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3D Condylar Forms and Positions in Association with Various Vertical Skeletal Patterns in Chinese Adolescents

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Abstract
In this study, the relationship between condylar asymmetry and the positions of the chin among various vertical skeletal patterns was evaluated with the use of images in cone-beam computed Tomography (CBCT). The CBCT scans of 75 Chinese adolescent patients attending the orthodontic clinics (aged 12-16 years, 42 girls and 33 boys) with 26 normodivergent, 25 hypodivergent and 24 hyperdivergent were selected. Bilateral reconstruction of the condyles of the subjects and the evaluation of asymmetries in the condyles and in the position of the chin was performed using 23 linear and angular measurements. The absolute difference in the values between that of the left and right side to that of the smaller side values contributed in the calculation of proportions of condylar asymmetries among different skeletal groups. The values for left condylar height (HCL), angle of condylar growth directions and horizontal plane (LHrp), angle of point (R-CyH), the most superior point on the right condyle to (R-Go) gonion, the midpoint on the contour connecting the ramus and the body of the mandible on the right lateral view to (R-Me) menton, the most inferior point on the mandibular symphysis (RCGM), angle of point (L-CyH), the most superior point on the left condyle to (L-Go) gonion, the midpoint on the contour connecting the ramus and the body of the mandible on the left lateral view to (L-Me) menton, the most inferior point on the mandibular symphysis (LCGM),distance of L-CyH) and the most superior point on the left condyle to (Meplane) horizontal crossing menton (LcyMe) showed significant differences amongst the three skeletal groups ($p<0.05$). Differences for CrP, Cy-Shr, Cy-Ssg, SgP, LC and HC amongst the condyles of both sides (right and left) surpasses a total of 20% in the ratio for more than 40% of all the subjects. Significant variation of condylar asymmetries amongst the three groups, with the condyles in a vertical position (Cy-Ssg) and angle of the condyle to the sagittal plane (SgP) having significant and positive relation to the position of the chin were determined .
Keywords CBCT, condylar asymmetries, vertical skeletal patterns, 3D reconstruction.

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Introduction

A large number of studies in orthodontics are related to the differences in the diagnosis, treatment plan and prognosis between dolichofacial types or hyperdivergent and brachyfacial types or hypodivergent. In the recent studies of orthodontics, there has been an increase in the desire to acquire treatment results wherein, the position of the condyle is maintained when the patient closes the mandible to maximum intercuspal position [1]. The condyle regulates the amount of mandibular growth, rate, and direction, as in the mandible and it is an important growth site [2]. Growth in the condylar process widely ranges from anterio-superior to posterior direction, hence resulting in highly diverse growth and morphology, the vertical jaw deviation, i.e., High or low angle and mandibular displacement direction is closely associated with condylar growth directions [3]. The different types of vertical skeletal patterns include non-divergent, hypodivergent and hyperdivergent and the most common clinical signs associated with these includes, short face, brachyfacial types, reduced lower anterior facial heights skeletal deep bites, low mandibular plane angle, reduced mandibular ramus length, shallow antigonial notch, anterior overbite in hypodivergent types and long faces, dolichofacial types, increases lower anterior facial heights, skeletal open bite, high mandibular plane angle, increased mandibular ramal length, deep antigonial notch, and anterior open bite in hyperdivergent types.

By utilizing the Materialise‘s Interactive Medical Image Control System (MIMICS), a highly specific software was used for the purpose of analysis, reconstruction of CBCT scans can be carried out for the orthodontic procedures. The quantitative surface and volumetric measurements can be done accurately by 3D reconstruction of images which allows easy interpretation of the data [4]. The production of an orthogonal image is a self-corrected magnified image at a ratio of 1:1 to allow highly accurate volumetric and surface measurements. When compared to any other method for assessment of craniofacial structures Cone Beam Computed Tomography being a promising method for 3D analysis [5]. The purpose of using 3D CBCT images in the field of dentistry have various reasons such as1) slicing of the images at coronal, sagittal and axial views which makes easy to visualize the internal structures; 2) the magnification or distortion of the images does not occur as seen in 2D images, so the measurements are of real sizes; 3) many anatomic structures such as, teeth and bones can be observed independently; 4) by changing the rotational axis three-dimensional images can be conveniently re-oriented, and 5) the spatial relationships among the craniofacial structures can be viewed [6].

The present study has been conducted in order to evaluate the relation of asymmetrical condyles and the position of the chin in various vertical skeletal patterns in the adolescent Chinese population, using reconstructed 3D models with the help of CBCT scans.

Materials and Methods

Selection of subjects

The patients (Chinese) records were obtained receiving treatment in the stomatological hospital of Jiangsu province in the department of orthodontics, who were examined using CBCT for the purpose of diagnosis on their first visit from Jan. 2015 to Oct. 2015.Selected records of 75 patients for the purpose of study that included CBCT scans, dental models, clinical examination and pictures for the purpose of study, according to the following inclusion criteria: 1) subjects with ages between 12 to 16 years; 2) no previous history of orofacial trauma or systemic disease; and 3) had not undergone any medical treatment that could alter the craniofacial growth pattern.

Classifications of subjects into three vertical skeletal pattern groups were made according to MPA angle. Subjects with an MPA angle between 21°-24° were classified as normodivergent (15 girls and 11 boys, aged 12.5±2.1 years) lower than 21° as hypodivergent (13 girls and 12 boys, aged 13.1±1.5 years) and greater than 30° as hyperdivergent (14 girls and 10 boys aged 12.3±1.6 years). Informed consents and declarations were taken from the guardians of all participants.

CBCT images

All the subjects had taken CBCT scans while sitting in a straight position, and their backs as almost perpendicular to the floor. Placement of ear rods within the external auditory meatus helped in achieving stabilization of the head, after which the patients were instructed to look straight into their own eye reflection in a mirror in order to attain the natural position of the head, with the ground parallel to the Frankfurt horizontal plane. Using the New Tom VG computerized Tomography X-ray system (SRL Company, Verona, Italy) with a 16cm × 18cm field of view and 0.25 mm voxel thickness a 360° CBCT scan was obtained. Parameters of exposure were 110 kVp, 0.7 mA, and 3.6s.

Linear and angular measurements

Exported data from the CBCT scans were viewed under the Mimics v10.0software for the purpose of diagnosis and reconstruction of the 3D images was carried out in the Digital Imaging and Communication in Medicine format. This study includes 21 anatomical landmarks (Table S1), 6 reference planes and 23 angular and linear measurements (Table S2).

Condylar reconstruction

Segmentation mask was made which included all of the facial bone structures (this mask is an accumulation of pixels of relevance that constituted a design to be worked with).Visualization of condyle along horizontal, coronal and sagittal fractional images, that on applying adaptive threshold divided by a range of bone density (from 226-3071, gray scale) advocated by the software Mimics. Using ILC and IRC planes (Table S1), the inferior limit of the condyles were determined. In order to differentiate condyles from its circumambient anatomy in order to reconstitute the 3D form, objectives were edited in Mimics that included outlining, cancelling and restoring the image to a particular threshold value. Determination of exact threshold value for a correct segment was obtained using estimated polylines, which are of a higher segmentally contour resolution of the currently segmented design. Calculation of 3D reconstruction was achieved using the smooth functions of Mimics and elaborate segmentation process. Condylar asymmetry was detected with the assistance of 3D reconstruction, which included a vivid and intuitionistic representation of the condyles.

Statistical analysis

Implying the analytical assortment of social sciences v13.0 software (SPSS Inc., Chicago, IL) for the statistical interpretation, comparison of cephalometric measurements amongst the three skeletal groups was carried out using one-way analysis of variance (ANOVA) and least significant posthoc difference tests.

Results

Comparison of condylar positions and forms

There were five measurements that differed significantly from one-way ANOVA findings (Table 1). The highest significant difference, according to Post-Hoc tests, was between the group 1 and group 2 for HCL, LCyMe, LHrP and RCGM, and in between group 1 and group 3 for LCGM (0.05).

Facial and condylar asymmetry correlation analysis

There was a significant positive correlation between Pog-Ssg. The arbitrary difference was determined amongst values of the left and right side measurements in group2 and group 3 for Cy-Ssg and for SgP (Table 2).

Table 1 Standard deviation measurements with significant differences amongst the three skeletal groups.

	Group 1	Group 2	Group 3	*P* values
HCL	17.72±3.14a	20.39±4.25b	19.40±3.71ab	0.040*
LcyMe	59.65±4.3a	63.29±5.99b	62.82±5.42b	0.034*
LHrP	65.25±3.8a	69.25±6.97b	67.30±6.28a,b	0.048*
LCGM	120.58±5.1a	115.97±6.23b	114.46±15.89b	0.049*
RCGM	120.03±5.12a	115.60±5.88b	117.80±7.79ab	0.042*

$p<0.05$ = *, Values with the same superscript letters are not significantly different.
Group 1 = normodivergent, Group 2 = hypodivergent; Group 3 = hyperdivergent

Proportions of condylar asymmetry

Absolute differences in the values of the measurements taken in ratios between that of both the side of the lesser side values for all of the subjects were calculated and then the values were recorded for the proportions of the subjects who had ratios more than that of 20%, 50% and 100%in each of the skeletal groups. The absolute difference in values of measurements between both the sides showed asymmetries in each group. Differences for CrP, Cy-Shr, Cy-Ssg , SgP, LC and HC between the left and right condyles surpasses a ratio of 20% for more than 30% of all the subjects (Table 3).

Discussion

Variations in Condylar asymmetries

One of the major sites of the regional growth control, are the condyles and it plays a key factor in deciding mandibular proportions, Hence the 3D interpretation of the mandibular condyles is very engrossing. Upon comparison with class II, or class III, the facial asymmetry is less significant in class I patients [7]. However, Sezgin et al. [8] found that the compelling effect on the asymmetrical condylar index was recorded in class II/1 malocclusion in comparison to class II/2 and class III malocclusions, although there's no difference recorded from class I malocclusion. Untreated malocclusions could possibly act as predisposing factor for condylar asymmetry [9]. Mathew et al. [10] found that there is a significant relationship between mandibular growth and MPA angle. According to Salgam [11] the condylar measurements were afflicted with the change in ANB angle.

Vertical skeletal patterns of the jaw can be related to size, position and growth direction of the condyles through the evaluation of the present research study in Chinese adolescents. In the present study, group 1 indicates normodivergent, group 2 indicates hypodivergent and group 3 indicates hyperdivergent. The condylar height on the left side and the angle of the left condylar growth direction and the horizontal plane (LHrP) in group 2 were larger than those measured in group 1.The increased condylar height in group 2 might be related to the decreased mandibular angle, which may contribute to hypodivergent skeletal patterns, Hence, in group 1 and group 2 had no compelling difference between the condylar positions. The indications of almost all of the measurements of condyles led to the development of vertical discrepancies, resulting in the finding of insignificant differences amongst the 3D outlook of the condyles that are concomitant with the cranial base, height and width of condyles in the condylar growth direction.

The temporomandibular joint is a special type of the joint which is developed by its approach to condylar and temporal blastemas, in contrary to many other joints of the human body [12]. In 25th to 26th gestational week, the complete differentiation of temporomandibular joint occurs which is comparatively slower than the other joints of the body [13]. The environmental factors are most likely to contribute to the growth of the condyle and the surrounding structures. The asymmetries of craniomandibular structures may be due to hereditary factors or congenital or can be acquired because of trauma or infection [14]. The developmental patterns of bones may be modified, thus resulting in asymmetries due to the application of quantitative and qualitative alterations led during growth [14]. The variation in the proportional range of asymmetries among persons is still not clear. The arbitrary difference in the assessment of both sides which is calculated in the present study, about six values have ratio above 20%, variations among more

Table 2 Pearson's correlations (r) between Pog-Ssg and the absolute difference values for left and right side measurements in each skeletal group.

Group		CrP	Cy-Me	Cy-shr	CGM	Cy-Ssg	SgP	WC	LC	HC	Cy-Scr
1	r	-0.433	0.813	-0.118	-0.007	0.190	0.975	-0.190	0.233	0.587	-0.011
	p	0.027	0.000	0.566	0.975	0.211	0.104	0.352	0.252	0.002	0.959
2	r	0.457	0.874	0.516	-0.011	0.113	0.226	-0.387	-0.20	0.315	-0.021
	p	0.025	0.000	0.010	0.959	0.38	0.289	0.062	0.333	0.134	0.939
3	r	-0.193	-0.126	-0.180	-0.076	0.024	0.019	-0.173	-0.16	-0.06	-0.290
	p	0.377	0.567	0.410	-0.076	0.942	0.932	0.430	0.458	0.778	0.382

The values for the condylar vertical position (Cy-Ssg) and the angle of the condyle to the sagittal plane (SgP) between the left and right sides were positively correlated with the shifting of the chin.

Table 3 Summary of the proportions (%) of subjects with condylar asymmetry, with the ratios of more than 20%, 50% and 100% in each skeletal group.

	Group 1 (%)			Group 2(%)			Group 3(%)			Total(%)		
	20	50	100	20	50	100	20	50	100	20	50	100
Crp	26.92	23.08	19.23	25.00	16.67	16.67	47.83	39.13	34.78	32.88	26.03	23.29
Cy-Me	3.85	0.005	0.00	8.33	0.00	0.00	8.70	0.00	0.00	6.85	0.00	0.00
Cy-shr	19.23	0.00	0.00	29.17	4.17	4.17	17.39	0.00	0.00	21.92	1.37	1.37
CGM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cy-Ssg	73.08	42.31	19.23	66.67	37.50	16.67	73.91	34.78	13.04	71.23	38.36	16.44
Sgp	15.38	7.69	3.85	25.00	8.33	8.33	26.09	17.39	8.70	21.92	10.96	6.85
WC	19.23	7.69	0.00	20.83	4.17	0.00	13.04	0.00	0.00	17.81	4.11	0.00
LC	23.08	0.00	0.00	37.50	4.17	0.00	30.43	0.00	0.00	30.14	1.37	0.00
HC	30.77	0.00	0.00	33.33	8.33	0.00	17.39	0.00	0.00	27.40	2.74	0.00
Cy-Scr	7.69	0.00	0.00	7.69	0.00	0.00	8.70	0.00	4.35	6.85	1.37	1.37

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

than 10% of all the subjects from which one measurement, Cy-Ssg (71.23%) presented with a variation of more than 65% of all the subjects. The most asymmetric are than 65% of all the subjects. The most asymmetric are CrP because 23.29% of all the subjects have ratios above 100% for the variations between both the sides of condyles. Amongst the three different skeletal patterns condylar height, HC and width of the condyle WC of group 1 and group 2, condylar length CL of group2 and group 3 and the angle of the condyle to the sagittal plane (SgP) amongst group 2 and group 3 showed relatively higher proportions of condylar asymmetries. An in-depth research to illuminate the associations of all these mechanisms is still required.

Facial asymmetry by unbalanced vertical ramus growth and vertical condylar positions

The magnitude of facial asymmetry may be mild or severe; it intensely needs to be corrected by orthodontic/orthopedic correction with or without orthognathic surgery. The smile and esthetics of the patient are affected majorly by the facial asymmetries and the correction of these asymmetries poses a great challenge for the clinician to deal with [15]. Sergio et al. [16] stated that the protocol for all treatments of facial asymmetries should incorporate the study of condylar hyperplasia and TMJ as a start off point. To design the best treatment plan and localize the dentofacial asymmetries its accurate diagnosis plays a key role, the orthodontic treatment in such cases is challenging [17].

In patients with juvenile idiopathic arthritis (JIA), the involvement of temporomandibular joint (TMJ) is seen in approximately 80% of patients [18]. According to a few studies, the craniofacial profile is altered in patients with juvenile idiopathic arthritis due to TMJ condylar damage [19]. However, Kristensen et al. [20] stated that there is not any existence of TMJ involvement in juvenile idiopathic arthritis. The values of absolute differences between both sides (right and left) in the present study, for the vertical position of the condyle (Cy-Ssg) and the angle of condyle to the sagittal plane (SgP), had a positive correlation with shifting of chin position. These findings bare a clear indication that the irregular vertical condylar positions and the vertical growth to the cranial base is a significant factor leading to the asymmetry of the mandibles.

Relation of temporomandibular disorders and proportions of condylar asymmetry

The estimated prevalence of temporomandibular disorders (TMD) ranges between 3–15% of the population [21]. According to Sato et al. [22] abnormal condyles were weakly correlated or not at all correlated with the signs and symptoms of TMD. However, there was no correlation found between the condylar asymmetries and TMD [23]. According to some studies using 3D-CT, the association between TMD and condylar height, length and width asymmetries were found [24]. In the present study, the ratio of measurements, Cy-Ssg (71.23%) was greater than 65%, in the distribution of all the subjects having ratios more than 20% of condylar differences. In the different population of TMD, the above percentages are much higher than 20% prevalence rate; it provides the information that the condylar asymmetries are not the only leading cause of TMD.

Advantages in the study of mandibular asymmetries under CBCT

The mandible is supposed to have the highest percentage of asymmetry in the human skull, reaching up to 74% [25]. Using various tools which include photographs, clinical examinations and radiographs such as lateral cephalogram, orthopantomography, and congenital Tomography mandibular asymmetry can be diagnosed. To diagnose the asymmetry, the most widely used radiographic method is panaromic radiographs. Because of the nonlinear magnification in different depths, they have the disadvantage of being unreliable horizontal measurements [26].For detecting the mandibular asymmetry using CBCT and anterior-posterior cephalograms, a study was carried out by Damstra et al. [27], who was found that the most reliable method more than the anterior-posterior cephalograms was CBCT for the purpose of diagnosis (intraclass correlation coefficient 0.957). De Vos et al. [28] has done the literature review of 86 articles for CBCT clinical application in the area of oral and maxillofacial region, it was concluded that because of the accuracy in 3D representation of a subject, low radiation and the possibility of converting the three-dimensional 3D images to two-dimensional (2D) images whenever required, 3D imaging in orthodontics is widely applicable. For assessing the presence of facial asymmetry, the standard method of measuring the mandibular longitude is not enough, the accurate level of asymmetry present can be detected by incorporating angular measurements using 3D software, plotting of the landmark needs to be better and also the acquisition of data needs to be accurate[29]. The use of CBCT allows a much more comprehensive study on condylar asymmetries, which in turn provides various 3D measurements including the volume of the condyle.

Conclusions

Many condylar measurements such as linear and angular had significant differences amongst the three skeletal group patterns, the angle of the condyle to the sagittal plane (SgP) and vertical positions of the condyle (Cy-Ssg) had contributed significantly to the shifting in the position of the chin. Furthermore, significant information about the percentages of the condylar asymmetries and relations between the condylar and facial asymmetry among Chinese adolescents is acquired through this study.

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Conflict of interest

The authors declare that they have no conflict of interest.

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