CLINICAL OF ORAL SCIENCE AND DENTISTRY

RESEARCH ARTICLE Open Access

Evaluation of the Mandibular Condylar Volume in Different Vertical Patterns with Cone Beam Computed Tomography in Young Adult Subjects

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Received Date: April 24, 2018 **Accepted Date:** May 18, 2018 **Published Date:** May 25, 2018

Abstract

Objectives: To test the hypothesis that there is no difference in mandibular condylar volume among subjects with different vertical jaw patterns using cone-beam computed tomography (CBCT).

Methods: The sample consisted of 60 Caucasian young subjects (17-36 years of age, 21 male and 39 females) who were randomly selected from the patient database at a private diagnostic center. Based on the vertical skeletal pattern, subjects were divided into three groups: group I or hypodivergent (18 subjects), group II or normodivergent (22 subjects), group III or hyperdivergent (20 subjects). Left and right temporomandibular joints (TMJs) of each subject were evaluated independently with cone beam computed tomography (CBCT). Volumetric measurements of the condyles were performed on CBCT records with Nemoscan software. Mandibular condylar volumetric measurements were compared among three groups by parametric tests.

Results: No significant differences between the right and left mandibular condylar volume measurements were found according to the results of Dahlberg´s coefficient. The Bonferroni test showed that the hyperdivergent group had a significant lower mandibular condylar volume respect to the other groups (P=0.0001). Statistically significant gender differences were found, females showed a significant lower mandibular condylar volume than males (P=0.001); (1.234 ± 374 mm^3 in females and 1.592 ± 302 mm^3 in males).

Conclusion: Vertical skeletal pattern appeared to be associated with a decreased mandibular condylar volume in asymptomatic Caucasian orthodontic population.

Keywords: *Mandibular condyle volume; Skeletal pattern; Cone-beam computed tomography; Segmentation.*

Introduction

The assessment of the morphology and volume of the mandibular condyle is essential for temporomandibular-orthodontic treatment planning. Orthodontic planning and treatment responses also depend on the skeletal pattern [1]. Many factors such as injuries, inflammatory-degenerative diseases or alteration in the position of the mandibular condyle in the temporal fossa may alter the equilibrium of temporomandibular joint (TMJ) components, resulting in pain, dysfunction, condylar growth problems and morphological or volumetric changes of the mandibular condyles [2].

In contrast to self-limiting physiological condylar remodeling, patients who undergo pathological condylar resorption may present decreases in mandibular ramus height, anterior open bite and temporomandibular disorders [3]. Due to the role of condylar growth in the development of the craniofacial complex, evaluation of condylar volume may seem relevant to improve understandings of TMJ morphology and craniofacial development. The mandibular condyle undergoes a remodeling process that responds to permanent stimuli from childhood to adulthood and results in the final size and shape of the mandible, which could be linked to the intermaxillary relationship [4].

In adulthood, the mandibular condyle seems to answer to functional demands, which could affect its shape, size and volume. Radiographic examination of TMJ structures is a valuable diagnostic record for evaluation of anomalies or adaptive changes of the TMJ that may alter initial intermaxillary relationship. However, there are limitations to image acquisition of the TMJ using conventional radiography. In daily practice, two-dimensional imaging techniques have been used widely to evaluate the morphology of the condyles [5]. The recent introduction of 3D technology in dentistry, such as the CBCT (Cone beam computerized tomography) allows a complete and reliable analysis of the TMJ and mandibular condyles with less radiation exposure and cost compared to the traditional medical computed tomography [6].

Quantitative measurements may be performed with CBCT in three spatial planes. This technology also provides volumetric information that can be valuable in visualizing the temporomandibular joints. In the literature there are studies evaluating the accuracy of linear and angular measurements of the craniofacial region on CBCT scans [7]. Measurements of the condyles may be better achieved in CBCT images respect to TMJ panoramic projections. Hilgers et al. [8] have reported that custom oblique multi-planar reformatted reconstructions with CBCT provide more accurate and reliable linear measurements of mandibular and TMJ dimensions than those made with conventional cephalograms in all three orthogonal planes. However, few studies have investigated the accuracy of measuring the volume of craniofacial structures on CBCT images [9,10]. Bayram et al. [11] demonstrated that the Cavalieri principle in conjunction with a planimetry method is a valid and effective tool for volume estimation of the mandibular condyle using CBCT images. A novel semi-automated method for 3D rendering of condyles using cone beam computed data has been developed [12]. The relationship between sagittal skeletal pattern and mandible condylar volume has also been studied [13]. However, little is known about the association between the vertical skeletal pattern and mandibular condylar volume. Although the term of mandibular condylar volume has appeared frequently in the literature, a bibliographic review in Medline using PubMed and the key words “mandibular condylar volume”, “vertical skeletal pattern ”, “vertical growth pattern” and “CBCT” showed that no published study has evaluated the mandibular condylar volume among the different vertical skeletal patterns using CBCT. Therefore, the purpose of this study is to compare the volume of mandibular condyles in different vertical skeletal patterns in a sample of young Caucasian subjects without TMJ dysfunction by using CBCT. Furthermore, a possible correlation between vertical skeletal pattern and mandible condylar volume will be analysed.

Materials and Methods

This research is a retrospective cross-sectional study. CBCT scans of 60 young adult Caucasian subjects (21 males and 39 females between 17 and 34 years of age); were randomly selected and evaluated from the pool of Caucasian young adult subjects with no history of craniomandibular disorders in the patient database at a private center. This study was approved by the Institutional Review Board.

None of the subjects had previous orthodontic treatment or missing teeth (except for third molars); and none had previously been diagnosed with craniofacial anomalies or aberrant skeletal growth patterns. Any subject with erosion, flattening, resorption or asymmetry of TMJ images was excluded from the sample, even though the subjects did not refer any history of craniomandibular disorders in order not to include any case of idiopathic condylar resorption. The 60 CBCT scans were retrieved from the computer data-base and retrospectively analysed. CBCT images were acquired with i-CAT™ cone beam 3D imaging (Imaging Sciences International Inc. Hatfield, Pennsylvania). The protocol was 13 cm FOV, 20 sec. and 0.3 voxel size. TMJ clinical history and exploration were reviewed to verify absence of TMJ dysfunction. The tomographic exam was imported in DICOM format to software Nemoscan™ version 11 (Nemotec. Madrid, Spain) for calculation of mandibular condyle volume. Once the volume was reoriented according to Frankfort plane, a virtual lateral cephalogram was generated. Frankfort mandibular plane angle (FMA) and postero-anterior facial height relationship (PFH/AFH) were measured to classify subjects into three groups based on vertical skeletal pattern.

The study sample consisted of 60 subjects divided in three groups: Group I or hypodivergent pattern with 18 subjects in whom FMA measured <190 and PFH/AFH was >650. Group II or normodivergent pattern with 22 subjects in whom FMA measured 20-290 and PFH/AFH was 60-640. Group III or hyperdivergent pattern with 20 subjects in whom FMA measured >300 and PFH/AFH was <590.

Mandibular condylar segmentation and volume

Two imaginary lines previously described by Xi et al. [12] were used to analyse the condyles: the Frankfort horizontal line and the "C plane" line, parallel to Frankfort and passing through the most caudal point (c point) of the sigmoid notch. Frankfort´s horizontal plane was constructed by joining the inferior orbital rim to the superior border of the external auditory meatus. The cranial part of the condylar process dissected by the "C Plane" was defined as the condylar volume of interest in this study (Figure 1A).

Manual segmentation of the condyles was performed following the subsequent steps: A bounding box was defined, in which the limits of the anatomical structure to be segmented were marked out. The selected area was then inverted. Scrolling through the axial slices, the operator manually drew the border of the condyle on each selected slice. The upper and lower limits of the condyle were standardized (Figures 1B-1E). This procedure was carried out every three slices, allowing the mesh to be edited. Next the mask of the condyles was built and finally, the new mask was used to build the final mesh of the condyles using the algorithms of mesh reconstruction through boundaries of mask. This approach lets us obtain information about the condyles, including their volume.

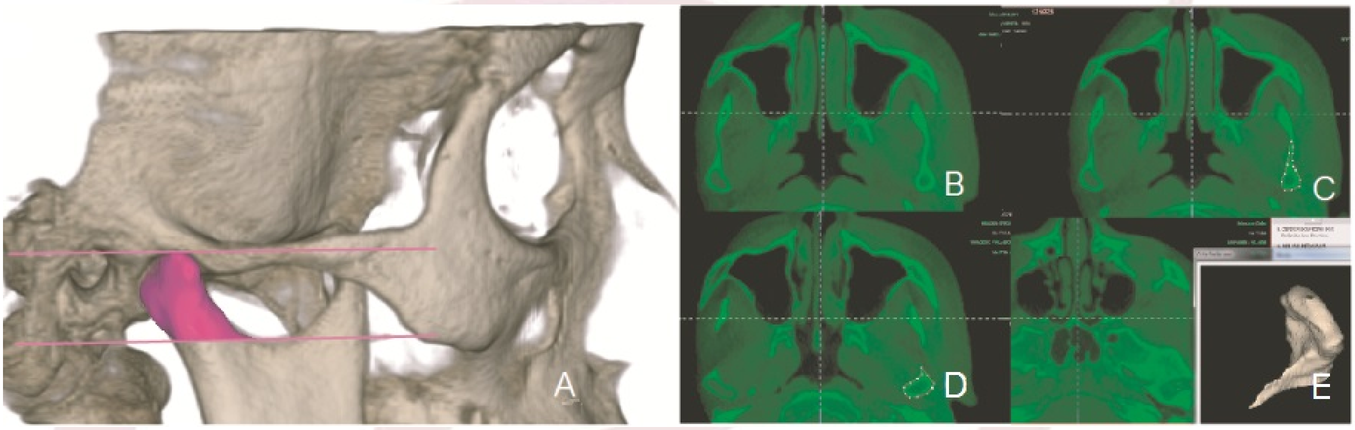

Figure 1: Mandibular condylar volume analysis. A, "Frankfort plane" and parallel line to Frankfort passing through the most caudal point of the sigmoid notch "C Plane". The cranial part of the condylar process dissected by the C Plane was defined as the condylar volume of interest in this study [11]. B-E, Manual segmentation of the condyles, progressive cuts were made from downwards to upwards on axial view. B, Lower limit of the condyle was traced where the sigmoid notch was viewed at first time. E, Upper limit of the condyle was defined where the first radiopaque area disappears.

Statistical analysis

To assess the significance of any errors during measurement, the same operator measured right and left condyles of 25 random patients twice with an interval of two weeks. The level of significance was set at 5%. No statistically significant differences were observed between the two measurements of volume; P=0.46.

All data were entered into Excel™ (Microsoft office 2010) and the statistical analysis was carried out with the Statistical Package for Social Sciences (SPSS™. V. 17.0 Windows). Levene´s test for homogeneity of variance for vertical skeletal pattern groups was not significant (P=0.557). Differences in volumetric measurements among the three groups were assessed using a one-way ANOVA, with a Bonferroni post hoc test used for multiple comparisons. The level of significance was set at 5% ($P<0.05$). Dahlberg´s coefficient between mean right (1.413 mm^3) and left (1.418 mm^3) condylar volume measurements was 0.014 with a P value of 0.67 so the mean of both sides´ measurements was used in this study.

Results

Mandibular condylar mean volume values for Groups I-III were 1.599 ± 366 mm^3, 1.418 ± 309 mm^3 and 1.050 ± 288 mm^3 respectively. According to the Bonferroni post hoc test the hyperdivergent Group III showed a statistically significant lower mandibular condylar volume than Groups I and II (P=0.0001 and P=0.0001 respectively; Table 1). The statistically significant differences between different vertical patterns are also represented as a box plot in Figure 2. Regarding sexual dimorphism, significant differences in condylar volume were found between male and female subjects. Table 2 and Figure 3 show a significantly smaller condylar volume in females (P=0.001; 1.234 ± 374 mm^3 volume in females and 1.592 ± 302 mm^3 in males). No evidence of interaction between sex and facial vertical pattern was found, indicating that the profiles are parallel, P=0.628 (Table 3 and Figure 4).

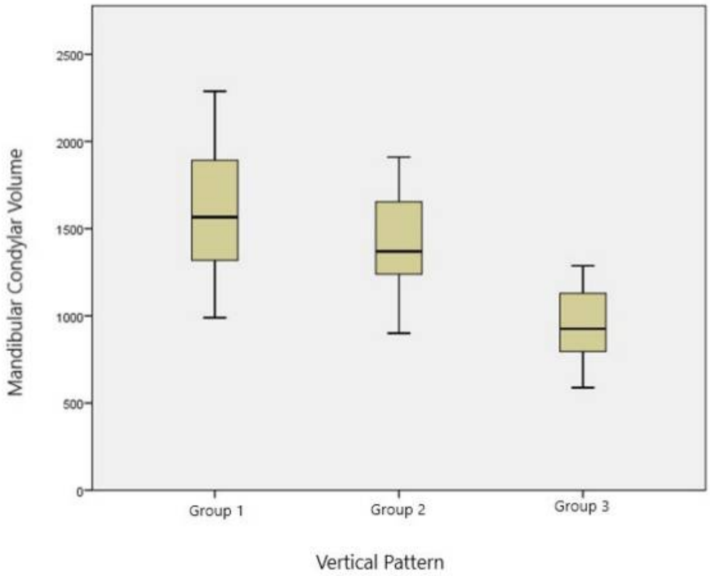

Figure 2: Box plot of mandibular condylar volume differences in different vertical patterns. Statistically significant differences were found between Group III-Group II and Group III-Group I. Variables=Group I: hypodivergent group; Group II: Normodivergent group; Group III: Hyperdivergent group.

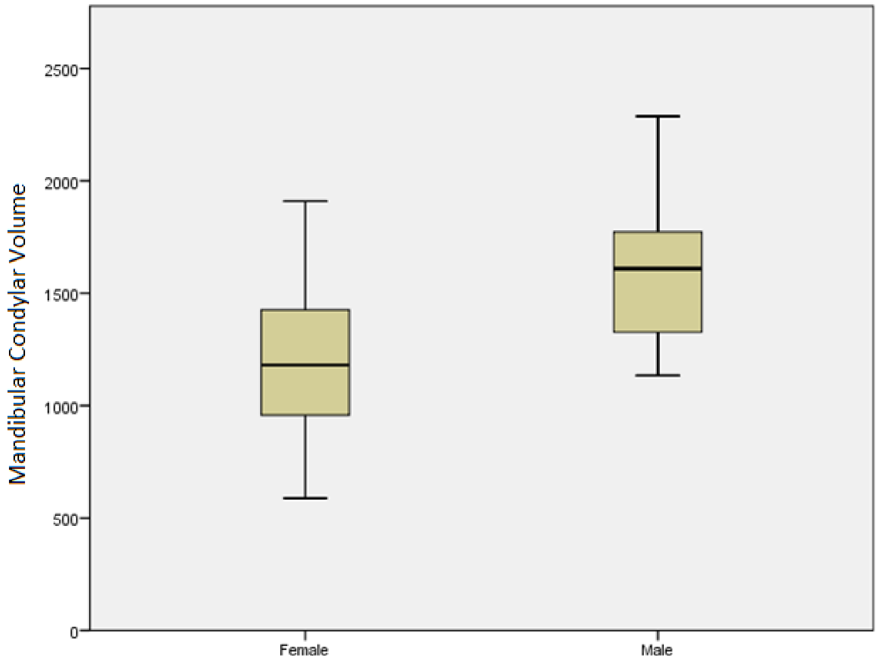

Figure 3: Box plot of mandibular condylar volume differences in relation to sex. Females showed a significantly smaller mandibular condylar volume than males.

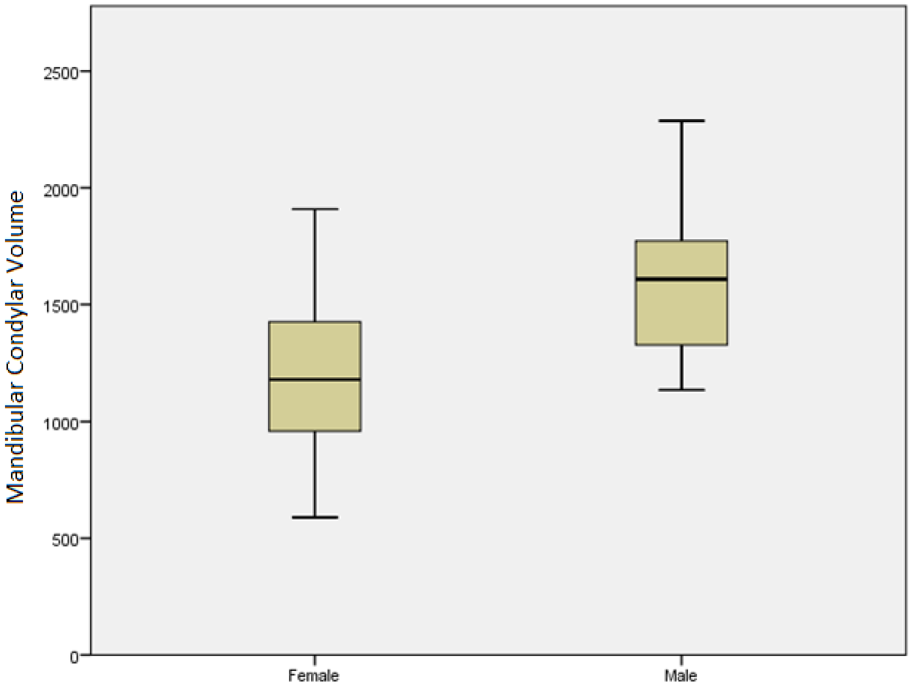

Figure 4: Profiles plot. Tests of between-subject's effects. Not interaction was found between sex and morphology (P=0.628).

	Facial pattern (I)	Facial pattern (J)	Mean difference (I-J)	Confidence interval		P
Bonferroni post-hoc	Group I	Group II	180.86	-40.06	401.78	0.144
		Group III	549.1	320.6	777.6	0.0001*
	Group II	Group I	-180.86	-401.78	40.06	0.144
		Group III	368.24	147.32	589.16	0.0001*
	Group III	Group I	-549.1	-777.6	-320.6	0.0001*
		Group II	-368.24	-589.16	-47.32	0.0001*
Group I: Hypodivergent skeletal pattern; Group II: Normodivergent skeletal pattern; Group III: Hyperdivergent skeletal pattern. *P<0.05.						

Table 1: Paired comparisons of mandibular condylar volume between different skeletal patterns using the Bonferroni post-hoc test.

	n=60	Mean (SD) mm		Confidence interval		P
				Lower limit	Upper limit	
FCV	39	1.234 (374)	FCV-MCV	-544	-172	0.001*
MCV	21	1.592 (302)				
FCV-MCV: Female Condylar Volume-Male Condylar Volume. *P<0.05.						

Table 2. Comparison of mandibular condylar volume regarding gender.

Source	Type III sum of squares	df	Mean square	F	P
Corrected model	4.49E+06	5	897945.8	10.464	0
Intercept	1.09+08	1	1.09E+08	1267.417	0
Vertical pattern	1849716	2	924858.2	10.778	0
Gender	1325946	1	1325946	15.452	0
Vertical pattern *Gender	80551.85	2	40275.92	0.469	0.628
Error	4891267	57	85811.7		
Total	1.26E+08	63			
Corrected total	9380996	62			
There was no found interaction between sex and morphology. P=0.628					

Table 3. Tests of between subject's effects.

Discussion

The adult mandibular condyle is elliptical in shape with considerable individual variation in its dimensions. Size of the mandibular condyles has been studied in two dimensions [14], although this approach is limited and does not represent the real dimension of the condyles. CBCT is considered the imaging technique of choice to study bone tissues in three spatial planes [15]. A study focused on condylar asymmetry in children shows that condylar volume and shape can be measured accurately with CBCT [16]. The introduction of CBCT provides a valuable tool for volumetric analysis of any structure of the facial region, including the mandibular condyle. In this research only data from young adult subjects (17-34 years of age) was included in order to avoid TMJ degenerative conditions that are more frequently observed in older subjects [17], excluding idiopathic condylar resorption that most often occurs in teenage girls [18]. The use of a normalized variable reduces the error associated with differences between subjects of different age [19]. Palconet et al. [20] found poor correlation between condylar changes observed on CBCT images and pain and other signs and symptoms of TMJ osteoarthritis. Therefore, this study excluded any case with erosion, flattening, resorption of mandibular condylar images or posterior displacement of the condyle in the fossa from the sample, even though the subjects did not report a history of TMJ disorders or the presence of signs and symptoms of temporomandibular disorders.

The mandibular condyle varies considerably in size and shape between individuals of different age and sex. The results of this study show that mandibular condylar volume was statistically significantly lower in females than in males (P=0.001; 1.234 ± 374 mm^3 in females and 1.592 ± 302 mm^3 in males). The wide range of values and standard deviations in volume also suggests high variability of mandibular condylar size among the subjects. These findings agree with previous research observing sexual dimorphism with higher condylar volume in males than in females [13,21,22]. The main purpose of this investigation is to evaluate mandibular condylar volume in different vertical jaw patterns using CBCT. We found that the difference of mandibular condyle volume between different vertical skeletal patterns was statistically significant (P<0.05). The mandibular condyle volume in subjects with a hyperdivergent pattern was significantly smaller compared to subjects with a hypodivergent pattern (P=0.0001) and with a normodivergent facial pattern (P=0.0001). Orthodontists have long been interested in the differences in diagnosis and planning treatment among the different vertical facial types. The relationship between mandibular condylar volume and vertical facial pattern using CBCT records has not been reported yet. This study is also focused on the assessment of average mandibular condyle volume measurements using CBCT. These data might serve as norms for the clinical assessment of mandibular condylar volume in the different vertical skeletal patterns obtained by CBCT. Numerous studies have attempted to evaluate the size and morphology of the mandibular condyles, most of them with 2D radiographic techniques such as lateral cephalograms and orthopantomograms [14,23]. Previous investigations have reported that TMJ size has a strong correlation with sagittal skeletal pattern [24]. Saccucci et al. [13] observed that subjects with a class III skeletal pattern showed a significantly greater condylar volume than class I and class II. However, until now mandibular condylar volume has not been related to the vertical skeletal pattern using CBCT technology.

Stress is an engineering term used to relate the amount of force per unit area (Stress=force/area) [25], therefore the reduction of the area or volume of the mandibular condyles could increase the stress on the TMJs. The present study would appear to be the first that reports that the mandibular condyle volume in subjects with hyperdivergent pattern is significantly smaller than in subjects with hypodivergent and normodivergent patterns. Further studies are needed to evaluate if there is an association between TMJ ID and specific anatomical factors like mandibular condyle volume. Regarding vertical skeletal pattern, previous studies have reported an association between TMJ ID and craniofacial morphology, although the cause-effect relationship may be unclear and has not been proven yet. In this way, some cephalometric characteristics such as a decrease in posterior facial height, decrease in ramus height are associated with TMJ internal derangement in young women [26].

The morphology and volume of the mandibular condyle may vary greatly between individuals and sex groups. The mean mandibular condylar volume values and standard deviations reported in this study with the ability to render and visualize mandibular condyles into 3D virtual images may help clinicians in diagnosis and treatment. The volumetric analysis of the condyles carried out in this study showed quantitative differences in mandibular condylar volume between the different vertical facial patterns. It is recommended that the orthodontist be careful not to overlook these morphologic characteristics at the initial examination and diagnosis.

Conclusion

- The null hypothesis that there are no differences among different vertical skeletal patterns was discarded. Rather, mandibular condyle volume in subjects with hyperdivergent pattern was significantly lower than in subjects with hypodivergent and normodivergent patterns.
- Vertical skeletal pattern was related with mandibular condylar volume in asymptomatic Caucasian orthodontic population.
- Females showed a significant lower mandibular condylar volume than males. These morphologic relationships should be considered during orthodontic planning and treatment.

Acknowledgement

We thank Amanda McGrosky for proofreading the text.

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