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RADIOGRAPHIC ASSESSMENT OF MANDIBULAR CONDYLE DENSITY IN DIFFERENT VERTICAL SKELETAL PATTERNS: A CBCT STUDY

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KEYWORDS

Bone density, CBCT, mandibular condyle, Vertical skeletal patterns.

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ABSTRACT

Introduction: The temporomandibular joint (TMJ) is crucial for stomatognathic functions, including chewing, speaking, and swallowing. The mandibular condyle, a vital component of the TMJ, has been extensively studied, particularly regarding its role as a primary growth center influencing the mandible's growth rate and size. Facial vertical skeletal patterns are key factors that can affect condylar bone density, leading to various structural and functional outcomes. The advent of cone beam computed tomography (CBCT) has revolutionized the assessment of the TMJ, offering higher accuracy than conventional 2D radiographs by providing detailed three-dimensional images for precise evaluation of condylar density. **Aim:** To radiographically evaluate mandibular condyle density across different vertical skeletal patterns using CBCT. **Materials and Methods:** This study analyzed thirty-three CBCT scans from the Oral Radiology Department archives at the Faculty of Dentistry, Suez Canal University. The scans were categorized into three groups based on vertical skeletal patterns: Group I (norm-divergent), Group II (hyperdivergent), and Group III (hypodivergent). **Results:** Significant differences were observed between the three groups. Group I (norm-divergent) exhibited the highest mandibular condyle density, followed by Group III (hypodivergent) and Group II (hyperdivergent). **Conclusion:** Vertical skeletal patterns significantly influence the density of the mandibular condyle.

INTRODUCTION

The temporomandibular joint (TMJ) is a highly intricate structure within the human body, playing a crucial role in the masticatory system. It is essential for functions such as chewing, speaking, and swallowing. The TMJ consists of several key components: the articular eminence, glenoid fossa, condylar process, and the articular disc situated between the condyle and the fossa. The condylar process, a primary structural element of the mandible, governs the growth and development of the mandibular bone in both sagittal and vertical dimensions [(1)]. Condyles are regarded as the most critical growth sites within the craniofacial complex due to their exceptional adaptability. The cartilaginous tissue of condyles allows them to regenerate in response to external stimuli, even after typical growth has ceased. In orofacial orthopedics, condyles are a primary focus because they play a pivotal role in ensuring long-term stability in orthognathic surgery.[(2)]

Given the strong relationship between form and function, most orthodontists expect connections between condylar characteristics and cranial shape. **Bjork,** detailed the change of the mandible from birth to adulthood. To predict the direction of growth in his long-term implant study, he postulated a number of structural features related to the mandible. Due to the significant variability observed in the growth rates of condyles, researchers identified only one consistent morphological characteristic: the inclination of the condyle [3]. Trabecular thickness, number, and spacing serve as markers for strength of the bone structure. The study also demonstrated that trabecular separation is the most sensitive indication of changes in bone metabolism, and that both reductions in trabecular thickness and number and their reflection on bone strength are related[4].

Depending on the functional pressure applied to the TMJ, different changes occur in the joint. Because bones are living tissues, they rebuild even after they have reached their maximum size. Changes in the functional pressure applied to bones were shown to influence their interior structure, and mechanical features were identified as factors influencing bone remodeling. Therefore, the thickness, density, and alignment of internal bone trabeculae vary depending on the mechanical environment [4]. Using CBCT scans which are more precise than conventional radiographs, the condyle and surrounding components can be investigated by dividing it into four slices in frontal and lateral planes, bilaterally. It was demonstrated that the diagnostic accuracy of CBCT is comparable to that of computed tomography. In multi-planar reconstructions, CBCT scans can be utilized to produce cross-sectional, cephalometric, and panoramic images. Published articles claim that the linear measurements made from these images are precise to within a millimetre. When measured with CBCT, the linear lengths between landmarks often employed in orthodontic evaluations were shown to yield exceptionally accurate data with an error rate of less than 1% [5]. Cone beam computed tomography (CBCT) has proven to be a reliable and precise technique for obtaining both volumetric and linear measurements of mandibular condyles, even when soft tissue is present. This makes CBCT a valuable tool for clinical diagnosis [6].

Numerous varieties of facial development can be distinguished by the way that the mandible rotates. When the mandible rotates clockwise, it expands excessively vertically in comparison to the horizontal plane. This process reduces vertical overbite and creates a hyperdivergent profile characterized by vertical growth. Conversely, when the mandible rotates in an anticlockwise direction, it leads to diminished vertical growth relative to the horizontal plane and an increased vertical overbite. This results in a hypodivergent profile associated with horizontal growth [7]. Various factors can contribute to different vertical growth patterns in the face. A “high angle” profile is characterized by an increased mandibular plane angle (MPA) and is typically associated with increased lower facial height (LFH). Conversely, a “low angle” profile features a reduced MPA and is usually linked with decreased LFH. A “normal angle” profile indicates a normal MPA with corresponding normal LFH. Additionally, the growth and development of the jaws, the dentoalveolar process, tooth eruption, and the functional dynamics of the tongue and lips also play crucial roles. Previous research indicates that the mandible rotates backward when vertical growth at the condyles is less than that at the alveolar processes or facial sutures. In contrast, the mandible rotates forward when the vertical growth at the condyles surpasses the combined vertical growth at the facial sutures and alveolar processes[8]. Consequently, the primary objective of this study was to evaluate the density of the mandibular condyle across various vertical skeletal patterns using radiographic techniques.

MATERIALS AND METHODS

This research was structured as a retrospective cross-sectional study, utilizing thirty-three Cone Beam Computed Tomography (CBCT) scans. These scans were retrieved from the archives of the Oral Radiology Department, Faculty of Dentistry, Suez Canal University. After the approval of Research Ethics Committee, Faculty of Dentistry, Suez Canal University (no.477\2022).

The imaging was performed using the Scanora 3Dx CBCT scanner (Soredex, Finland). The field of view was fixed at 240x 165mm for all images using standard resolution mode, the operating parameters were 90 KVp, 10 MA and effective exposure time 3.2 seconds. The voxel size was 0.5mm using a flat panel detector. All scans were exposed using the same parameters fixed to ensure standardization. The sample size was determined using G*Power version 3.1 statistical software to ensure adequate statistical power. A total sample of at least thirty-three CBCT scans (11 each group) were found to be sufficient to detect a power of 80% at a significant level of 5% ($p< 0.05$).

The CBCT scans utilized in this study were selected based on specific eligibility criteria to ensure the accuracy and relevance of the data. The inclusion criteria were as follows:

a) Inclusion Criteria:

- Unidentified full skull CBCT scans.
- Patients within the age range of 20-40 years.
- High-quality CBCT scans without any artifacts obscuring the condylar region.
- Absence of orthodontic appliances in the CBCT scans.
- A complete set of permanent dentitions, excluding third molars.
- No radiographic evidence of pathology in the condyles or glenoid fossa.
- Male or female patients were included in the study.

b) Exclusion criteria:

- Skeletal asymmetry.
- Temporomandibular joint disorders.

Study design:

The CBCT scans were equally divided into three groups, each consisting of 11 scans, based on the vertical skeletal pattern of the subjects. The angles relevant to the study used for sample grouping were derived from the lateral 3D skull views provided by the Cone Beam Computed Tomography (CBCT) as described by **Bajracharya *et al.*** [9)]

1. **Group I:** Normal Vertical Skeletal Patterns (Normodivergence)

This group included scans meeting the following criteria:

- SN to mandibular plane angle: 32° ± 4°
- Y-axis to Frankfort plane angle: 61° ± 4°
- Frankfort to mandibular plane angle: 25° ± 3°
- Gonial angle: 124° ± 5°
- Cranial base angle: 132° ± 5°

2. **Group II**: High Vertical Skeletal Patterns (Hyperdivergence)

Scans in this group were required to have:

- SN to mandibular plane angle: > 37°
- Y-axis to Frankfort plane angle: > 66°
- Frankfort to mandibular plane angle: > 29°
- Gonial angle: > 129°
- Cranial base angle: > 138°

3. **Group III**: Low Vertical Skeletal Patterns (Hypodivergence)

The inclusion criteria for scans included in this group were:

- SN to mandibular plane angle: < 27°
- Y-axis to Frankfort plane angle: < 57°
- Frankfort to mandibular plane angle: < 19°
- Gonial angle: < 119°
- Cranial base angle: < 127°

The planes and angles used for scans' grouping are [10] :

- **Mandibular plane:** Plane passing through Me (menton) tangent to lower border of the mandible.
- **SN line:** The line joining the S (sella) and N(nasion) representing the anterior cranial base.
- **SN to mandibular plane angle:** The angle between mandibular plane and the SN plane.
- **Y-axis line:** Line from S to Gn (gnathion) indicating direction of mandibular growth.
- **Frankfort (FH)plane:** The facial plane connecting Or(orbitale) and P(porion).
- **Y-axis to Frankfort plane angle**: the angle between the axial plane and the Sella-Gnathion plane (y-axis).
- **Gonial angle**: measured by passing a tangent to the posterior surface of the ramus of the mandible and the mandibular plane.
- **Cranial base angle:** the angle between SN (Sella- Nasion) plane and the (Sella- Basion)

Radiographic Analysis

The method for radiographic analysis was meticulously standardized. Initially, the reference sagittal and coronal planes were aligned to center on the right condyle head. In the axial image, the sagittal plane was adjusted to bisect the right condyle head into medial and lateral sections, while the coronal plane was modified to split the condyle into equal anterior and posterior halves. To evaluate the condylar density across different vertical skeletal patterns and compare the groups (normodivergence, hyperdivergence, and hypodivergence), as well as the right and left condyles in each scan, specific measurements were obtained from the CBCT scans after categorizing the scans into the three study groups.

Assessment of Condylar Head Density[11] :

- The axial slice showcasing the largest mediolateral diameter of the mandibular condyle was selected for analysis. The images were magnified up to 200% to enhance the visibility of the morphology and the distinction between cortical and cancellous bone boundaries.
- The densities of the cortical and cancellous bones of the condyles were measured bilaterally, one at a time, on this axial slice.
- Initially, the total density of the whole cross-sectional area of the condyle assessed in Hounsfield units (HU), comprising both cortical and cancellous bone densities, was determined. This was done by delineating the cortical boundary of the condylar head using the Region of Interest (ROI) icon with a polyline feature (Fig. 1a).
- Subsequently, the density of the cancellous bone was assessed by outlining the cancellous bone boundary on the condylar head, excluding the cortical outline, and then calculating the average value (Fig. 1b).

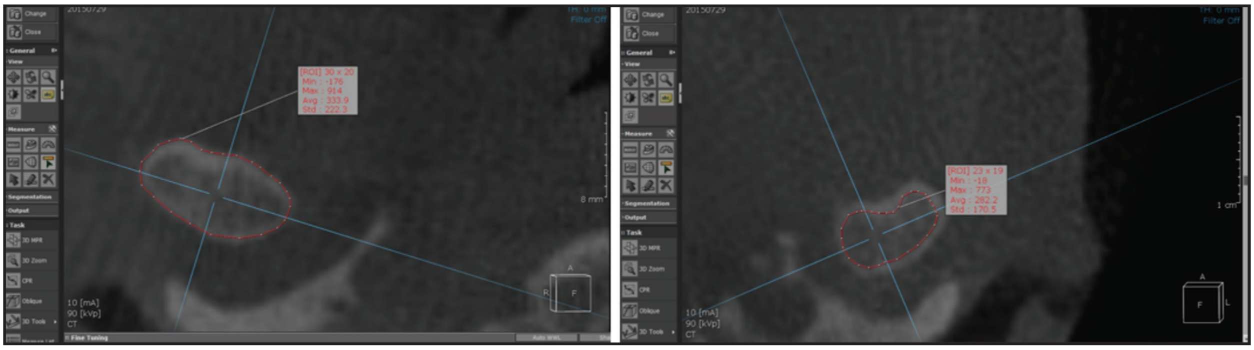

Fig. (1) Show the method of measuring the mandibular condyle density; **(1, A):** Demonstrating the average total density of the head of the condyle for both cortical and the cancellous bone. **(1, B):** Delineation of the cancellous bone of the head of the condyle with exclusion of the cortical boundary

- Finally, the cortical bone density was computed by subtracting the cancellous bone density from the total bone density obtained.
- These measurements were conducted for all subjects in Groups I, II, and III, for both the right and left condylar heads.

Statistical analysis

The data were input into a computer and analyzed using IBM SPSS software version 20.0 (Armonk, NY: IBM Corp). The Shapiro-Wilk test was applied to verify the normality of the distribution. Quantitative data were described using range (minimum and maximum), mean, standard deviation, and median. The significance of the findings was assessed at a 5% significance level.

The statistical tests employed in this study included:

1. **One-Way ANOVA Test:** It was used to compare normally distributed quantitative variables between two distinct time periods.
2. **Kruskal-Wallis Test:** for comparing abnormally distributed quantitative variables across more than two groups. For pairwise comparisons among these groups, the Dunn's multiple comparisons test was used.

RESULTS

This study aimed to assess the mandibular condylar density in various vertical skeletal patterns utilizing cone beam computed tomography (CBCT). The evaluation included total cancellous and cortical bone densities.

Total bone density (cancellous and cortical)

Table (1) shows results for the comparison between the two sides in each group regarding total bone density cancellous and cortical. For Group I, a statistically significant difference was found between the right and left sides ($p=0.041^*$) where the right side showed higher total bone density than the left. For Group II, a statistically significant difference between right and left ($p=0.003^*$) was revealed where similarly, the right side showed higher total bone density in comparison to the left side. While for Group III, a statistically non-significant difference between right and left sides was revealed ($p=0.697$).

Table (1) *Comparison between the two sides in each group regarding total bone density (cancellous and cortical)*

	Total bone density cancellous and cortical		T	P
	Right	Left		
Group I (n = 11)	330.4 ± 106.5	266.4 ± 119.4	2.315*	0.041*
Group II (n = 11)	262.5 ± 69.30	196.9 ± 65.12	3.748*	0.003*
Group III (n = 11)	255.1 ± 79.53	244.4 ± 50.96	0.405	0.697

t: *Paired t-test* **p**: *p value for comparing between the two studied sides in each group*
*: *Statistically significant at* $p \leq 0.05$
Group I: Normodivergence, Group II: Hyperdivergence, Group III: Hypodivergence

Table (2) presents comparison of the total bone density, including cancellous and cortical bone, between the three groups for both, right and left sides. There was no statistically significant difference in total bone density detected on the right side (p=0.101), as well as the left side among the three groups (p=0.159). However, a significant difference was revealed in overall bone density (mean of right and left sides) across the three groups (p=0.032*), with Group I exhibiting the highest total bone density, followed by Group III, and then Group II.

Table (2) *Comparison of the total bone density, including both cancellous and cortical densities, across the three groups for each side.*

Total bone density cancellous and cortical	Group I (n = 11)	Group II (n = 11)	Group III (n = 11)	F	P
Right	330.4 ± 106.5	262.5 ± 69.30	255.1 ± 79.53	2.480	0.101
Left	266.4 ± 119.4	196.9 ± 65.12	244.4 ± 50.96	1.962	0.159
Total AVERAGE (right and left sides)	298.41±115.40	229.70±73.83	249.71±64.76	3.760	0.032*
Sig. bet. grps.	p1=0.028*, p2=0.223, p3=0.771				

SD: *Standard deviation* **F**: *F for One way ANOVA test* **P:** *p value for comparing between the studied groups.*
p_1: *p value for comparing between* **Group I** *and* **Group II**
p_2: *p value for comparing between* **Group I** *and* **Group III**
p_3: *p value for comparing between* **Group II** *and* **Group III**
*: *Statistically significant at* $p \leq 0.05$
Group I: Normodivergence, Group II: Hyperdivergence, Group III: Hypodivergence.

DISCUSSION

Bone structure strength is primarily determined by the number, thickness, and spacing of trabeculae. Reductions in trabecular thickness and number negatively impact bone strength, with trabecular separation serving as the most sensitive indicator of changes in bone metabolism. Additionally, factors such as the characteristics of age, masticatory muscles and the presence or absence of teeth significantly influence condylar density. Consequently, the thickness, density, and alignment of the internal bone trabeculae within the condyle adjust according to mechanical conditions. [(3)]

Considering the critical role of the mandibular condyle in growth and its response to applied loads, this study was undertaken to assess the bone density of the mandibular condyle across various vertical skeletal patterns using cone beam computed tomography (CBCT).

Thirty-three cone beam computed tomography (CBCT) scans were obtained from the archives of the Oral Radiology Department, Faculty of Dentistry, Suez Canal University, without regard to the gender of the subjects. These scans were categorized into three groups based on their vertical skeletal patterns: Group I, with normal vertical skeletal patterns (normodivergent); Group II, with high-angle cases (hyperdivergent); and Group III, with low-angle cases (hypodivergent). Specific angles were measured and used for assigning the scans into one of the study groups.

This sample size was similar to that of **Farinazzo *et al.***[12] and **Cattaneo *et al***[13]. The sample size chosen according to sample size equation and it was taken without any sex prediction as reported by **Girardot**[14], **Swasty *et al.*** [15].

The age range for the selected patients' scans was between 20 and 40 years, consistent with other studies. [2,16,17,18] This age period is considered stable for the development and growth of the head and face. During this phase, the effects of growth are less pronounced, and the permanent dentition is more stable compared to the variability observed during the mixed dentition stage.

In the study of **Saccucci *et al.,*** [19] CBCT technology offers clinicians three dimensional high-resolution images with quick scan times (10–70 seconds) and less radiation exposure, which is advantageous to both patients and practitioners. Therefore, it can record the anatomy needed for orthodontic treatment planning, which is very helpful in orthodontic study. When used properly, CBCT imaging data provides more accurate information for treatment planning than other imaging modalities, enabling orthodontists to deliver better results. Also, according to **García-Sanz *et al.*** [5] CBCT imaging has been proven to be extremely reliable for obtaining mandibular condyle volumetric and linear measurements accurately. Additionally, it was reported by **Sonal *et al.*** [20] and **Arayapisit *et al.*** [21] that CBCT scans are more reliable and accurate than panoramic X-rays and cephalograms. Furthermore, **Rodriguez *et al.*** [17] carried out a study to confirm the accuracy of cephalometric measurements extracted from CBCT scans.

Regarding results of the current study, comparison between the three studied groups showed statistically significant differences in the mean mandibular condylar bone density (cortical and cancellous) where group I (normo-divergence) showed the highest density values followed by group III (hypo-divergence), then group II (hyper-divergence).

These findings align with those of **Ozdemir *et al.***[22] who observed that patients with hyperdivergent facial types typically exhibit less dense bone compared to individuals with other facial types. Similarly, **Ding *et al.*** [23] found that bone density is linked to vertical facial type, with lower bone density in hyperdivergent (Group II) patients than in hypodivergent (Group III) patients. In addition, their results revealed no significant differences in age or sex between the two groups. While this was in disagreement with **Kim *et al.*** [11] who concluded that the bone density was higher in (hyper-divergent) than (normo and hypo-divergent) skeletal patterns. This may be due to difference in sample size and differentiation of each sub-group between the age and gender.

CONCLUSION

Based on the findings of this study, the following conclusions can be made:

The variation in vertical skeletal patterns significantly impacts the density of the mandibular condyle where the normo-divergence pattern shows the highest density values.

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