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ORIGINAL ARTICLE

Three-dimensional condylar positions and forms associated with different anteroposterior skeletal patterns and facial asymmetry in Chinese adolescents

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Abstract

Objective. To evaluate the association of condylar asymmetry and chin position with different anteroposterior skeletal patterns using three-dimensional models reconstructed from cone-beam computed tomography (CBCT) images. ***Materials and methods.*** CBCT scans of 123 Chinese adolescents (aged 11–15 years, 68 girls and 55 boys) with 64 skeletal Class I, 46 Class II and 13 Class III were selected from scans of patients attending the orthodontic clinic. The condyles of the subjects were reconstructed bilaterally and 25 linear, angular and volumetric measurements were performed to evaluate the asymmetry of the condyles and position of the chin. The proportions of condylar asymmetry in the different skeletal groups were calculated by the absolute difference value between the left and right sides to the smaller side value. One-way analysis of variance and Pearson's correlations were used to analyse the data. ***Results.*** The values for RV, RCL, LCH, RCH, LCGM, RCGM, LCo-Me and RCo-Me were significantly different among the three skeletal groups ($p < 0.05$). There were significant positive correlations between Pog-Ss and Co-Sh, Co-Me in the Class I and II groups ($p < 0.05$). Asymmetries for Co-Ss, Co-Sh, CP and SP between the left and right condyles exceeded a ratio of 20% for more than 30% of the subjects. ***Conclusion.*** Condylar asymmetry varied significantly among the three skeletal groups, with the vertical position of the condyle (Co-Sh) and height of the mandibular ramus (Co-Me) being significantly and positively related to the chin position.

Key Words: *CBCT, condylar asymmetry, 3D reconstruction, anteroposterior skeletal patterns*

Introduction

The condyle is an important growth site in the mandible, comparable to the growth plates of the long bones [1], which can regulate the direction, rate and amount of mandibular growth. Facial asymmetry occurs when the development of different sites or regions is not symmetrical or evenly balanced. As a common clinical manifestation, abnormal development may be followed by chin deviation, mid-line shift, contralateral crossbite and maxillary cant. There are many causes for this asymmetry, including congenital abnormalities and acquired disorders, trauma and disease and developmental deformities including asymmetric condylar growth [2].

With the assistance of the highly sophisticated Materialise's Interactive Medical Image Control System (MIMICS) analysis software, cone-beam computed tomography (CBCT) images can be easily reconstructed for orthodontic assessments. 3D reconstruction allows much more user-friendly data interpretation and the image magnification is self-corrected to produce an orthogonal image at a 1:1 ratio to permit quantitative surface and volume measurements with high accuracy [3].

CBCT is a promising method for the 3D assessment of craniofacial structures. However, there are few studies that have assessed the condyles of growing adolescents. Therefore, the objective of the present study was to evaluate the association of condylar asymmetry and chin position with different anteroposterior skeletal patterns in Chinese adolescents, using 3D models reconstructed from CBCT scans.

*Y. Zhang and B. Che contributed substantially and equally to this work and should be considered as joint principal co-authors.

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Materials and methods

Subjects' records selection

Records were obtained of Chinese patients who sought treatment in the Orthodontic Department of the Stomatological Hospital of Jiangsu Province and who had undergone a CBCT examination for diagnostic purposes on their first visit from November 2011 to February 2012. The records of 123 persons were selected for the study including CBCT scans, clinical examination observations, dental models and photographs for the study based on the following inclusion criteria: (1) subject aged between 11–15 years; (2) no previous history of apparent facial trauma or systemic disease; and (3) no medical treatment that might alter the craniofacial growth pattern.

Subjects were classified into three anteroposterior skeletal pattern groups according to the ANB angle. Subjects with an ANB angle between 1–5° were classified as skeletal Class I (36 girls and 28 boys, aged 12.8 ± 2.1 years), larger than 5° were skeletal Class II (25 girls and 21 boys, aged 13.2 ± 1.6 years) and smaller than 1° were skeletal Class III (seven girls and six boys, aged 12.5 ± 1.8 years). Declarations and informed consents were obtained from the parents of all participants. The study was approved by the Ethics Committee of Nanjing Medical University (15 July 2011).

CBCT images

All CBCT scans were taken with the subjects sitting in an upright position, with their backs as nearly perpendicular to the floor as possible. The head was stabilized by ear rods placed within the external auditory meati and the subjects were instructed to look into their own eyes reflected in a mirror to obtain a natural head position, with the Frankfort horizontal plane parallel to the floor. A 360° CBCT scan was acquired using a NewTom VG Computerized Tomography X-ray System (SRL Company, Verona, Italy) with a 16 cm × 18 cm field of view and 0.25 mm voxel thickness. Exposure parameters were 110 kVp, 0.7 mA and 3.6 s.

Linear and angular measurements

Image reconstructions and measurements were undertaken by two examiners (BC and YZ) who did not participate in the study design. Data from the CBCT scans were exported to MIMICS V10.0 software (Materialise NV Technologielaan, Leuven, Belgium) in the Digital Imaging and Communications in Medicine format, in which the 3D images were reconstructed. Twenty-one anatomic landmarks and six reference planes (Table I) and 25 linear, angular and volumetric measurements (Table II) were included in the study.

Condylar reconstruction and volumetric measurements

A segmentation mask that included all facial bone structures was created (the mask is a collection of pixels of interest constituting an object that you wish to work on). In the range of bone density (gray scale from 226–3071) recommended by the MIMICS software, the condyle was visualized in coronal, sagittal and horizontal sectional images, which could then be segmented by applying an adaptive threshold. The inferior limit of the condyle was determined by the ILC and IRC planes (Table I). To separate the condyle from the surrounding structures and to reconstruct its 3D form, editing functions in MIMICS were performed including drawing, erasing and restoring the image with a certain threshold value. The calculated polylines are the high resolution segmentation contours for the current segmentation object and they were used in this study to determine the exact threshold values for a correct segmentation. After the elaborate segmentation process and using the smoothing function of MIMICS, the 3D reconstruction was calculated. By providing a vivid and intuitionistic representation of the condyle, the 3D reconstruction assisted the detection of the condylar asymmetry (Figure 1).

Statistical analysis

Statistical analysis employed the Statistical Package for the Social Sciences V13.0 software (SPSS Inc., Chicago, IL). One-way analysis of variance (ANOVA) and post-hoc least significant difference tests were used to compare cephalometric measurements among the three skeletal pattern groups. Differences in the condylar measurements between the left and right sides were calculated and Pearson's correlation (r) analysis of these differences and shift of the chin was performed for each of the three anteroposterior skeletal groups. The level of probability for statistical significance was set at $\alpha = 0.05$.

Twenty of the CBCT images were re-reconstructed and re-measured by the same two examiners after a period of 3 months to evaluate intra-examiner and inter-examiner reliability. Differences between the original and the repeated measurements were analysed using the intra-class correlation coefficient (ICC) test. The ICC results ranged from 0.78–0.86, indicating good measurement agreements.

Results

Comparing of condylar positions and forms in different anteroposterior skeletal patterns

From the one-way ANOVA findings, eight measurements differed significantly (Table III). From the post-hoc tests, there were highly significant differences between the Class I and II groups for RV ($p = 0.01$), RCL ($p = 0.003$), LCH ($p = 0.004$),

Table I. Definitions of anatomic landmarks and planes.

Landmark	Definition
S	Sella, the mid-point of the cavity of sella turcica
CoH-l	The most superior point of the left condylar head
In-l	On the left condyle, scroll the horizontal sectional images in superior-inferior direction and verify the largest width along the *x*-axis, the innermost point
Out-l	On the left condyle, scroll the horizontal sectional images in superior-inferior direction and verify the largest width along the *x*-axis, the outermost point
Ant-l	On the left condyle, scroll the horizontal sectional images in superior-inferior direction and verify the largest width along the *y*-axis, the most anterior point
Post-l	On the left condyle, scroll the horizontal sectional images in superior-inferior direction and verify the largest width along the *y*-axis, the most posterior point
CA-l	On the left condyle, scroll the horizontal sectional images in superior-inferior direction and verify the most inferior point on sigmoid notch
CB-l	On the left condyle, on the horizontal plane that crossed CA-l, along the *y*-axis, the most posterior point
Mid-l	The mid-point between CA-l and CB-l
Go-l	Gonion, the mid-point of the contour connecting the ramus and body of the mandible of the left lateral view
Me	Menton, the most inferior point on the mandibular symphysis (i.e. the bottom of the chin)
CoH-r	The most superior point of the right condylar head
In-r	On the right condyle, scroll the horizontal sectional images in superior-inferior direction and verify the largest width along the *x*-axis, the innermost point
Out-r	On the right condyle, scroll the horizontal sectional images in superior-inferior direction and verify the largest width along the *x*-axis, the outermost point
Ant-r	On the right condyle, scroll the horizontal sectional images in superior-inferior direction and verify the largest width along the *y*-axis, the most anterior point
Post-r	On the right condyle, scroll the horizontal sectional images in superior-inferior direction and verify the largest width along the *y*-axis, the most posterior point
CA-r	On the right condyle, scroll the horizontal sectional images in superior-inferior direction and verify the most inferior point on sigmoid notch
CB-r	On the right condyle, on the horizontal plane that crossed CA-l, along the *y*-axis, the most posterior point
Go-r	Gonion, the mid-point of the contour connecting the ramus and body of the mandible of the right lateral view
Pog	Pogonion, the most anterior point on the contour of the chin
S-hor plane	Horizontal plane passing through the point S and parallel to the Frankfort horizontal plane
S-sag plane	Sagittal plane passing through point S and hard tissue glabella and vertical to S-hor plane
S-cor plane	Coronal plane passing through point S and vertical to S-hor and S-sag planes
ILC plane	Inferior plane of left condyle, horizontal plane crossed CA-l
IRC plane	Inferior plane of right condyle, horizontal plane crossed CA-r
Me plane	Horizontal plane crossed Me

RCH ($p = 0.007$), LCo-Me ($p = 0.000$) and RCo-Me ($p = 0.001$); between the Class I and II groups for LCGM ($p = 0.01$) and RCGM ($p = 0.001$); and between the Class II and III groups for LCGM ($p = 0.002$), RCGM ($p = 0.000$), LCo-Me ($p = 0.002$) and RCo-Me ($p = 0.000$).

Correlation analysis of condylar and facial asymmetry

For the Class I and II groups, there were significantly positive correlations between Pog-Ss and the absolute difference values between the left and right sides for Co-Sh ($p = 0.007$ for Class I and $p = 0.004$ for Class II) and for Co-Me ($p = 0.004$ for Class I and $p = 0.04$ for Class II) (Table IV).

Proportions of condylar asymmetry in different skeletal patterns

The proportions of condylar asymmetry present in the three skeletal groups are summarized in Table V. The ratio of the absolute difference value of measurements between the left and right sides to the smaller side value for each subject was calculated and then the proportion of subjects whose ratios were more than 20%, 50% and 100% in each skeletal group was recorded. Asymmetries were common in each group, as shown by the absolute differences between the left and right sides. Differences for Co-Ss, Co-Sh, CP and SP between the left and right condyles exceeded a ratio of 20% for more than 30% of subjects.

Table II. Linear angular and volumetric measurements.

Measurements	Definition	Measurements	Definition
Size measurements (mm)			
LCH	Left condylar height: distance of CoH-l to ILC plane	RCH	Right condylar height: distance of CoH-r to IRC plane
LCL	Left condylar length: distance between In-l and Out-l	RCL	Right condylar length: distance between In-r and Out-r
LCW	Left condylar width: distance between Ant-l and Post-l	RCW	Right condylar width: distance between Ant-r and Post-r
Position measurements (mm)			
LCo-Sh	Distance of CoH-l to S-hor plane	RCo-Sh	Distance of CoH-r to S-hor plane
LCo-Sc	Distance of CoH-l to S-cor plane	RCo-Sc	Distance of CoH-r to S-cor plane
LCo-Ss	Distance of CoH-l to S-sag plane	RCo-Ss	Distance of CoH-r to S-sag plane
LCo-Me	Distance of CoH-l to Me plane	Rco-Me	Distance of CoH-r to Me plane
Pog-Ss	Distance of pog to S-sag plane		
Angular measurements (°)			
LCGM	Angle of point CoH- to Go-l to Mel	RCGM	Angle of point CoH-r to Go-r to Me
LHP	Angle of left condylar growth direction and horizontal plane	RHP	Angle of right condylar growth direction and horizontal plane
LCP	Angle of left condylar growth direction* and coronal plane	RCP	Angle of right condylar growth direction* and coronal plane
LSP	Angle of left condylar growth direction and sagittal plane	RSP	Angle of right condylar growth direction and sagittal plane
Volumetric measurements (mm^3)			
LV	Volume of the left condyle above ILC plane	RV	Volume of the right condyle above IRC plane

*The lines Mid-l to CoH-l and Mid-r to CoH-r represent vectors of condylar growth direction.

Discussion

Advantages of CBCT for the study of mandibular asymmetry

Mandibular asymmetry may be diagnosed by various tools including clinical examinations, photographs and radiographs such as panoramic, lateral cephalogram and computerized tomogram [4–7]. However, inaccuracies in the condylar outline and landmark identification in 2D radiographs cause difficulties with measurements for cephalometrics [8,9]. 3D imaging is becoming widely available [10] and, for dentomaxillofacial imaging, CBCT systems produce images having high resolution and minimal distortion [11]. The multiple image views and user-friendly 3-D reconstruction models with CBCT allow convenient clinical applications [11–15]. When comparing digital cephalometric radiographs and CBCT images, perfect agreement was shown between the CBCT images and the physical measurements [16]. In addition to accuracy, with new and innovative 3D technology, CBCT provides much more comprehensive information on condylar asymmetry and allows many 3D measurements including the volume of the condyle.

Variation in condylar asymmetry among the three groups

3D evaluation of the mandibular condyle is particularly interesting, because the condyles, regarded as sites for major regional growth control, play an important role in the dimensions of the mandible. Sezgin et al. [17] found that Class II/1 malocclusion had a significant effect on the condylar asymmetry index when compared to Class II/2 and Class III malocclusions, but was not different from Class I malocclusion. Sağlam [18] also found that condylar measurements were affected by the changes of ANB angle.

The present pioneer study in Chinese adolescents evaluated whether the position, size, volume and growth direction of the condyle could be related to the anteroposterior skeletal relationship of the jaws. As shown in Table III, the anteroposterior condylar lengths on both sides (LCL and RCL) and the volume on the right side (RV) in the Class I group were larger than those measured in the Class II group. Since there was no significant difference in the condylar positions between the Class I and Class II groups, then the decreased anteroposterior condylar length in the Class II group might contribute to a distally positioned mandible to cause the Class II skeletal pattern. The mandibular angles on both sides,

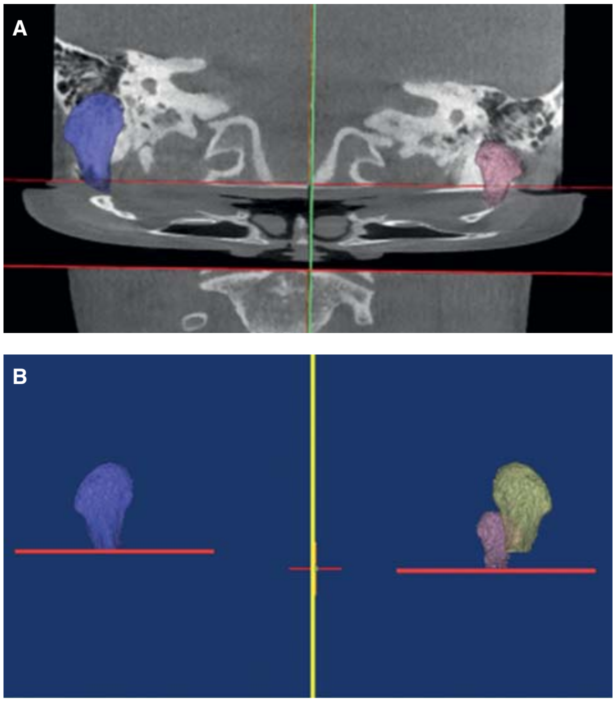

Figure 1. Representative coronal views illustrating asymmetric condyles after CBCT 3D reconstruction using MIMICS software. (A) Asymmetric left (pink) and right (blue) condyles. (B) Mirror image (yellow) of the partly superimposed right condyle showing significant asymmetries for condylar positions, sizes and volumes.

represented by LCo-Me and RCo-Me, in the Class III group were larger than in the Class I and, in particular, the Class II group. No significant differences were found either in the 3D positions of the condyles related to the cranial base, in condylar growth direction, or in the height and width of the condyles, which indicated that most of the measured features of the condyles contributed little to the formation of anteroposterior discrepancies.

Temporomandibular joint (TMJ) development during pre-natal life lags other joints of the body in the timing of TMJ appearance and progress [19]. Therefore, the growth of the condyle and surrounding tissues is likely to be influenced by a variety of environmental factors. Although asymmetries of the mandibular condyles and rami are considered to be common physiological variations [7,9], it is still not clear in what proportion of persons the range of these asymmetries can vary. In the present study, calculated by the absolute difference value of left and right sides, seven measurements had a ratio above 20% for differences in more than 10% of all subjects, of which two measurements, Co-Ss (69.1%) and CP (84.6%), had differences in more than 65% of all subjects (Table V). CP was the most asymmetric measurement, as 50.4% of all subjects had a ratio of above 100% for differences between the left and right condyles. Among the three different skeletal patterns, the condyar height (HP) of the Class I group, the length (LP) and width (WP) of the Class II group and the angle of the condyle to sagittal plane (SP) of the Class I and II groups showed much higher proportions of condylar asymmetry. Further research is needed to elucidate the mechanisms of these associations.

Proportion of condylar asymmetries related to temporomandibular disorders (TMD)

TMD have a prevalence ranged between 10–50% in various populations [20,21]. The relationship between TMD and abnormal condyles has been studied for many years, but there is still confusion regarding the relevance [22], as several studies have been unable to find any significant associations [18,23,24]. In the present study, in the proportion of all subjects who had a ratio of more than 20% for condylar differences, two measurements, Co-Ss (69.1%) and CP (84.6%), were greater than 65% (Table V). This percentage is much higher than the 20% prevalence of TMD in various populations, providing further evidence that condylar asymmetry is not a pivotal cause of TMD.

Unbalanced vertical condylar position and vertical ramus growth contributions to facial asymmetry

Facial asymmetry is very common and ranges from the smallest detectable differences to serious

Table III. Mean (standard deviation) measurements having significant differences among the three skeletal groups.

	Class I	Class II	Class III	*p*-value
RV	1733 ± 380^{a}	1548 ± 380^{b}	1717 ± 356*a*,b	0.04*
RCL	14.98 ± 1.95^{a}	13.84 ± 2.06^{b}	14.77 ± 1.58*a*,b	0.01*
LCH	18.45 ± 2.78^{a}	17.01 ± 2.26^{b}	18.55 ± 2.41*a*,b	0.01*
RCH	18.10 ± 2.91^{a}	16.64 ± 2.36^{b}	18.06 ± 3.12*a*,b	0.02*
LCGM	119.65 ± 4.91^{a}	118.73 ± 5.14^{a}	123.52 ± 3.48^{b}	0.009**
RCGM	120.23 ± 5.59^{a}	119.54 ± 4.53^{a}	125.20 ± 2.77^{b}	0.002**
LCo-Me	80.85 ± 5.87^{a}	76.29 ± 7.21^{b}	82.85 ± 7.42^{a}	0.000***
RCo-Me	81.06 ± 6.17^{a}	76.49 ± 7.07^{b}	84.14 ± 7.34^{a}	0.000***

*$p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Values with the same superscript letters are not significantly different.

Table IV. Pearson's correlations (r) between Pog-Ss and the absolute difference values for left and right side measurements in each skeletal group.

Class		V	CL	CH	CW	Co-Ss	Co-Sh	Co-Sc	CGM	Co-Me	CGM	CP	SP
I	*r*	−0.002	−0.091	0.113	−0.133	0.214	0.334	0.001	−0.056	0.357	0.137	−0.207	0.104
	p	0.99	0.47	0.38	0.29	0.09	0.007**	0.99	0.66	0.004**	0.28	0.10	0.42
II	*r*	0.172	0.248	0.189	0.198	0.088	0.412	0.274	0.008	0.312	0.083	0.198	0.191
	p	0.25	0.10	0.21	0.19	0.56	0.004**	0.07	0.96	0.04*	0.58	0.19	0.20
III	*r*	0.198	−0.318	−0.023	0.321	−0.09	0.038	−0.264	0.167	0.012	−0.117	−0.376	−0.157
	p	0.52	0.29	0.94	0.29	0.77	0.90	0.38	0.59	0.97	0.70	0.21	0.61

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The values for condylar vertical position (Co-Sh) and ramus height (Co-Me) between the left and right sides were positively correlated with shifting of the chin.

Table V. Summary of the proportions* (%) of subjects with condylar asymmetry, with ratios of more than 20%, 50% and 100% in each skeletal group.

	Class I			Class II			Class III			Total subjects		
	20%	50%	100%	20%	50%	100%	20%	50%	100%	20%	50%	100%
V	15.6%	3.1%	1.6%	15.2%	2.2%	0.0%	15.4%	0.0%	0.0%	15.4%	2.4%	0.8%
CL	12.5%	0.0%	0.0%	21.7%	2.2%	0.0%	0.0%	0.0%	0.0%	14.6%	0.8%	0.0%
CH	14.1%	0.0%	0.0%	6.5%	2.2%	0.0%	0.0%	0.0%	0.0%	9.8%	0.8%	0.0%
CW	7.8%	0.0%	0.0%	23.9%	0.0%	0.0%	7.7%	0.0%	0.0%	13.8%	0.0%	0.0%
Co-Ss	62.5%	35.9%	17.2%	76.1%	60.9%	13.0%	76.9%	53.8%	15.4%	69.1%	47.2%	15.4%
Co-Sh	34.4%	6.3%	1.6%	37.0%	6.5%	0.0%	38.5%	23.1%	0.0%	35.8%	8.1%	0.8%
Co-Sc	1.6%	0.0%	0.0%	4.3%	0.0%	0.0%	0.0%	0.0%	0.0%	2.4%	0.0%	0.0%
CGM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Co-Me	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HP	7.8%	3.1%	3.1%	2.2%	0.0%	0.0%	7.7%	0.0%	0.0%	5.7%	1.6%	1.6%
CP	90.6%	71.9%	50.0%	76.1%	67.4%	47.8%	84.6%	69.2%	61.5%	84.6%	69.9%	50.4%
SP	35.9%	9.4%	6.3%	34.8%	2.2%	0.0%	15.4%	7.7%	7.7%	33.3%	6.5%	4.1%

*Proportion: the proportion of absolute difference value of measurements between the left and right sides to the smaller side value.

deformities [25]. Condylar asymmetry is also a relatively common condition that may result in facial asymmetry and malocclusion [26]. However, one other study found that condylar asymmetry in children with juvenile idiopathic arthritis was not significantly related to asymmetry in the facial appearance [27]. In the present study, the absolute difference values between the left and right sides for condylar vertical position (Co-Sh) and ramus height (Co-Me) were positively correlated with shifting of the chin position (Table IV). This finding indicated that the unbalanced vertical condylar position and vertical growth to the cranial base might be important contributory factors to the mandibular asymmetry.

Conclusions

Several of the linear, angular and volumetric condylar measurements differed significantly among the three skeletal pattern groups and the vertical position of the condyles (Co-Sh) and height of the mandibular ramus (Co-Me) could contribute significantly to the shifting of the chin position. This study provided further information on the proportions (percentages) of condylar asymmetry and the associations between condylar and facial asymmetry in a population of Chinese adolescents.

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