Int. J. Oral Maxillofac. Surg. 2020; 49: 932–939
https://doi.org/10.1016/j.ijom.2019.09.004, available online at https://www.sciencedirect.com

International Journal of Oral & Maxillofacial Surgery

Clinical Paper
TMJ Disorders

Association between hypoplastic condyles and temporomandibular joint disc displacements: a cone beam computed tomography and magnetic resonance imaging metrical analysis

Y.-S. Liu[1,2,3,4,5], A.U.-J. Yap[1,6,7,8], J. Lei[1,2,3,4,5], M.-Q. Liu[1,2,3,4,5], K.-Y. Fu[1,2,3,4,5]

[1]Center for TMD & Orofacial Pain, Peking University School & Hospital of Stomatology, Beijing, China; [2]Department of Oral & Maxillofacial Radiology, Peking University School & Hospital of Stomatology, Beijing, China; [3]National Clinical Research Center for Oral Diseases, Beijing, China; [4]National Engineering Laboratory for Digital and Material Technology of Stomatology, Beijing, China; [5]Beijing Key Laboratory of Digital Stomatology, Beijing, China; [6]Department of Dentistry, Ng Teng Fong General Hospital, National University Health System, Singapore; [7]Faculty of Dentistry, National University of Singapore, Singapore; [8]National Dental Centre Singapore, Singapore

Y. -S. Liu, A. U. -J. Yap, J. Lei, M. -Q. Liu, K. -Y. Fu: Association between hypoplastic condyles and temporomandibular joint disc displacements: a cone beam computed tomography and magnetic resonance imaging metrical analysis. Int. J. Oral Maxillofac. Surg. 2020; 49: 932–939.

Abstract. This study investigated the association between hypoplastic condyles and disc displacements without reduction (DDw/oR). Consecutive patients with non-syndromic unilateral condylar hypoplasia were recruited and clinical, cone beam computed tomography (CBCT) and magnetic resonance imaging (MRI) data were acquired. Linear measurements including condylar head width, depth, height and condyle length were determined with CBCT while MRI was used to assess disc position, morphology and displacement. A total of 43 patients were enrolled of which 93.02% had a history of temporomandibular disorders (TMDs) and 83.72% presented with TMD signs and symptoms. Depth and height of the condylar head along with condyle length of hypoplastic joints (6.68 ± 1.67 mm, 4.97 ± 1.25 mm and 14.49 ± 3.02 mm, respectively) were significantly lesser than normal joints (7.77 ± 1.26 mm, 6.35 ± 1.45 mm and 18.20 ± 3.18 mm) ($P < 0.001$). The prevalence of DDw/oR was significantly higher in hypoplastic joints (79.07% versus 13.95%) ($P < 0.001$). Joints with hypoplastic condyles had shorter disc lengths (6.99 ± 2.16 mm vs, 8.45 ± 2.26 mm) ($P = 0.007$). Furthermore, disc displacements were significantly more advanced (8.52 ± 2.84 mm) and severe (76.74% with severe translations) when compared to the contralateral side (4.77 ± 2.97 mm and 32.56%) ($P < 0.05$). A significant association was observed between condylar hypoplasia and temporomandibular

joint DDw/oR with hypoplastic joints exhibiting more severely displaced and deformed discs. DDw/oR coupled with repaired degenerative joint disease may mimic condylar hypoplasia radiographically.

Key words: temporomandibular disorders; condylar hypoplasia; disc displacement without reduction; osteoarthritis; degenerative joint diseases; condylar remodelling.

Accepted for publication 10 September 2019
Available online 26 September 2019

Mandibular condylar hypoplasia has been defined as the 'incomplete or underdevelopment' of the temporomandibular joint (TMJ) owing to congenital or acquired reasons[1,2]. Congenital hypoplasia usually occurs in utero and involves diverse pathological processes[1,3]. They are often associated with head and neck syndromes including Treacher Collins syndrome, hemifacial microsomia, Goldenhar syndrome, Hallerman–Streiff syndrome and hemifacial atrophy[3,4]. Acquired condylar hypoplasia occurs after birth during the development process of the condyle. Although their pathogenesis is not well understood, acquired hypoplasia has been linked to trauma, infection and radiation injury of the TMJ and adjacent structures as well as rheumatoid arthritis[1,3]. On radiographic examination, hypoplastic condyles have normal morphology and structure but are diminished in size. When marked, they can lead to mandibular asymmetry/deviation and occlusal plane canting if unilateral or micrognathia when bilateral[1].

Degenerative joint disease (DJD) is a degenerative condition involving the TMJ characterized by deterioration of articular tissue with concomitant osseous changes in the condyle and/or articular eminence[5]. The prevalence of TMJ DJD is estimated to range from 8% to 35% in the general population based on radiographic assessment[6,7]. Prevalence was found to be considerably higher (approximately 60%) in individuals with TMJ disc displacement without reduction (DDw/oR)[8]. Many previous studies had described a possible causal relationship between DDw/oR and TMJ DJD[8,9]. Displaced discs may well interfere with condylar mobility and lead to' increased loading of the anterior surfaces of condyles. Articular cartilage and subarticular bone destruction could progressively develop over time. TMJ DJD may bring about deviation in condylar form and even dentofacial deformities, especially in youths.

A case report was recently published documenting the transition from 'normal' condyle morphology to joint flattening/erosion and ultimately a smaller remodelled 'normal' condyle in a 16-year-old male with DDw/oR[10]. Remodelling of the TMJs is an adaptive process essential for stress distribution and function. The condyle is considered the primary growth centre of the mandible and the condylar cartilage plays an essential role in mandible development. It is divided into the fibrous articular covering, proliferative layer, hypertrophic zone and calcified cartilage. Cell generation in the proliferative layer of the condylar cartilage exists until age 20 years.[11] With its potential capacity of active remodelling, repair or regeneration of degenerated TMJ is highly viable in children and adolescents. Condylar repair (remodelling with no new bone formation) leads to smaller joints while regeneration (remodelling with new bone formation) results in joints with original form and shape[11–13].

At our centre, a number of adolescents and young adults presented with complaints of malocclusion and facial asymmetry without any congenital deformities or history of overt TMJ injury. They were subsequently diagnosed with unilateral or bilateral condylar hypoplasia upon radiographic investigation. Considering the available literature, it was hypothesized that hypoplastic condyles may arise after DDw/oR and DJD repair. The objective of this study was thus to evaluate the association between hypoplastic condyles and TMJ DDw/oR in patients presenting with non-syndromic unilateral condylar hypoplasia. Prevalence of DDw/oR, degree of disc displacement and disc morphology were also compared between hypoplastic and contralateral joints. The null hypotheses were as follows: (a) the prevalence of TMJ DDw/oR in hypoplastic condyles is low, and (b) hypoplastic condyles do not have more severely displaced or deformed discs when compared to contralateral joints.

Materials and methods

Ethics approval from the Biomedical Institutional Review Board of Peking University School of Stomatology was obtained prior to starting the study (PKUSSIRB-201522045). Consecutive patients who attended our centre with non-syndromic unilateral condylar hypoplasia from August 2015 to August 2016 were invited to participate in the study. Subject inclusion criteria were as follows: (1) CBCT imaging showing bilateral TMJs with normal condylar shape/bony architecture and no degeneration but with one side exhibiting smaller condylar size and thinner condylar neck[14], and (2) amenable to magnetic resonance imaging (MRI). Exclusion criteria were: (1) CBCT images revealing TMJs with degenerative changes including condylar erosion/destruction, bone sclerosis, osteophyte formation, deviation in form and cyst-like lesions[14], (2) presence of unilateral condylar hyperplasia, (3) presence of congenital/syndromic deformities, (4) history of overt TMJ trauma, infection, tumor or radiation, (5) presence of systemic joint diseases, e.g. rheumatoid arthritis. Subjects' chief complaints, history and clinical findings including maximum mouth opening, TMJ sounds, mandibular movements, TMJ and masticatory muscle palpation and dentofacial discrepancies were documented.

Images of the bilateral TMJs were obtained using a three-dimensional multi-image CBCT (J. Morita Corp. Kyoto, Japan) at 76–80 kV and 4.2–6.0 mA, field of view 6×6 cm^2. The scanned data were reconstructed, and multiple images of the axial, coronal, and sagittal planes of the condyles at 0.375-mm slice intervals were acquired. Morphological evaluation of condyle was performed using Kinzinger's method[15]. Linear measurements were determined from the axial, coronal and sagittal slices with the largest condylar diameters (Fig. 1), and included width (mediolateral dimension), depth (anteroposterior dimension) and height of the condylar head as well as the condylar length (CL). The width and depth of the condylar head were obtained in the axial plane, while the height was obtained in the coronal plane. Condyle length was determined in the sagittal plane by calculating the vertical distance from the most superior point of

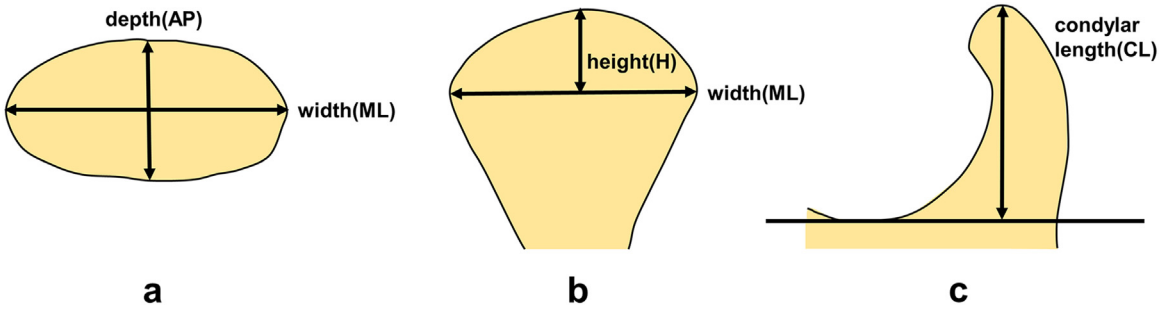

Fig. 1. Morphological assessment of the condyles: Condylar head depth (anteroposterior (AP) diameter) and width (mediolateral (ML) diameter) in axial plane (A), height (H) in coronal plane (B) and condylar length (CL) in sagittal plane (C).

the condyle to the tangent of the sigmoid notch that parallels the Frankfurt-Horizontal (FH) plane (FH plane).

MRI was carried out in closed-mouth and maximum-opening positions using a 1.5-Tesla MRI scanner (NOVUS, Siemens, Munich, Germany) with TMJ surface coils. Subjects were placed supine with their heads positioned with the FH plane perpendicular to the floor. The centre beam was then lined up with the sagittal plane. The MRI protocol consisted of an initial low-resolution T1-weighted [repetition time (TR) 300 ms; echo time (TE) 10 ms] axial localizing scan, followed by Proton-weighted (TR 1760 ms, TE 15 ms) oblique sagittal scan vertical to the long axis of each condyle. The field of view was 12 × 12 cm^2 and matrix size was 512 × 512. Slice thickness and inter-slice spacing were set at 2 mm and 0.2 mm, respectively.

Disc displacement takes place when the posterior band of the disc is located anterior to the 11:30 position and the intermediate zone of the disc is anterior to the condylar head in the maximum intercuspal position[2]. A diagnosis of disc displacement with reduction (DDwR) is ascribed if the intermediate zone of the disc is located between the condylar head and the articular eminence on full opening. Conversely, the joint is deemed to have DDw/oR if the intermediate zone of the disc is located anterior to the condylar head.

Based on Hu's[16] method, the sagittal slice with the largest cross-section of the condyle (usually the central slice) was selected for tracing and analysis. Point A was the most superior point of glenoid fossa; point B and point D were the most posterior and anterior points of disc, respectively; point C was the midpoint of intermediate zone. The length of AB was defined as the displaced distance and the summation of BC and CD was disc length. If the disc was severely deformed and point C could not be identified, the length of BD was measured directly as the disc length (Fig. 2).

Evaluation of disc morphology was conducted in the closed-mouth position, and was classified as follows[16]: Type I – biconcave configuration with no deformity; Type II – biconcave configuration with thick posterior band or mildly folded; Type III – moderate folded, U-shaped or V-shaped disc with sufficient length to cover the condylar head; Type IV – folded and shortened disc with inadequate length to cover the condylar head; Type V – severely folded, biconvex or rounded configuration (Fig. 3).

Angular assessment of the posterior band location based on a clock face[17] was adopted to determine the degree of disc displacement. The largest sagittal slice in the closed-mouth position was chosen to trace the contour of condyle, disc and articular fossa. The most superior point of condyle was defined as 12

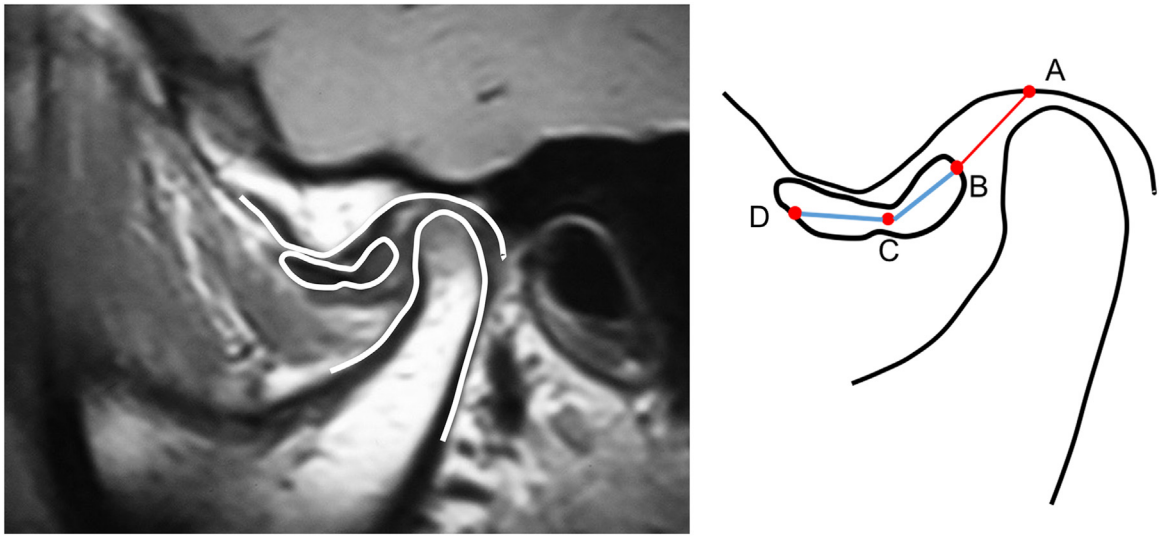

Fig. 2. Measurement of disc length and displaced distance. (A) The most superior point of the glenoid fossa; (B) the most posterior point of the disc; (C) the midpoint of the intermediate zone; (D) the most anterior point of the disc.

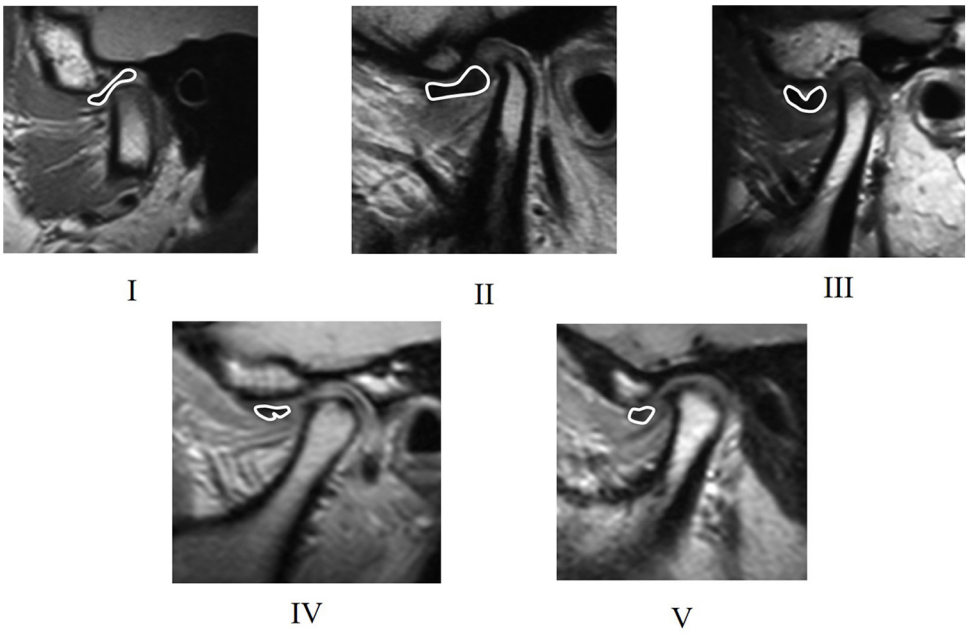

Fig. 3. Classification of disc morphology.

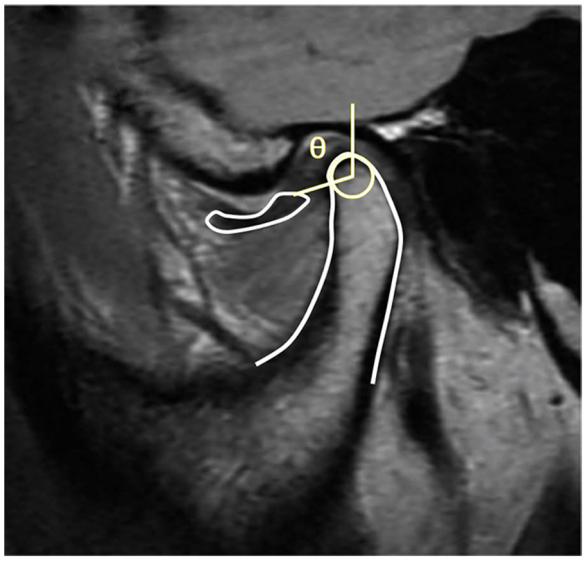

Fig. 4. Angular assessment of disc displacement.

Table 1. Percentage of subjects with temporomandibular disorder (TMD) complaints, history and signs/symptoms.

	With TMD	Without TMD	Total
TMD chief complaint	17 (39.53%)	26 (60.47%)	43
TMD history	40 (93.02%)	3 (6.97%)	43
TMD signs/symptoms during initial visit	36 (83.72%)	7 (16.27%)	43

o'clock. The angle (θ) of the posterior band location was measured (Fig. 4), and the degree of disc displacement was classified as normal ($-15° < \boldsymbol{\theta} \leq 15°$), mild ($15° < \boldsymbol{\theta} \leq 45°$), moderate ($45° < \boldsymbol{\theta} \leq 75°$), severe ($75° < \boldsymbol{\theta} \leq 105°$), and very severe ($\boldsymbol{\theta} > 105°$)[2,5,17].

Statistical analysis

All data were analysed using IBM SPSS Statistics for Windows, version 24.0 (IBM Corp., Armonk, NY, USA) with significance level set at 0.05. Normality of data was assessed using the Kolmogorov–Smirnov test. As the data were normally distributed, quantitative CBCT and MRI measurements were compared using paired samples *t*-test. The prevalence of DDw/oR, disc morphology and angular assessment were compared with the χ^2 test.

Results

A total of 43 patients (mean age 22.71 ± 6.21 years) with unilateral hypoplastic condyles were enrolled in this study. They were comprised of 31 females (72.1%) and 12 males (27.9%). Their chief complaints and reasons for treatment seeking were pain, clicking, limited mouth opening, facial asymmetry and orthodontic or orthognathic referral. Although only 39.53% (17/43) of the patients presented with TMD complaints, 93.02% (40/43) of them had a history of TMD, including one or more symptoms such as joint pain, clicking, locking and/or limited mouth opening. Physical examination revealed that 83.72% (36/43) of the subjects had TMD signs and symptoms (joint pain when opening the mouth, joint tenderness, clicking or crepitus, locking, limited mouth opening) (Table 1).

Mean width, depth and height of the condylar head as well as condyle length for hypoplastic and normal joints are shown in Table 2. No significant difference in width of condylar head was observed between hypoplastic and normal joints ($P = 0.063$). Depth and height of condylar head as well as condyle length

Table 2. Mean condylar head width, depth, height and condyle length.

	Hypoplastic side	Contralateral side	P^*
Width of condylar head (mm)	17.99 ± 2.60	18.63 ± 2.34	0.063
Depth of condylar head (mm)	6.68 ± 1.67	7.77 ± 1.26	<0.001
Height of condylar head (mm)	4.97 ± 1.25	6.35 ± 1.45	<0.001
Condyle length (mm)	14.49 ± 3.02	18.20 ± 3.18	<0.001

* Paired samples *t*-test.

was significantly lesser in hypoplastic joints ($P < 0.001$) (Fig. 5).

Prevalence of DDw/oR in hypoplastic joints (79.07%, 34/43) was significantly higher than the contralateral normal joints (13.95%, 6/43) (Table 3).

Discs of hypoplastic joints (6.99 ± 2.16 mm) were significantly shorter than their contralateral side (8.45 ± 2.26 mm, $P = 0.007$). Displaced distance on the hypoplastic side was also significantly longer (8.52 ± 2.84 mm vs. 4.77 ± 2.97mm, $P < 0.001$) (Fig. 6).

Frequency of the different types of disc morphology is shown in Table 4. The most common disc morphology on the hypoplastic side was type IV, while it was type III on the contralateral side. The difference was statistically significant ($P = 0.001$).

Displacement angle is shown in Table 5; 76.74% (33/43) of the discs in hypoplastic joints were severely or very severely displaced. Incidence was substantially higher than on the contralateral side. On the contrary, normal disc position and mild displacements were more frequently observed on the contralateral side (Table 5).

Discussion

This study assessed the association between hypoplastic condyles and TMJ DDw/oR. In addition, it compared the prevalence of DDw/oR, degree of disc displacement and disc morphology between hypoplastic and contralateral normal joints. The term 'atrophy' denotes the wasting away of a body part or organ, especially as a result of degeneration. TMJ or condylar atrophy is, however, not specified in the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD)[5]. Clinically, radiographic presentations of small condyles with no evidence of degenerative changes would likely be diagnosed as condylar hypoplasia[14]. Patients with this condition are mostly adolescents and young adults. The term 'hypoplasia' was thus deemed more appropriate than 'atrophy' given absence of TMJ DJD and the mean age of patients. As the prevalence of TMJ DDw/oR in hypoplastic condyles was significantly higher than on their contralateral side, and hypoplastic condyles presented more severely displaced or deformed discs, both null hypotheses were rejected.

TMJ disc displacements are very common in both symptomatic and asymptom-

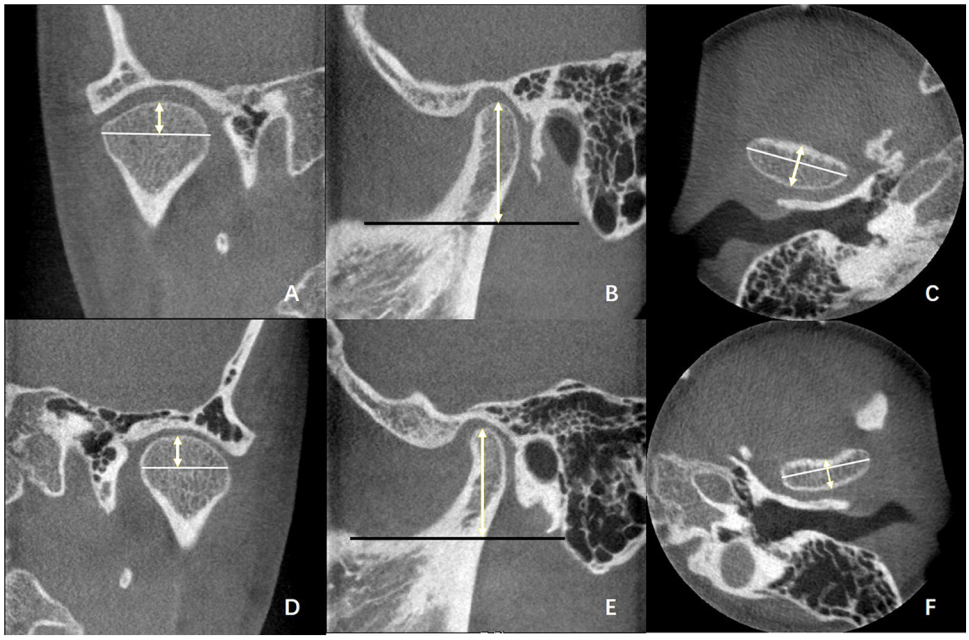

Fig. 5. Bilateral temporomandibular joint cone beam computed tomograohy images of a patient with unilateral hypoplastic condyle (A–C: the contralateral side; D–F: the hypoplastic side). The white double arrows indicated the height of condylar head (A, D), the condylar length (B, E) and the condylar depth (C, F).

Table 3. Prevalence of disc displacement in hypoplastic and contralateral joints.

	Normal (%)	DDwR (%)	DDw/oR (%)	P^*
Hypoplastic side	2.32 (1/43)	18.60 (8/43)	79.07 (34/43)	<0.001
Contralateral side	20.93 (9/43)	65.12 (28/43)	13.95 (6/43)	

DDwR, disc displacement with reduction; DDw/oR, disc displacement without reduction.
* χ^2 test.

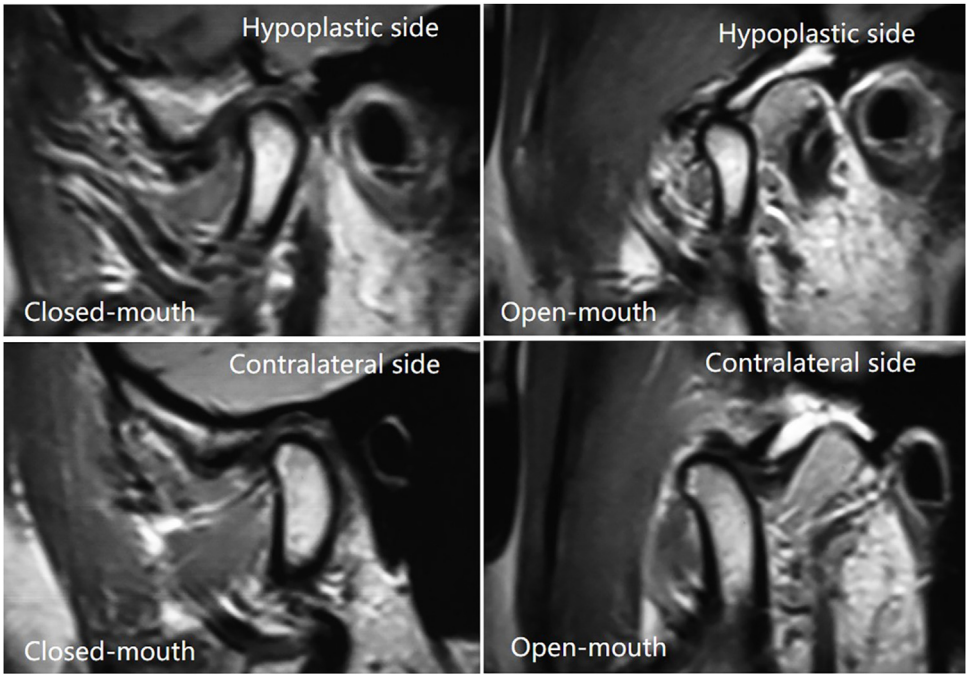

Fig. 6. Bilateral temporomandibular joint magnetic resonance image of a patient. The disc length is shorter and disc displacement is greater on the hypoplastic side.

Table 4. Comparison of disc morphology in hypoplastic and contralateral joints.

	Type I (%)	Type II (%)	Type III (%)	Type IV (%)	Type V (%)	P^*
Hypoplastic Side	2.32 (1/43)	9.30 (4/43)	13.95 (6/43)	65.12 (28/43)	9.30 (4/43)	0.001
Contralateral Side	20.93 (9/43)	23.26 (10/43)	32.56 (14/43)	20.93 (9/43)	2.32 (1/43)	

* χ^2 test.

Table 5. Angular assessment of disc displacement in hypoplastic and contralateral joints.

	Normal (%)	Mild (%)	Moderate (%)	Severe (%)	Very severe (%)	P^*
Hypoplastic side	2.32 (1/43)	2.32 (1/43)	18.60 (8/43)	48.84 (21/43)	27.91 (12/43)	<0.001
Contralateral side	20.93 (9/43)	11.63 (5/43)	34.88 (15/43)	25.58 (11/43)	6.98 (3/43)	

* χ^2 test.

atic populations. DJD had been linked to DDw/oR[9,18] and attributed to joint overloading or decreased adaptive capacity of articular surfaces. The main function of the TMJ disc is to coordinate the surface of the condyle and articular fossa, as well as to disperse stress during functional movements. When the TMJ disc is displaced, structural and functional balance may be disrupted. Dias and co-workers stated that joints with DDwR and DDw/oR were 2.73 and 8.25 times more likely to have DJD, respectively[19]. Other studies have demonstrated that decreased condyle volume with progressive disc displacement[20]. In addition, DDw/oR could be accompanied by reduced condylar height and asymmetric joint growth[21,22]. A series of studies on the relationship between disc displacement, facial morphology and mandibular development showed that patients with unilateral DDw/oR had more obvious changes in facial morphology and facial asymmetry[23–25]. Animal experiments had also confirmed that DDw/oR ensued in shortened and flattened condyles as well as arrested mandibular growth and development[26,27]. All of the fore mentioned studies suggest that anterior TMJ disc displacement, especially without reduction, can produce degenerative changes in the condyles and affect mandible development, resulting in abnormal facial morphology.

By definition, mandibular condylar hypoplasia relates to the 'incomplete or under-development' of the TMJ with reduced condyles of normal morphology and structure. It is plausible that radiographically diagnosed condylar hypoplasia may not be due to 'incompleteness' or 'under-development' but a repaired degenerated joint. The latter was established by Lei and co-workers in a randomized trial where approximately 50% of joints with DJD exhibited repair in the control group without splint therapy[13]. The condyle could have transited from 'normal' size/morphology to condylar flattening/erosion, and eventually a remodelled smaller ''normal'' joint as de-

scribed by Liu and others[10]. A diagnosis of 'hypoplasia'' may thus be inaccurate particularly if etiology cannot be ascertained.

There are other diseases that can also lead to condylar resorption or destruction, producing diminutive condyles or underdeveloped mandibles. They include juvenile idiopathic arthritis (JIA) and idiopathic condylar resorption (ICR). Both conditions have very similar clinical presentations and may resemble condylar hypoplasia radiographically. JIA is a chronic autoimmune arthritis that occurs in children under 16-year-old and lasts for more than 6 weeks. It can affect multiple joints including the TMJs[28]. JIA can affect unilateral or bilateral joints and patients may have joint swelling, limitation of joint motion, pain or tenderness. The TMJ discs of patients with JIA are, however, mainly flattened and centrally perforated but are seldom displaced when examined with MRI[29]. ICR is relatively uncommon and involves the gradual alteration of condylar morphology which manifests as loss of condylar height[30]. These patients generally present with high mandibular plane angle, class II skeletal pattern and progressive open bite. Due to their scarcity, no research had been conducted on disc displacements in ICR.

This study demonstrated a significant association between condylar hypoplasia and DDw/oR. Hypoplastic joints exhibited more severely displaced and deformed discs when compared to normal contralateral joints. DDw/oR coupled with repaired DJD may mimic condylar hypoplasia radiographically. It is prudent that a history of TMJ clicking and locking be elucidated for patients presenting with non-syndromic condylar hypoplasia. JIA and ICR should also be ruled out. Although the present study yielded several notable outcomes, it had several limitations. Firstly, a causal relationship between DDw/oR (with DJD repair) and condylar hypoplasia could not be established with the cross-sectional design used. A longitudinal study is required to confirm this. It is, however, challenging to design a longitudinal study on the natural history of DDw/oR and DJD without intervention as it is unethical to withhold care. Secondly, the sample size though reasonable could be increased to enhance statistical power, precision and reliability of results. Lastly, although the presence of TMD complaints and TMD history was examined, the duration of DDw/oR, which has bearing on TMJ DJD, was not specifically explored. This should be considered for future work as with the assessment of sideways disc displacements and joint effusion.

Funding

This work was supported by the Capital Clinical Research Project (Z141107002514157) from Beijing Municipal Science & Technology Commission.

Competing interests

The authors declare no conflicts of interest.

Ethical approval

Ethics approval was obtained by the Ethics Committee of Peking University School Hospital of Stomatology (PKUSSIRB-201522045).

Patient consent

Not required.

Statement to confirm

All authors have agreed and consented for submission.

References

1. Buchbinder D, Kaplan A. Biology. In: Kaplan A, Assael L, editors. *Temporomandibular disorders diagnosis and treatment*. Philadelphia PA: Saunders; 1991. p. 11–23.
2. de Leeuw R, Klasser GD. *Orafacial pain: guidelines for assessment, diagnosis, and management*. Chicago: Quintessence; 2013: 146–67.
3. Kaneyama K, Segami N, Hatta T. Congenital deformities and developmental abnormalities of the mandibular condyle in the temporomandibular joint. *Congenit Anom (Kyoto)* 2008;**48**:118–25. http://dx.doi.org/10.1111/j.1741-4520.2008.00191.x.
4. Galea CJ, Dashow JE, Woerner JE. Congenital abnormalities of the temporomandibular joint. *Oral Maxillofac Surg Clin North Am* 2018;**30**:71–82. http://dx.doi.org/10.1016/j.coms.2017.09.003.
5. Schiffman E, Ohrbach R, Truelove E, Look J, Anderson G, Goulet JP, et al. International Rdc/Tmd Consortium Network IafDR, Orofacial Pain Special Interest Group IAftSoP. Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) for Clinical and Research Applications: recommendations of the International RDC/TMD Consortium Network and Orofacial Pain Special Interest Group. *J Oral Facial Pain Headache* 2014;**28**:6–27. http://dx.doi.org/10.11607/jop.1151.
6. Brooks SL, Westesson PL, Eriksson L, Hansson LG, Barsotti JB. Prevalence of osseous changes in the temporomandibular joint of asymptomatic persons without internal derangement. *Oral Surg Oral Med Oral Pathol* 1992;**73**:118–22.
7. Kalladka M, Quek S, Heir G, Eliav E, Mupparapu M, Viswanath A. Temporomandibular joint osteoarthritis: diagnosis and long-term conservative management: a topic review. *J Indian Prosthodont Soc* 2014;**14**:6–15. http://dx.doi.org/10.1007/s13191-013-0321-3.
8. Lei J, Han J, Liu M, Zhang Y, Yap AU, Fu KY. Degenerative temporomandibular joint changes associated with recent-onset disc displacement without reduction in adolescents and young adults. *J Craniomaxillofac Surg* 2017;**45**:408–13. http://dx.doi.org/10.1016/j.jcms.2016.12.017.
9. Dias IM, Coelho PR, Assis NMSP, Leite FPP, Devito KL. Evaluation of the correlation between disc displacements and degenerative bone changes of the temporomandibular joint by means of magnetic resonance images. *Int J Oral Maxillofac Surg* 2012;**41**:1051–7. http://dx.doi.org/10.1016/j.ijom.2012.03.005.
10. Liu YS, Yap AU, Lei J, Fu KY. Is temporomandibular joint disc displacement without reduction a plausible cause of condylar hypoplasia? A case report. *Curr Dent* 2019;**1**:68–73. http://dx.doi.org/10.2174/2542579X01666180919121059.
11. Nanci A. *Temporomandibular joint. Ten Cate's oral histology: development, structure, and function*. St.Louis Missouri: Mosby Elsevier; 2013: 311–27.
12. Lei J, Liu MQ, Yap AU, Fu KY. Condylar subchondral formation of cortical bone in adolescents and young adults. *Br J Oral Maxillofac Surg* 2013;**51**:63–8. http://dx.doi.org/10.1016/j.bjoms.2012.02.006.
13. Lei J, Yap AU, Liu MQ, Fu KY. Condylar repair and regeneration in adolescents/young adults with early-stage degenerative temporomandibular joint disease: a randomized controlled study. *J Oral Rehabil* 2019;**46**:704–14. http://dx.doi.org/10.1111/joor.12805.
14. Perschbacher S. Temporomandibular joint abnormalities. In: White SC, Pharoah MJ, editors. *Oral radiology: principles and interpretation*. 7th edn. St. Louis, Missouri: Elsevier Mosby; 2014. p. 500–1.
15. Kinzinger G, Kober C, Diedrich P. Topography and morphology of the mandibular condyle during fixed functional orthopedic treatment — a magnetic resonance imaging study. *J Orofac Orthop* 2007;**68**:124–47. http://dx.doi.org/10.1007/s00056-007-0650-0.
16. Hu YK, Yang C, Xie QY. Changes in disc status in the reducing and nonreducing anterior disc displacement of temporomandibular joint: a longitudinal retrospective study. *Sci Rep* 2016;**6**:34253. http://dx.doi.org/10.1038/srep34253.
17. Orsini MG, Kuboki T, Terada S, Matsuka Y, Yatani H, Yamashita A. Clinical predictability of temporomandibular joint disc dis-

placement. *J Dent Res* 1999;**78**:650–60. http://dx.doi.org/10.1177/00220345990780020401.

18. Moncada G, Cortes D, Millas R, Marholz C. Relationship between disk position and degenerative bone changes in temporomandibular joints of young subjects with TMD. An MRI study. *J Clin Pediatr Dent* 2014;**38**:269–76.
19. Dias IM, Cordeiro PC, Devito KL, Tavares ML, Leite IC, Tesch Rde S. Evaluation of temporomandibular joint disc displacement as a risk factor for osteoarthrosis. *Int J Oral Maxillofac Surg* 2016;**45**:313–7. http://dx.doi.org/10.1016/j.ijom.2015.09.016.
20. Kurita H, Ohtsuka A, Kobayashi H, Kurashina K. Alteration of the horizontal mandibular condyle size associated with temporomandibular joint internal derangement in adult females. *Dentomaxillofac Radiol* 2002;**31**:373–8. http://dx.doi.org/10.1038/sj.dmfr.4600727.
21. Zhuo Z, Cai X, Xie Q. Is anterior disc displacement without reduction associated with temporomandibular joint condylar height in juvenile patients younger than 20 years? *J Oral Maxillofac Surg* 2015;**73**:843–9. http://dx.doi.org/10.1016/j.joms.2014.12.013.
22. Xie Q, Yang C, He D, Cai X, Ma Z, Shen Y, et al. Will unilateral temporomandibular joint anterior disc displacement in teenagers lead to asymmetry of condyle and mandible? A longitudinal study. *J Craniomaxillofac Surg* 2016;**44**:590–6. http://dx.doi.org/10.1016/j.jcms.2016.01.019.
23. Gidarakou IK, Tallents RH, Kyrkanides S, Stein S, Moss ME. Comparison of skeletal and dental morphology in asymptomatic volunteers and symptomatic patients with unilateral disk displacement without reduction. *Angle Orthod* 2003;**73**:121–7. http://dx.doi.org/10.1043/0003-3219(2003)73<121:Cosadm>2.0.Co;2.
24. Gidarakou IK, Tallents RH, Kyrkanides S, Stein S, Moss ME. Comparison of skeletal and dental morphology in asymptomatic volunteers and symptomatic patients with normal temporomandibular joints. *Angle Orthod* 2003;**73**:116–20. http://dx.doi.org/10.1043/0003-3219(2003)73<116:Cosadm>2.0.Co;2.
25. Gidarakou IK, Tallents RH, Stein S, Kyrkanides S, Moss ME. Comparison of skeletal and dental morphology in asymptomatic volunteers and symptomatic patients with unilateral disk displacement with reduction. *Angle Orthod* 2004;**74**:212–9. http://dx.doi.org/10.1043/0003-3219(2004)074<0212:Cosadm>2.0.Co;2.
26. Bryndahl F, Warfvinge G, Eriksson L, Isberg A. Cartilage changes link retrognathic mandibular growth to TMJ disc displacement in a rabbit model. *Int J Oral Maxillofac Surg* 2011;**40**:621–7. http://dx.doi.org/10.1016/j.ijom.2011.01.004.
27. Jiao Z, Wang X, Zhang X, Yang C. Experimental study on mandibular length and facial symmetry of low estrogen level and anterior disc displacement of temporomandibular joint. *Sci Rep* 2018;**8**:15635. http://dx.doi.org/10.1038/s41598-018-34023-4.
28. Petty RE, Southwood TR, Manners P, Baum J, Glass DN, Goldenberg J, He X, Maldonado-Cocco J, Orozco-Alcala J, Prieur AM, Suarez-Almazor ME, Woo P. International League of Associations for rheumatology classification of juvenile idiopathic arthritis: second revision, Edmonton, 2001. *J Rheumatol* 2004;**31**:390–2.
29. Kellenberger CJ, Bucheli J, Schroeder-Kohler S, Saurenmann RK, Colombo V, Ettlin DA. Temporomandibular joint magnetic resonance imaging findings in adolescents with anterior disk displacement compared to those with juvenile idiopathic arthritis. *J Oral Rehabil* 2019;**46**:14–22. http://dx.doi.org/10.1111/joor.12720.
30. Huang YL, Pogrel MA, Kaban LB. Diagnosis and management of condylar resorption. *J Oral Maxillofac Surg* 1997;**55**:114–9. discussion 119-20.

Address:
Kai-Yuan Fu
Center for TMD & Orofacial Pain and Department of Oral & Maxillofacial Radiology
Peking University School & Hospital of Stomatology
No. 22 Zhong Guan Cun South Avenue
Beijing100081
China
Tel.: +86 10 82195342; Fax: +86 10 62173402
E-mail: kqkyfu@bjmu.edu.cn