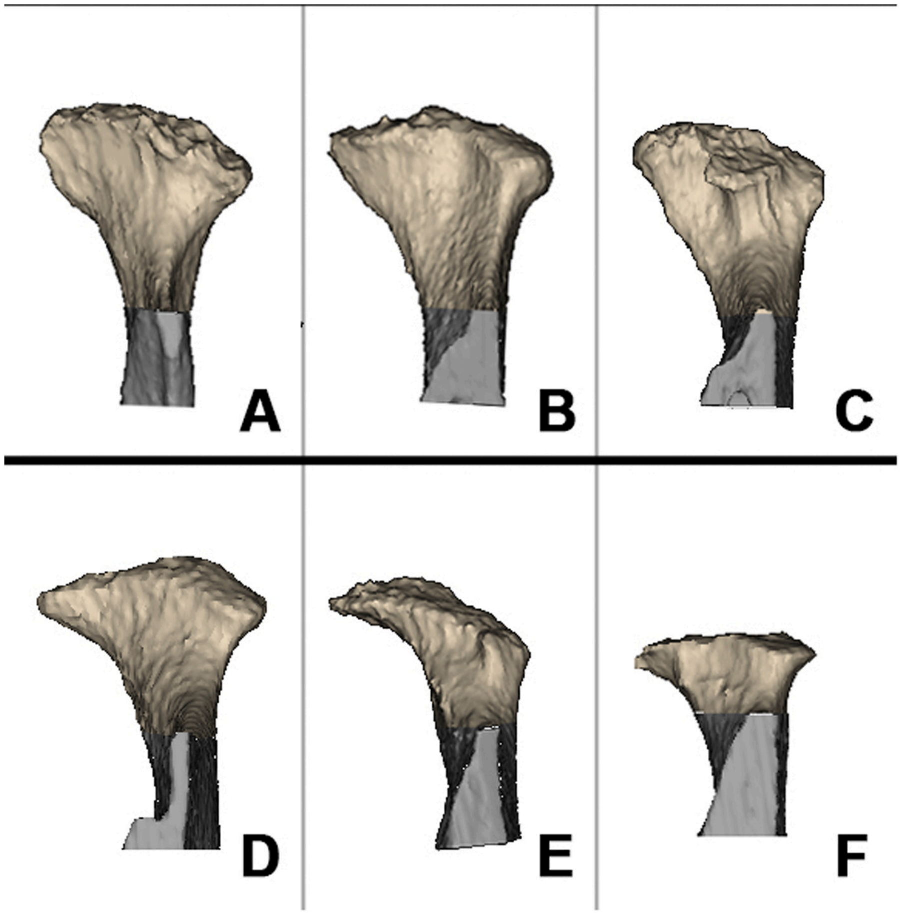

Fig. 5. Three-dimensional images of severe CRSS results: (A) L1/M3 (left condyle); (B) L2/M2 (left condyle); (C) L1/M2 (left condyle); (D) L1/M1 (left condyle); (E) L0/M1 (left condyle); (F) L0/M0 (left condyle).

Table 1A. Results of CRSS evaluation and cephalometric analysis.

Variables	Normal Mean (SD)	Mild Mean (SD)	Moderate Mean (SD)	Severe Mean (SD)
SNA (°)	82.5 (3.7)	82.3 (4.4)	81.9 (3.5)	80.8 (3.4)
SNB (°)	79.8 (4.8)	79.2 (5.3)	77.0 (4.0)	73.7 (4.6)
ANB (°)	2.8 (3.7)	3.1 (4.2)	4.9 (3.3)	7.0 (3.4)
MP to SN (°)	34.2 (7.1)	35.5 (8.2)	41.5 (7.5)	47.7 (7.4)
Ar–Go′ (mm)	47.9 (6.3)	47.3 (7.0)	42.4 (5.7)	39.2 (3.7)
Go′–Pog (mm)	61.9 (5.3)	62.8 (5.3)	61.1 (4.2)	59.9 (5.2)
Ar–Go′–Me (°)	121.2 (7.7)	120.0 (7.4)	123.1 (7.5)	123.6 (5.8)

SD, standard deviation.

Discussion

Temporomandibular joint osteoarthrosis (TMJ-OA) is a degenerative process with a non-inflammatory origin that is closely related to condylar remodelling.[6] Disc displacement is one of the common causes of TMJ-OA or condylar remodelling.[8,9] The pathological process is characterized by the deterioration and repair of the articular cartilage and subchondral bone.[6] Bone resorption, sclerosis, osteophyte formation, and various degrees of morphological changes in the condyle may occur in TMJ-OA.[7]

TMJ-OA is generally a self-limiting disease with a satisfactory prognosis.[17] Dysfunctional condylar remodelling may be complicated by prolonged masticatory disturbances. In teenagers and young adults in particular, certain circumstances of TMJ-OA are accompanied by Class II deformities.[2,5] In recent years, the concept of idiopathic condylar resorption (ICR) or condylar resorption has gained attention.[2,13] The lack of a grading method for condylar morphological changes has caused some conceptual confusion in diagnosis.

An objective grading system for condylar morphological changes in TMJ-OA – the condylar remodelling scoring system (CRSS) – is proposed here. This work improves the radiological diagnosis of TMJ-OA in the following ways. First, the CRSS provides a reliable method to classify the different degrees of condylar remodelling in TMJ-OA. Second, this classification of morphological changes will

Table 1B. Cephalometric comparison of different CRSS types.

Variables	Normal vs mild		Normal vs moderate		Normal vs severe		Mild vs moderate		Mild vs severe		Moderate vs severe	
	t	*P*-value	*t*	*P*-value	*t*	*P*-value	*t*	*P*-value	*t*	*P*-value	*t*	*P*-value
SNA (°)	0.3	0.775	0.9	0.375	2.9	0.005*	0.5	0.636	2.2	0.033*	1.9	0.057
SNB (°)	0.6	0.567	3.3	0.001*	7.4	< 0.001*	2.4	0.019*	6.0	< 0.001*	4.2	< 0.001*
ANB (°)	−0.4	0.677	−3.3	0.002*	−6.9	< 0.001*	−2.5	0.016*	−5.7	< 0.001*	−3.6	< 0.001*
MP to SN (°)	−0.9	0.386	−5.4	< 0.001*	−1-0.7	< 0.001*	−3.0	0.004*	−7.6	< 0.001*	−4.7	< 0.001*
Ar–Go′ (mm)	0.5	0.605	5.0	< 0.001*	10.1	< 0.001*	3.9	< 0.001*	8.3	< 0.001*	3.9	< 0.001*
Go′–Pog (mm)	−0.9	0.381	0.8	0.407	2.2	0.030*	1.8	0.082	3.0	0.004*	1.5	0.145
Ar–Go′–Me (°)	0.9	0.386	−1.3	0.205	−2.0	0.047*	−2.1	0.038*	−3.0	0.003*	−0.5	0.649

Independent-samples *t*-test, *t*-values; *significant, $P < 0.05$.

help clarify the confusion between the concepts of TMJ-OA and ICR.[5] Third, this classification of morphological changes would be a helpful tool to evaluate the disease course and treatment outcome of TMJ-OA and ICR. The CRSS will help to clarify whether ICR is an uncontrollable progressive disease or a self-limiting remodelling process.

The relationship between ICR and TMJ-OA remains unresolved. Whether ICR is a separate disease or a subtype of TMJ-OA has yet to be determined and results in confusion and problems. Although many articles using the term ICR have been published, little progress has been made towards obtaining a unanimous consolidated definition beyond Arnett's original definition. An objective method to evaluate the 3D condylar morphological changes in TMJ-OA or ICR is lacking.[18] Arnett et al.,[12] who introduced the use of 'ICR', divided condylar remodelling into functional and dysfunctional circumstances. Two main aspects defined dysfunctional remodelling: condylar morphological changes and dentofacial deformity. If TMJ-OA entails joint morphological changes, decreased ramus height, altered occlusion, or a decreased growth rate, the process would exemplify dysfunctional remodelling. The present study demonstrated that the skeletal profile of the mild score group showed almost no difference from that of the normal score group. However, significant changes in the skeletal pattern could occur when the condyles appeared to have moderate to severe morphological changes. The condyles with moderate morphological changes were inclined to be associated with a retrognathic and clockwise rotating mandible, shorter ramus height, and reduced mandibular length. Furthermore, the condyles with severe morphological changes were prone to present with a retrognathic and clockwise rotating mandible, shorter ramus height, reduced mandibular length, larger mandibular angle, and maxillary retrusion. These changes could logically be due to the condylar remodelling and subsequent shortening of the ramus. The larger gonial angle and shorter mandibular length observed in the severe group strongly suggest a close association between the development of TMJ-OA and mandibular morphogenesis. At the same time, the maxillary change in the severe group might occur secondary to the mandibular retrusion. These results suggest that ICR may be a form of dysfunctional remodelling of the TMJ-OA. Until now, the level of evidence on the aetiology and management of ICR have been low.[19] As the clinical features of ICR are comparable to those found in other TMJ-OA conditions, until the aetiology of this entity is completely elucidated, it should be included in the same context of osteoarthritic disease for the sake of discussing its management.

The CRSS in this study provided a feasible qualitative evaluative method for the extent of the involvement of functional or dysfunctional remodelling. In the CRSS, a normal condyle is divided into 10 anatomical regions using 11 anatomical reference landmarks on 3D views. The reference landmarks were selected based on the anatomical relationship between the condyle, disc, and joint ligaments. The condylar head is elongated transversely and is convex both transversely and anteroposteriorly. The articular convexity of the condylar head is divided into medial and lateral slopes by a variable prominent crest, which is seen in the frontal view, and anterior and posterior surfaces that slope inferiorly from the transverse ridge at its summit towards the anterior ridge and posterior ridge, respectively. The lateral and medial poles of the condyle, which are just below the articular surface, are usually marked by distinct bony tubercles for attaching the capsule and meniscus.[20–22] The functional articular surface inside the lower joint capsule is defined by points B and G, which represent the outermost and innermost edges, respectively (Fig. 1). Between points B and G, there is a curved line that can be seen on 3D images, and below that, there is the attachment area of the superior head of the lateral pterygoid muscle.

The lateral pole of the condyle extends slightly beyond the outer surface of the ramus and is roughened to attach the lateral collateral ligaments but not the muscle fibres. Furthermore, there is often a well-developed lateral subcondylar tubercle, a bony protuberance on the lateral aspect of the neck of the condyle with a narrow groove separating the tubercle from the articular surface of the condyle, which is the ligamental attachment site. The medial pole of the condyle juts considerably beyond the inner surface of the ramus and is also slightly roughened to attach the articular disc as well as fibres from the superior lateral pterygoid muscle.[23–25] Point C represents the bony protuberance on the lateral pole. The area between G and H represents the attachment area of the capsule and the lateral pterygoid muscle.

The CRSS allows the area involved in the pathological progress of TMJ-OA to be quantified. The degree of condylar remodelling can be classified according to the reference landmarks. The changes in mild TMJ-OA mainly involved the articular surface between points B and G. The changes in moderate TMJ-OA partially involved the attachment areas of the joint capsule and the temporomandibular ligaments on the lateral and medial poles. Severe TMJ-OA

Table 2. Evaluation of condylar volume changes according to quantitative measurements.

Type	Number	Volume 1 (mm^3) Mean (SD)	Volume 2 (mm^3) Mean (SD)	*t*	*P*-value
Cortical type					
Continuous	187	928 (333)	927 (341)	0.033	0.974
Discontinuous	156	1006 (385)	907 (345)	8.346	< 0.001 *
Density type					
Hypodense	89	954 (333)	844 (319)	6.658	< 0.001 *
Normal density	171	1000 (338)	969 (322)	3.614	< 0.001 *
Sclerosis	83	896 (415)	895 (392)	0.166	0.868
Total		963 (359)	918 (343)	6.489	< 0.001 *

SD, standard deviation. Paired-samples t-test, t-values; *significant, $P < 0.05$.
[a]Volume 1: initial condyle; Volume 2: follow-up condyle.

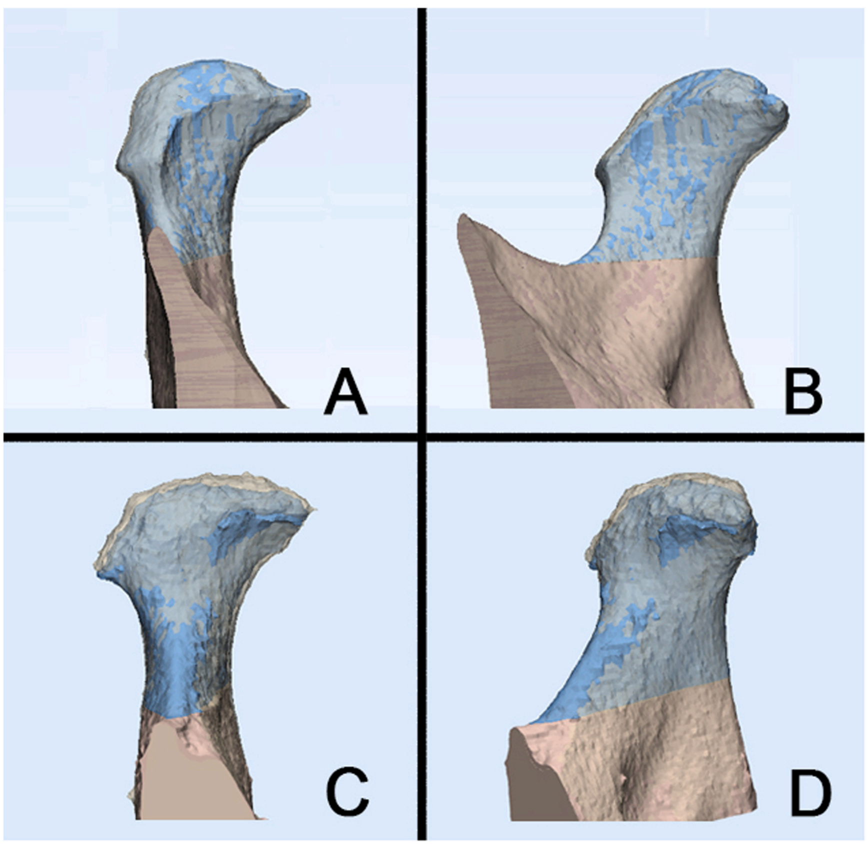

Fig. 6. The stability of severe TMJ-OA (sTMJ-OA). The initial condyle is shown with a translucent surface and the final condyle in blue. (A) Frontal and (B) oblique views of a condyle. The condyle was stable and had an initial volume of 728 mm^3 and a final volume of 737 mm^3 (CVCR = −1%). (C) Frontal and (D) oblique views of another condyle. The condyle was unstable and had an initial volume of 1100 mm^3 and a final volume of 931 mm^3 (CVCR = 15%).

meant that the attachment areas of the medial and lateral poles were lost. A CRSS score of no more than 4 points was defined as a significantly reduced condylar volume, which could be defined as severe TMJ-OA. The intra- and inter-observer agreement showed that the CRSS had good diagnostic consistency and reliability.

The clinical signs and symptoms of the TMJ might be associated with the derangements of the condyle–disc complex and inflammatory joint disorders (synovitis, capsulitis, retrodiscitis, and osteoarthritis).[4] This study revealed that the clinical signs and symptoms of the TMJ might not predict condylar morphological change. It was also found that the condyles were more prone to morphological change in female patients than male patients, and in adult patients than in adolescent patients, consistent with most of the literature.[6,12]

A quantitative volumetric analysis of the condyles provides a more accurate and reproducible scientific research protocol for longitudinal follow-up and quantitative analysis of condylar changes.[26] The CRSS, based on 3D CBCT images, helps to accurately qualify the extent of TMJ-OA. The lateral and medial poles of the condyle were evaluated separately to reveal how the condylar height reduction occurred.

The CRSS scores of the lateral pole were found to be significantly lower than those of the medial pole (mean 2.73 vs 3.14), indicating that the lateral pole is first involved in the course of the lesion and is more severely affected. The condyle can rotate on a fixed axis that is generated by connecting the medial poles of the bilateral condyles. In the opening and closing movement of the mandible, the lateral poles translate like a windshield wiper and do not align with the fixed axis of rotation. The motion range and stress on the lateral side are higher than those on the medial side, which seems to be one of the reasons why the degree of condylar remodelling on the lateral side is more severe than that on the medial side.[27]

Whether TMJ-OA or ICR progresses indefinitely or becomes somewhat quiescent is still unclear. The study results showed that sTMJ-OA did not exhibit unlimited and progressive bone resolution. The majority of sTMJ-OA patients with a continuous and normal density or sclerosed cortex showed no significant morphological or quantitative volumetric changes. Condyles with a discontinuous and hypodense cortex showed an increased probability of volume reduction. These results indicate that after the condyle has undergone a phase of cortical destruction in the initiation of TMJ-OA, it reforms smooth and continuous cortical bone. The whole process is known as condylar remodelling,[11] and the condyles have self-rehabilitation abilities. In the

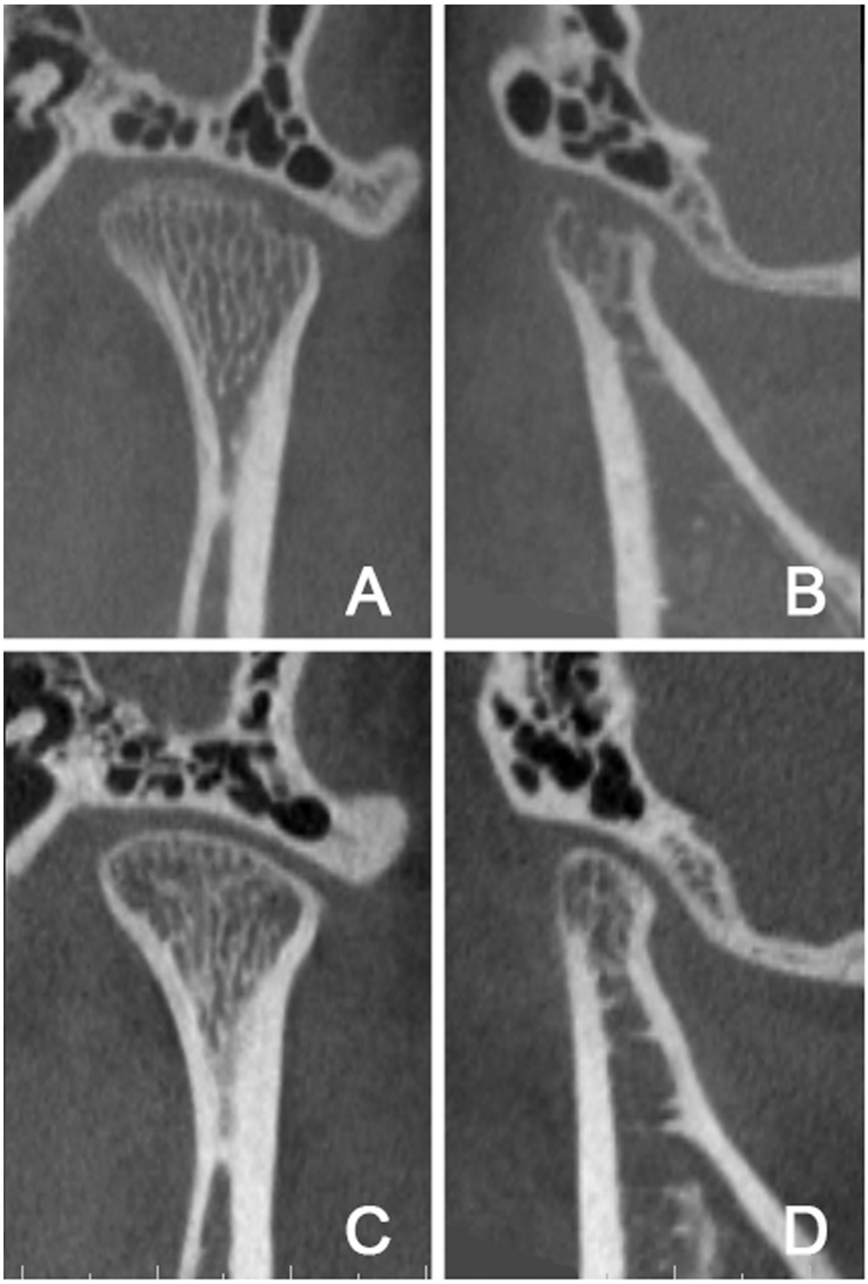

Fig. 7. Cortical bone change in severe TMJ-OA (sTMJ-OA). The cortex of the condylar surface was discontinuous at the first visit (A, B) and transformed into a continuous and sclerosed cortex after the observation period (C, D).

present study, most condyles with a discontinuous cortex transformed into a stable state featuring an intact and continuous cortex in the natural course. This indicates that the discontinuous cortex may be a remodelling phase rather than a lasting condition. The TMJ condyle is covered by fibrocartilage tissue with a distinct fibrous superficial zone, which may contain a reservoir of stored fibrocartilage stem cells that can produce mature chondrocytes and osteoblasts and generate cartilage and bone.[28]

In conclusion, the condylar remodelling scoring system (CCRS) is an innovative and feasible method for classifying the degree of condylar remodelling with good reliability. The lateral side of the condyle exhibited a slightly more severe degree of remodelling than the medial side. Patients with severe condylar morphological changes in TMJ-OA were found to be more prone to present with a retrognathic and clockwise rotating mandible, shorter ramus height, reduced mandibular length, larger mandibular angle, and maxillary retrusion. Compared to the continuous cortex type, the discontinuous cortex type in severe TMJ-OA was found to be unstable. The discontinuous cortex type condyle had the ability to self-rehabilitate and had mostly converted into the continuous cortex type during follow-up (mean 2 years).

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Competing interests

None.

Ethical approval

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Patient consent

Not required.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ijom.2022.08.001.

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