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Research article

Association between bilateral condylar resorption and reduced volumes of the craniofacial skeleton and masticatory muscles in adult patients: A retrospective study

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ABSTRACT

Objectives: This retrospective cohort study aimed to analyze volumes of craniomaxillofacial bone and masticatory muscles of young adults with bilateral idiopathic condylar resorption.
Methods: This was a retrospective cohort study of 84 adults with bilateral idiopathic condylar resorption (BCR) and 48 adults with normal temporal-mandibular joint (TMJ) matched for age and sex (mean age, 23.2 ± 3.6 years). The volumes of craniomaxillofacial bone and masticatory muscles, as well as intercondylar angle were measured. Unpaired t-tests and Pearson correlation tests were applied to analyze the data. Multivariable linear regression models were used to estimate the association between bilateral condylar volume and volumes of craniomaxillofacial bone and masticatory muscles adjusted for age, sex, and disc status.
Results: Compared to the control group, the BCR group displayed significant decreased volumes of craniomaxillofacial bone ($p < 0.001$), craniomaxillofacial bone without mandible ($p < 0.001$), mandible ($p < 0.001$), mandible without mandibular condylar process ($p < 0.001$), bilateral masseter muscle ($p < 0.001$) and bilateral temporalis muscle ($p < 0.001$), as well as the intercondylar angle ($p < 0.001$). These variables were significantly correlated to the volume of mandibular condylar process ($0.5< r < 0.8$; $p < 0.001$). By linear regression analyses, significant associations were found for the bilateral condylar volume with craniomaxillofacial bone volume and mandible bone volume.
Conclusions: Young adults with BCR displayed smaller volumes of craniomaxillofacial skeleton and masticatory muscles, and smaller intercondylar angle than the normal patients. The craniofacial musculoskeletal volume and intercondylar angle are associated with mandibular condylar process volume.

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1. Introduction

Idiopathic condylar resorption (ICR) refers to the mandibular condyle destruction with unclear causes and pathogenesis. The prevalence of ICR in juvenile eastern Chinese patients (range from 10 to 20 years old) with temporomandibular disorders (TMDs) has been estimated to be around 67.56 %. The condyle can be affected both unilaterally and bilaterally, and frequently happened in adolescent girls during the pubertal growth spurt. Resorption of the condyle results in reduced mandibular growth and subsequent alteration of dental occlusion and may even affect the total craniofacial growth in advanced long-term stage.

Although some patients with bilateral ICR have normal face, aberrant craniofacial morphology was seen in most of the bilateral ICR patients. A growing number of published articles have described a specific pattern of craniofacial morphology of patients with bilateral ICR [1–3]: diminished posterior facial height, steepening of the mandibular plane angle, loss of chin projection, and anterior open bite. In the clinical practice, we found that a considerable proportion of patients with bilateral ICR showed typical "ICR face", that is, less developed craniofacial bone and masticatory muscles. However, this phenomenon has not been reported so far.

Previous studies relied on traditional two-dimensional cephalometric radiography for morphological assessment of ICR patients, and the two variables-sella-nasion-basion (SNB, mandibular anteroposterior projection) and A-point-nasion-B-point (ANB, relative position of mandible to maxilla)-appeared to be the main parameters that demonstrate the anteroposterior position of mandible. However, it has been well established that the reliability of SNB and ANB as indicators of anteroposterior maxilla and mandible position is affected directly by vertical sella-nasion (SN) pitch and horizontal SN length [4]. Therefore, if a patient has short cranial base, he/she could demonstrate normal sella-nasion-A-point (SNA, maxillary anteroposterior projection), SNB and ANB values which falsely despite the presence of true underlying retrognathism. In contrast, the volumetric analysis of craniofacial bone and masticatory muscles based on CT data has better reliability. Therefore, we aim to uncover the alterations in the craniofacial bone and masticatory muscles of patients with bilateral ICR.

In this study, measurements on the whole head CT data were performed in patients with bilateral ICR and patients with normal TMJ. The differences between 2 groups were evaluated to analyze differences of craniofacial skeleton, masticatory muscles and intercondylar angle. Further, the associations between the aforementioned variables and condyle volume were investigated.

2. Patients and methods

2.1. Study design

To address the research purpose, an observational retrospective study was designed and implemented. A total of 132 consecutive adult patients who visited the Department of Oral Surgery in Shanghai Ninth People's Hospital from January 2013 to February 2022 were reviewed in this study. Inclusion criteria were as follows: (1) age between 18 and 30 years; (2) have TMJ-MRI examination, craniomaxillofacial CT scan and lateral cephalometric X ray. Exclusion criteria included: (1) skeleton class III malocclusion by lateral cephalometric analysis (ANB$<0^\circ$, Wits < -2mm); (2) history of orthognathic surgery, functional appliance or orthodontics treatment; (3) congenital deformities (e.g. microsomia, Treacher Collins syndrome), systemic disease (e.g. juvenile rheumatoid arthritis), infection, jaw fracture, muscular disorders, or other clinically significant pathologies affecting the growth of the craniofacial skeleton. (4) aberrant CT scans (dental implants and metal restorations that interfere with imaging and measurement).

Based on MRI images, TMJ were divided into 2 groups according to Yang's classification [5]: normal and bilateral condylar resorption (BCR, the stage of condylar resorption >3). Digital imaging and communications in medicine (DICOM) data from craniomaxillofacial CT were acquired using GE Medical CT System (GE, Chalfont St. Giles, U.K.) with the standard protocol (120 kV, 220 mA, 0.7 mm slice thickness). Patients were positioned with their frankfort horizontal (FH) plane coincident with the vertical plane and instructed to maintain the mandible in the habitual rest position. The complete medical and dental histories were also reviewed and recorded.

This retrospective study followed all the tenets of the Declaration of Helsinki for research involving human subjects, and was critically reviewed and approved by the institutional review board of Shanghai Jiao Tong University School of Medicine (institutional review board no. SH9H-2022-T92-2).

Table 1
Definitions of variables by volumetric and angular measurements.

Abbreviation	Name	Definition
CB	Craniomaxillofacial bone	Volume of craniomaxillofacial bone (Fig. 1)
CBwoM	Craniomaxillofacial bone without mandible	Volume of craniomaxillofacial bone without mandible (Fig. 1)
MB	Mandible bone	Volume of mandible bone (Fig. 1)
MwoMC	Mandible without mandibular condyle	Volume of mandible bone without bilateral mandibular condyles (Fig. 1)
MC	Mandibular condyle	Volume of bilateral mandibular condyle (Fig. 1)
MM	Masseter muscle	Volume of bilateral masseter muscle (Fig. 2)
TM	Temporalis muscle	Volume of bilateral temporalis muscle (Fig. 2)
ICA	Intercondylar angle	Angle between the horizontal long axis (the line through the most lateral and medial point of the condylar head) of bilateral condyle (Fig. 3)

2.2. Study variables

For 3D image reconstruction and analysis, Mimics software (Mimics version 17; Materialise, Leuven, Belgium) was used to measure the volumes of the craniofacial bone and masticatory muscle. The variables which measured in this study were listed in Table 1 and illustrated in Figs. 1–3. The primary end point was the volume of craniomaxillofacial bone (CB), the secondary end points were the volume of mandible bone (MB) and masseter muscle (MM) and the intercondylar angle (ICA).

2.3. Measurement of volumes of craniofacial bone

The measurements of craniofacial bone volume were carried out according to a previous study [6]. A threshold of 226–3071 hounsfieldunit (HU) was used to create a mask that encompassed the bone but excluded the teeth. Since the HU of tooth enamel overlap with the cortical bone, manual adjustment was performed in the sagittal and coronal plane on each slice. The software calculated the bone volume by means of voxel addition, and volume was expressed in cubic millimeters (Fig. 1A).

To dissect mandibular condylar process, the FH plane was used as a reference plane. FH plane was formed by the bilateral uppermost points on the bony external auditory meatus (porion) and lowest point on the right inferior borders of the bony orbit (orbitale). The mandibular condylar process was defined as the area above the base plane that was parallel to the FH plane and passing through the most inferior point of the mandibular notch (Fig. 1B).

2.4. Measurement of masticatory muscles

The masseter and temporal muscles play a crucial role in mastication. The temporal muscles are mainly responsible for the chopping movement of the mandible, while the masseter muscles make the grinding movement. The measurements of masticatory muscles volume were carried out according to a previous study [7]. A threshold of −5 to 135 HU was used to create a mask that encompassed the muscles but excluded the bone and teeth. On the axial and coronal scans, the muscles were manually delineated in every slice to ensure accuracy. Volumes of bilateral masseter muscle and bilateral temporalis muscle were automatically calculated from the 3D model of the manually segmented muscles (Fig. 2A–C).

2.5. Measurement of intercondylar angle (ICA)

The measurements of intercondylar angle (ICA) were carried out according to previous studies [8,9]. Briefly, on the 3D reconstruction of mandible, the most lateral and medial poles were marked. This allowed the longitudinal axis to be determined and the intercondylar angle to be measured (Fig. 3).

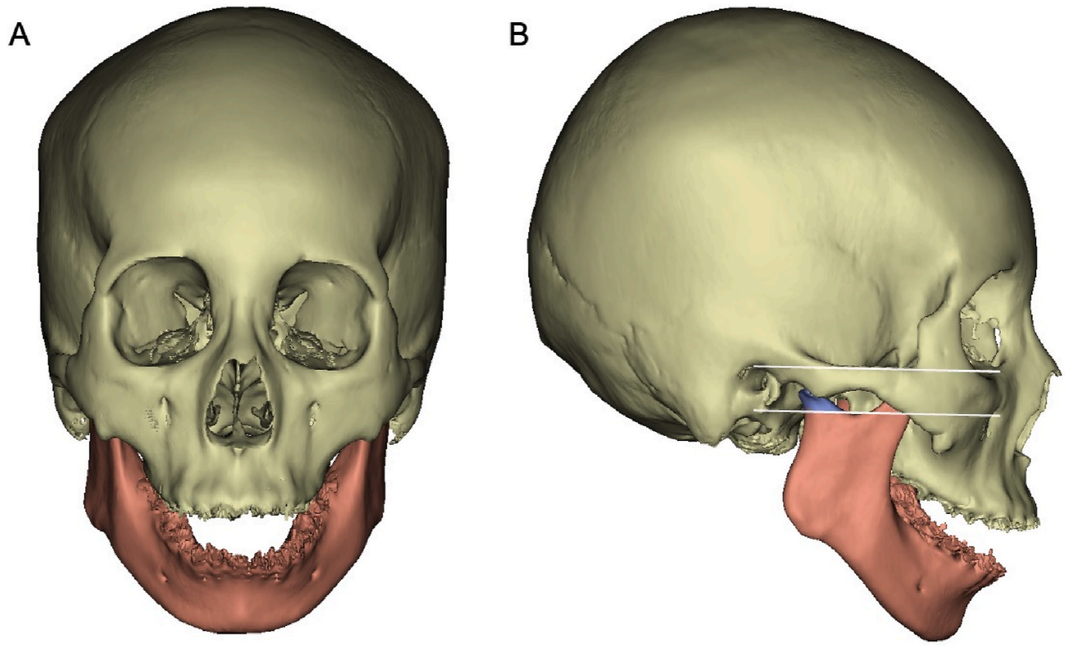

Fig. 1. The 3D reconstruction images of craniofacial bone. (A) frontal view. (B) lateral view. The upper white line indicates the horizontal plane, and the lower white line indicates the plane which parallel to the FH plane and passing through the most inferior point of the mandibular notch.

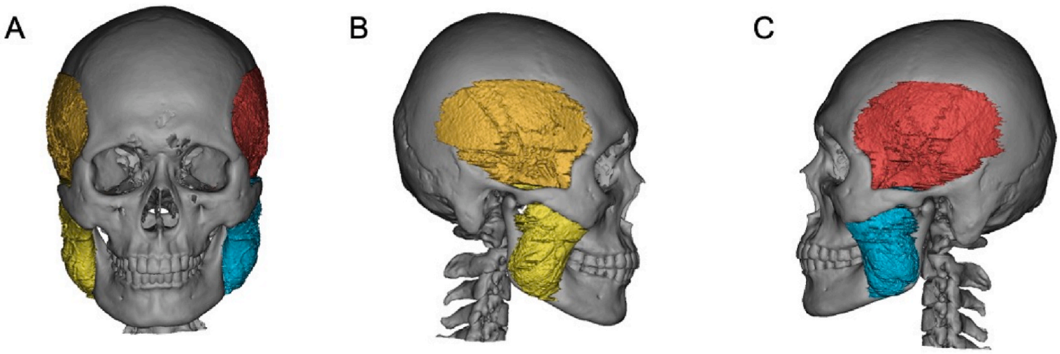

Fig. 2. The 3D reconstruction images of bilateral masseter muscle and bilateral temporalis muscle. (A) frontal view. (B) right lateral view. (C) left lateral view.

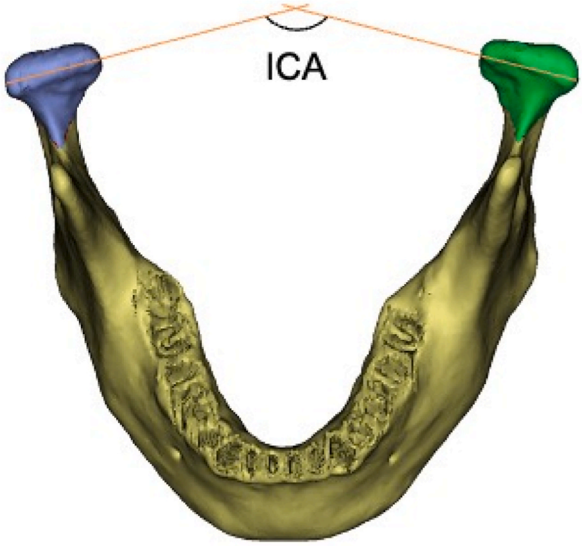

Fig. 3. The longitudinal axis of the condyles and the intercondylar angle (ICA).

2.6. Statistical analysis

Data were entered into a spreadsheet (MS Excel 2007, Microsoft Inc., Redmond, Washington) at the end of the study and analyzed using GraphPad Prism 9.0 software package (GraphPad Software, San Diego, USA) and statistical software package (SPSS, version17.0, Chicago, Illinois) by an independent statistician (J.G.).

Blinding of the evaluator to the identities of patients and study groups was maintained throughout the process with a coding system. Measurements were performed by 3 independent examiners (B.L.T., Z.D.H. and W.X.) in random order, and re-measured by 3 other independent examiners (J.Y.L., Z.J. and Y.S.J.). The mean of the two measurements is used as the final result. The inter-class correlation coefficient (ICC) analysis was conducted to evaluate the inter-observer reliability.

Table 2
Participant demographic characteristics.

Variable and Grade	Control group	BCR group	P value
Age (years)	24.4 ± 3.6	22.7 ± 3.7	NS
Gender, n (%)			NS
Male	5 (10.4)	7 (8.3)	
Female	43 (89.6)	77 (91.7)	
Disc displacement without reduction	0 (0)	84 (100)	<0.01

Participants in the BCR group demonstrated significant reduced condylar volume compared to the control participants ($p < 0.001$): the volumes of the right condyle and left condyle in the control group were 2280 ± 514.5 mm^3 and 2334 ± 547.2 mm^3, respectively; while the volumes of the right condyle and left condyle in the BCR group were 977.9 ± 314.1 mm^3 and 973.5 ± 306.0 mm^3, respectively.

Data were expressed as means ± standard deviations for quantitative variables and numbers and percentages for qualitative variables. Significance of mean differences between control and BCR groups were calculated using the Student's T-test or Mann-Whitney *U* test for unpaired observations. For determination of the correlation between bone/muscle volume/ICA and condyle volume, the Pearson correlation test was calculated. According to the Pearson correlation coefficient (r), the strength of correlation between two variables is classified into five grades: very weak ($0 \leq r < 0.2$), weak ($0.2 \leq r < 0.4$), moderate ($0.4 \leq r < 0.6$), high ($0.6 \leq r < 0.8$), very high ($0.8 \leq r < 1.0$). A multiple linear regression analysis was conducted to assess which variables independently influenced the primary end point (volume of craniomaxillofacial bone). P value less than 0.05 was considered statistically significant.

3. Results

A total of 132 subjects were recruited in this study (Table 2). Group sample sizes of 48 and 84 achieve 100.00 % power to reject the null hypothesis of equal means when the population mean difference is $\mu1 - \mu2 = 516047.0–609967.0 = -93920.0$ with standard deviations of 57438.0 for group 1 and 79935.0 for group 2, and with a significance level (alpha) of 0.05 using a two-sided two-sample unequal-variance *t*-test. The distributions of age and sex were evaluated for compatibility between the 2 groups. The participants were equally distributed according to age and gender between the control and BCR groups ($p > 0.05$). The ICCs for inter-observer agreement were between 0.81 and 0.92, demonstrating an excellent reliability of the raters.

The results of the CT volumetric analysis were shown in Table 3 and Fig. 4(A-F). Compared to the control group, the CB in the BCR group reduced for 15.4 %, the CBwoM in the BCR group reduced for 14.6 %, the MB in the BCR group reduced for 22.9 %, and the MwoMC in the BCR group reduced for 20.3 %.

Compared to the control group, the volume of bilateral MM in the BCR group reduced for 22.4 %, the volume of bilateral TM in the BCR group reduced for 22.5 %, the ICA in the BCR group reduced for 20.5 %. Significant differences were found between the control and BCR groups regarding to the aforementioned variables.

The highest coefficient was found between bilateral condylar volume and mandible volume ($r = 0.798$; $p < 0.01$). Significant and high correlation ($0.6 < r < 0.8$; $p < 0.01$) was also found between the condylar volume and the variables of the craniomaxillofacial bone (Table 4). Also, the ICA was significantly associated with condylar volume ($r = 0.701$; $p < 0.01$). As regarding to masticatory muscle, moderate but significant correlations were found of the condylar volume with the masseter muscles ($r = 0.602$; $p < 0.01$) and temporalis muscles ($r = 0.595$; $p < 0.01$) (Table 4).

In order to analyze which factors might influence volume of craniomaxillofacial bone, we ran a multiple linear regression analysis. We considered volume of craniomaxillofacial bone as dependent variable, and gender (male or female), age at data collection, disc status (normal or displacement), mandible volume and bilateral condylar volume as covariates. Among the covariates, mandible volume ($\beta = 5.233$, 95 % CI = 3.739 to 6.727, $p < 0.01$) and bilateral condylar volume ($\beta = 14.77$, 95 % CI = 0.142 to 29.4, $p < 0.05$) positively associated with the volume of craniomaxillofacial bone (Table 9).

We further performed multiple linear regression analysis to analyze which factors might influence the secondary end points. The results demonstrated that the gender ($\beta = 5946$, 95 % CI = 2032 to 9859, $p < 0.01$) and bilateral condylar volume ($\beta = 6.057$, 95 % CI = 4.556 to 7.558, $p < 0.01$) positively associated with the mandible volume (Table 10), disc position ($\beta = -22.94$, 95 % CI = −31.64 to −14.24, $p < 0.01$) negatively associated with the intercondylar angle (Table 11, normal disc position = 0, disc displacement = 1), and gender ($\beta = 7533$, 95 % CI = 3128 to 11,938, $p < 0.01$) and mandible volume ($\beta = 0.4063$, 95 % CI = 0.2136 to 0.5990, $p < 0.01$) positively associated with the volume of masseter muscle (Table 12).

4. Discussion

This retrospective cohort study aimed to compare volumes of craniomaxillofacial bone and masticatory muscles between young adults with bilateral idiopathic condylar resorption and young adults with normal TMJ. Our results suggested that the patients with bilateral condylar resorption have changes in craniofacial musculoskeletal volume: reduced volume of craniofacial bone and

Table 3
Results of the volumetric analysis.

Variables	Control group	BCR group	P value
CB (mm^3)	609,967 ± 79,935	516,047 ± 57,438	<0.01
CBwoM (mm^3)	546,598 ± 73,055	467,004 ± 53,048	<0.01
MB (mm^3)	63,210 ± 10,233	48,752 ± 6842	<0.01
MwoMC (mm^3)	58,699 ± 9544	46,798 ± 6630	<0.01
MC (mm^3)			
left	2280 ± 514.5	977.9 ± 314.1	<0.01
right	2334 ± 547.2	973.5 ± 306.0	<0.01
MM (mm^3)			
left	23,329 ± 4313	17,931 ± 4226	<0.01
right	22,831 ± 4107	17,886 ± 4082	<0.01
TM (mm^3)			
left	32,618 ± 6820	25,439 ± 6160	<0.01
right	32,877 ± 7126	25,293 ± 6520	<0.01
ICA (°)	140.8 ± 10.9	111.9 ± 12.5	<0.01

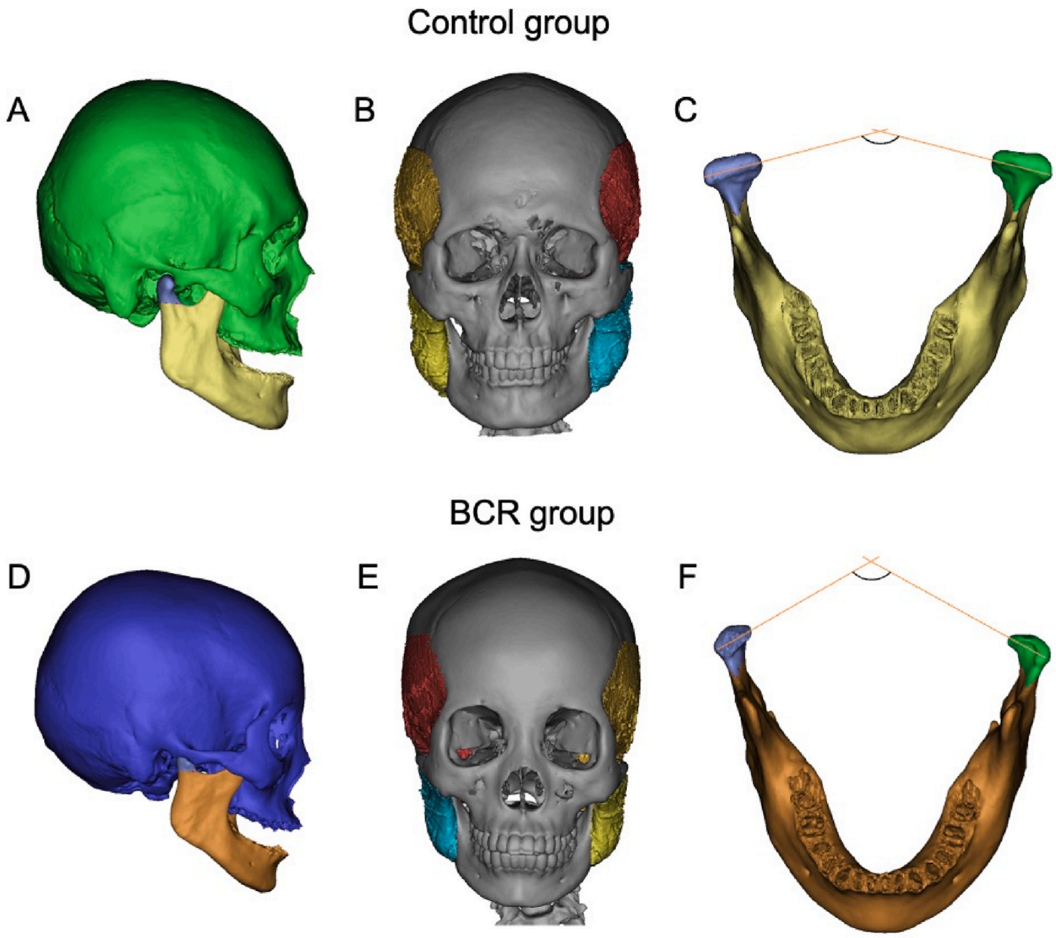

Fig. 4. Representative 3D reconstruction images of the control patient and BCR patient. (A–C) The craniomaxillofacial bone, bilateral masseter muscle, bilateral temporalis muscle and intercondylar angle of the control patient. (D–F) The craniomaxillofacial bone, bilateral masseter muscle, bilateral temporalis muscle and intercondylar angle of the BCR patient.

Table 4
Correlation between condylar volume and craniofacial musculoskeletal parameters.

Measurement		Correlation coefficients	
		r	p
Bilateral condylar volume	CB	0.692	<0.01
	CBwoM	0.645	<0.01
	MB	0.798	<0.01
	MwoMC	0.739	<0.01
	ICA	0.701	<0.01
Unilateral condylar volume	MM	0.602	<0.01
	TM	0.595	<0.01

Further, we performed the same model all the secondary end points. As for the volume of craniomaxillofacial bone, significant and high correlation ($r > 0.6$; $p < 0.01$) was found with the craniomaxillofacial bone parameters, moderate but significant correlations were found with the ICA and volumes of masticatory muscles ($0.4 \leq r < 0.6$; $p < 0.01$) (Table 5).

masticatory muscles, as well as the decreased intercondylar angle. Modest but significant associations were found between condylar volume and volumes of masticatory muscle. High and significant associations between condylar volume and craniofacial bone volume and intercondylar angle, were also addressed. By linear regression analyses, significant associations for the bilateral condylar volume were found with craniomaxillofacial bone volume and mandible bone volume.

The herein presented correlations between condylar volume and volumes of craniofacial bone and masticatory muscle raise the question of whether this interaction is based on functional adaptation or genetics.

Craniofacial musculoskeletal growth is a composite result of genetic and epigenetic factors, modulated by functional needs and

Table 5
Correlation between volume of craniomaxillofacial bone and craniofacial musculoskeletal parameters.

Measurement		Correlation coefficients	
		r	p
CB	CBwoM	0.996	<0.01
	MB	0.778	<0.01
	MwoMC	0.771	<0.01
	MC	0.692	<0.01
	ICA	0.461	<0.01
	MM	0.446	<0.01
	TM	0.484	<0.01

As regarding to the volume of mandible bone, significant and high correlations ($r > 0.6$; $p < 0.01$) were found with the variables of craniomaxillofacial bone and masseter muscle, while moderate and significant correlations were found with the temporalis muscle volume and ICA ($0.4 \le r < 0.6$; $p < 0.01$) (Table 6).

Table 6
Correlation between volume of mandible bone and craniofacial musculoskeletal parameters.

Measurement		Correlation coefficients	
		r	p
MB	CB	0.778	<0.01
	CBwoM	0.720	<0.01
	MwoMC	0.995	<0.01
	MC	0.798	<0.01
	ICA	0.541	<0.01
	MM	0.643	<0.01
	TM	0.599	<0.01

Regarding to the ICA, significant and high correlation ($r = 0.701$; $p < 0.01$) was found with the condylar volume, while moderate but significant correlations were found with the volume of temporalis muscle and craniomaxillofacial bone ($0.4 \le r < 0.6$; $p < 0.01$) (Table 7).

Table 7
Correlation between intercondylar angle and craniofacial musculoskeletal parameters.

Measurement		Correlation coefficients	
		r	p
ICA	CB	0.461	<0.01
	CBwoM	0.436	<0.01
	MB	0.541	<0.01
	MwoMC	0.501	<0.01
	MC	0.701	<0.01
	MM	0.383	<0.01
	TM	0.431	<0.01

As for volume of masseter muscle, significant and high correlations ($r > 0.6$; $p < 0.01$) were found with the volume of mandible bone and temporalis muscle, while moderate and significant correlations were found with the craniomaxillofacial bone volume and ICA ($0.4 \le r < 0.6$; $p < 0.01$) (Table 8).

Table 8
Correlation between volume of masseter muscle and craniofacial musculoskeletal parameters.

Measurement		Correlation coefficients	
		r	p
MM	CB	0.446	<0.01
	CBwoM	0.398	<0.01
	MB	0.643	<0.01
	MwoMC	0.622	<0.01
	MC	0.602	<0.01
	ICA	0.383	<0.01
	TM	0.787	<0.01

Table 9
Multiple linear regression model for volume of craniomaxillofacial bone.

Variables	β value	95 % CI	P value
Gender	−27471	−59602 to 4660	0.0929
Age	−650.1	−3306 to 2006	0.6282
Disc status	6836	−32126 to 45,797	0.7285
Mandible volume	5.233	3.739 to 6.727	<0.0001
Bilateral condylar volume	14.77	0.1420 to 29.40	0.0479

Table 10
Multiple linear regression model for mandible volume.

Variables	β value	95 % CI	P value
Gender	5946	2032 to 9859	0.0032
Age	192	−113.2 to 497.3	0.2154
Disc status	2185	−2350 to 6719	0.3422
Bilateral condylar volume	6.057	4.556 to 7.558	<0.0001

Table 11
Multiple linear regression model for intercondylar angle.

Variables	β value	95 % CI	P value
Gender	−2.000	−9.707 to 5.707	0.6084
Age	−0.054	−0.644 to 0.536	0.8556
Disc status	−22.94	−31.64 to −14.24	<0.0001
Mandible volume	−9.83e-006	−0.00035 to 0.00033	0.9545
Bilateral condylar volume	0.0025	−0.0011 to 0.0059	0.1673

Table 12
Multiple linear regression model for volume of masseter muscle.

Variables	β value	95 % CI	P value
Gender	7533	3128 to 11,938	0.0010
Age	132.7	−212.6 to 478.1	0.4481
Disc status	−1916	−6865 to 3033	0.4447
Mandible volume	0.4063	0.2136 to 0.5990	<0.0001
Bilateral condylar volume	0.9904	−1.025 to 3.005	0.3323

with variable interactions between hard and soft tissues. During the postnatal growth of bones, a continuous remodeling process takes place to maintain a form appropriate to their biomechanical function. In this study, the incidences of disc displacement in the control and BCR group were 0 % and 100 %, respectively. There are literatures reported that patients with temporomandibular disorders have reduced maximum bite force [10–14]. We speculated that the decreased contractive forces of the masticatory muscles applied lower tension on the periosteal membrane, resulted in the less developed craniofacial bone. Several studies on animals at their growth period provide further support for this association. For example, growing rats raised on a soft rather than a normal diet had reduced dental arch dimensions, narrower premaxilla, and smaller frontal bones at the most lateral part of the temporal crest, which are masticatory muscle attachment sites [15]. Also, unilateral atrophy of the masseter muscle by botulinum toxin A injection in the growing rabbits lead to significantly reduced mandibular ramus height and zygomatic arch length on the ipsilateral side [16]. Likewise, clinical studies found that individuals with smaller masseter and temporalis muscle cross-sectional areas have narrower mandible and maxillary dental arch [17,18]. The above-mentioned studies demonstrated that the remodeling response of bone to mechanical demands is the functional adaptation of bone. On the other hand, malocclusion induced by condylar resorption also impaired the masticatory function, caused significant reduction of mandible width and mandibular bone mineral density [19]. Therefore, the craniofacial musculoskeletal underdevelopment may be caused by condylar resorption via reducing maximum bite force and impairing masticatory function.

Apart from the changes in the craniofacial musculoskeletal volume, we also found that the intercondylar angle was significantly lower in the BCR group than in the control group. Although some researchers found no association between the horizontal condylar inclination and disc displacement [20], there are many studies reported that the medial horizontal inclination of the mandibular condyle was associated with disk displacement without reduction [21–24]. Our study also found significant correlation between the ICA and disk displacement. There are several possible explanations for the decreased intercondylar angle in joints with disc displacement, according to these authors. Due to the larger tendency of lateral ligament stretch during mouth opening movements, joints with a larger condylar angle (rotated medially) may have a greater tendency to disc displacement. Another explanation was that alteration in the stress distribution in the condyle could cause bony resorption of the anterior lateral pole of the condyle, resulting in a decreased intercondylar angle.

Muscle dimensions develop later in childhood and adolescence to support the adult dentition, skeletal frame, phonation, and deglutition. The muscles are considered adaptive in nature and grow to support function [25]. Coordination between skeletogeneis and myogenesis is indispensable for normal development and postnatal function of musculoskeletal system [26]. Moderate but significant correlations were found between the condylar volume and the volumes of masseter muscles and temporalis muscles. The underlying reasons might be: (1) the volumes of masseter muscles and temporalis muscles were not precise due to the vague boundary of muscles in the Mimics software; (2) maximal bite force is also affected by the height and weight of the individual [11]; (3) the volumes of masseter and temporal muscle during biting, as well as masticatory muscle electromyographic activity, should be taken into consideration to assess the muscle function [27].

Due to the retrospective nature of this study, we were unable to determine whether condylar resorption was the etiologic cause of impaired craniofacial musculoskeletal growth, or whether craniofacial musculoskeletal underdevelopment was a craniofacial form that predisposes patient to condylar resorption. Further longitudinal cohort study is needed to determine whether disc repositioning surgery could result in a return to normal facial growth. Also, prospective longitudinal studies would be helpful in determining if there is a temporal relationship between craniofacial morphological changes and condylar changes.

Another limitation of this study is the small sample size. Considering that the Shanghai 9th Peoples Hospital was one of the best hospitals in China, we believed that the sample size of BCR group in the study was big on a country basis.

The postnatal craniofacial growth follows its temporal dynamics [28]. It is the upper face that initially shows the highest postnatal growth rate, which can be attributed to its connection with the neurocranium. This rate undergoes a continuous decline and decelerated from the age of 11 onwards. By contrast, the midface initially grows slowly. The eruption of the first permanent teeth activates the masticatory muscles, thus promotes midface growth. Last comes the lower face, with the mandible grows and develops for a longer time, in some cases it can extended to twenty years of age [29]. Therefore, early interventions to reverse condylar resorption may rescue the craniofacial musculoskeletal growth. In the clinical practice, if a patient showed short but wide condyles in dental panoramic x-ray, or a suspicious craniofacial morphology is identified, the MRI should be taken to assess the TMJ condition.

5. Conclusion

Young adults with BCR displayed smaller volumes of craniomaxillofacial skeleton and masticatory muscles, and smaller intercondylar angle than the controls. Both craniofacial musculoskeletal volume and intercondylar angle are positively associated with mandibular condylar process volume.

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Data availability statement

Anonymized data not published within this article can be obtained from the corresponding author Chi Yang by request from any qualified investigator.

CRediT authorship contribution statement

Jing Ge: Writing – original draft, Methodology, Funding acquisition, Formal analysis. **Lingtong Bo:** Data curation. **Dahe Zhang:** Data curation. **Xiang Wei:** Data curation. **Jiayi Li:** Data curation. **Jiong Zhao:** Data curation. **Shijing Yue:** Data curation. **Qianyang Xie:** Data curation. **Pei Shen:** Data curation. **Zhigui Ma:** Data curation. **Bing Fang:** Supervision. **Chi Yang:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

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

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