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# *Three-Dimensional Analysis of Age and Eichner Index-Related Volumetric Changes in Mandibular Condyles*

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## ABSTRACT

***Introduction:*** The impact of condyle volume is influenced by the presence of posterior occlusal support and age. This study aimed to retrospectively explore how age, Eichner index, and gender influence condyle volume in three dimensions, through the classification of occlusal support using the Eichner index.

***Material and Methods:*** Cone-beam computed tomography (CBCT) images of 232 patients (107 males and 125 females) aged 18-76 years were retrospectively analysed. ITK-SNAP open-source software was utilized to measure volume of condyles with semi-automated segmentation. CBCT images were analyzed based on age, gender, and the status of posterior occlusal support. Posterior occlusal support status was assessed by categorizing it into three groups according to the Eichner index: A) indicating no loss of posterior occlusal support; B) representing one to three units of occlusal support loss; and C) denoting four units of posterior occlusal support loss. For normality, Kolmogorov Smirnov test was performed and Pearson test was used to determine the correlations of continuous variables. Student's t test was used to investigate the difference between age and gender, and paired t test was used to evaluate the difference between left and right volume. $P < 0.05$ was considered significant.

***Results:*** There was no statistically significant difference between the mean right and left condyle volume ($p>0.05$). The mean condyle volume was higher in males than females, but this difference was not statistically significant ($p>0.05$). A statistically significant negative correlation was detected between age and condyle volume ($p<0.05$). Age and Eichner index were statistically significantly positively correlated ($p<0.05$). A statistically significant negative correlation was determined between condyle volume and Eichner index ($p<0.05$).

***Conclusion:*** Volumetric measurement of the condyles using CBCT and comparison with Eichner index is crucial to assess abnormalities and bony changes affecting the TMJ in association with occlusal support and to examine and prevent complications. Although it was found that the condyle volume decreased significantly with increasing age and decreasing occlusal support, no significant difference was revealed between genders in the present study.

***Keywords:*** Condyle volume, semi-automated segmentation, posterior occlusal support, Eichner index, cone-beam computed tomography.

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## Introduction

The condyle is an essential region of temporomandibular joint (TMJ) and mandible's primary growth centre and is capable of multi-directional growth and remodelling. In this way, which can response to continual stresses through bone remodelling and influence the size of mandible in adults.[1] During the process of abnormal TMJ loading or sustainable physical stress exceeds adaptive ability, alterations in mandibular bone occur for non-functional remodelling. Advancing age and functional changes cause morphologic and histologic differentiation in the TMJ.[2,3] Significant effects on mandibular growth and development are observed due to changes in adult masticatory function. These include reconfiguration of the articular elements in TMJ, alterations in position between articular disc and mandibular condyle, contributions from parafunctional habits, and changes in occlusion.[1,3] Decreased mandibular growth may produce some changes such as condylar volume, ramus height and retrusion of the mandible. Condylar volume alterations may be mostly detected with arthritis, asymmetry, anterior disc displacement and decreased masticatory function as a result of tooth loss.[2,4]

The maximum bite force, an essential indicator in the assessment of masticatory muscles, correlates with muscle cross-sectional area.[5] Occlusal force is greatly affected by the declining frequency of natural teeth in mouth; therefore, patients with artificial dentition have been shown to have less masticatory muscle strength.[6,7]

The Eichner index is one of the most extensively used dental indices in epidemiological studies and is most effective

in establishing intermaxillary contacts and enhancing functional dental occlusion. In this index, posterior teeth are categorised according to the presence or absence of occlusal contact between premolars and molars.[8,9] There are many studies supporting the interpretation of masticatory ability with Eichner index and confirming that occlusal force is reduced more in the group with reduced occlusal support. The classification of occlusal supports was performed according to the Eichner index.[10,11] The Eichner index divides molar teeth into four support areas.[12]

Numerous diagnostic imaging techniques are available to evaluate TMJ structures. Furthermore, cone-beam computed tomography (CBCT) is is preferable three-dimensional (3D) imaging technique for optimal visualization of bony components, which is partially cost-effective, low radiation and short acquisition time.[13-15]

In the current study, ITK-SNAP version 4.0.2 (Penn Image Computing and Science Laboratory), which processes 3D models with manual and semi-automated segmentation, was used to perform condylar volume measurement.[15,16]

The purpose of this study was to restrospectively investigate the effect of age, Eichner index and gender on mandibular condyle volume by classifying the effects of masticatory force according to the Eichner index using CBCT.

## Materials and Methods

Ethical approval was provided from Clinical Research Ethics Committee prior to commencement of the study (Protocol No: 2024/76). The images used in the present study were acquired between 2022 and 2024 at the Department of Dentomaxillofacial Radiology, Lokman Hekim University Faculty of Dentistry, using a NewTom VGi EVO (QR, Verona, Italy) CBCT device. Images were from the tomography archive and asymptomatic patients who underwent CBCT examination for various indications were selected. Multiplanar images were acquired from 12x8, 15x12, 16x16, 17x19 and 24x19 FOV (field of view) with a voxel size of 0.3 $mm^3$ and a slice thickness of 1 mm. Inclusion criteria for this study were CBCT scans obtained from patients aged 18-76 years between 2020 and 2022. Exclusion criteria included patients with syndromes or facial growth disorders, presence of distortion, magnification, artifacts or foreign bodies in the study area on CBCT images, metabolic bone diseases, cysts, tumors or fracture lines in the study area, trauma and odontogenic infections in the maxillofacial region. CBCT images of 232 patients (107 males and 125 females) aged 18-76 years (mean age: 44.12±16.01) were retrospectively assessed.

### *Classification According to the Eichner Index*

The CBCT images included in the study were classified according to the Eichner index regarding the condition of the posterior occlusal supports. The Eichner index categorises the molars into four support areas and classifies them as follows:[10-12]

A1) Four support zones are present and there are no missing teeth.
A2) Four support areas are present, but there is a missing tooth on one side of the jaw.
A3) Four support areas present, but missing teeth on both sides.
B1) The patient has sufficient number of support teeth to form three support areas.
B2) The patient has enough support teeth to form two support areas.
B3) The patient has a number of support teeth sufficient to create only one support area.
B4) Only anterior contact is present, no support area in the molar region.
C1) There is at least one tooth without a support area in both mandible and maxilla.
C2) There is at least one tooth in the mandible or maxilla without a support area.
C3) Complete edentulism prevails on both sides of the jaw.

### *Condylar 3D Reconstruction and Volume Measurement*

ITK-SNAP (Penn Image Computing and Science Laboratory) open source software was used to measure the volume of the mandibular condyles. CBCT DICOM datasets were transmitted into ITK-SNAP and visualized in coronal, sagittal and axial slices. Mandibular condyles were characterized by semi-automatic segmentation (Figure 1). Afterward, manual segmentation was conducted to ensure precision. The superior and inferior borders of condyle volumes were identified in coronal, sagittal, and axial views. The disappearance of the sigmoid notch marked the recognition of the inferior border. The region where the area of the coronal portion increased, rather than declined, marked the onset of sigmoid area. Consequently, mandibular condyle could be dimensioned using the standard method without incorporating sigmoid area. This was in agreement with Bayram *et al.*[17], Safi *et al*.[1] and Tecco *et al.*[18]. The volume of mandibular condyles was automatically measured by program in cubic millimeters. The volume of each condylar side was measured separately.

The data obtained were recorded as age, gender and posterior occlusal support. Posterior occlusal support status was splited into three categories according to Eichner index (A: no loss of posterior occlusal support; B: one to three units of occlusal support loss; C: four units of posterior occlusal support loss) (Figure 2).[12,19]

All assessments were conducted by two dentomaxillofacial radiologists, one with five years of experience (EMAO) and the other with seven years of experience (AA). To ensure inter-observer and intra-observer calibration and reliability of the evaluations, 20% of the images were reviewed by the same observers two weeks after the initial assessment. The mean of the results from the initial and subsequent measurements was then utilized for statistical analysis.

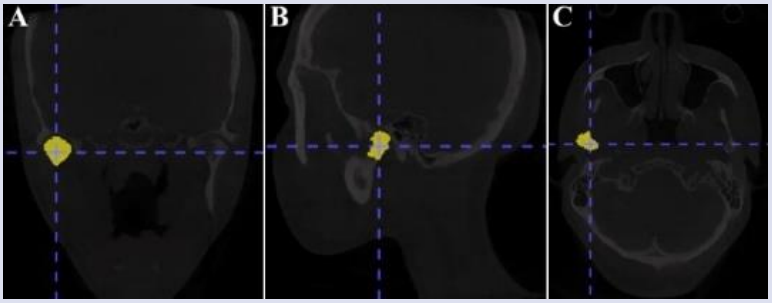


*Figure 1: The volumetric analysis performed using ITK-SNAP software is demonstrated in CBCT image; A. Coronal section, B. Sagittal section, C. Axial section.*

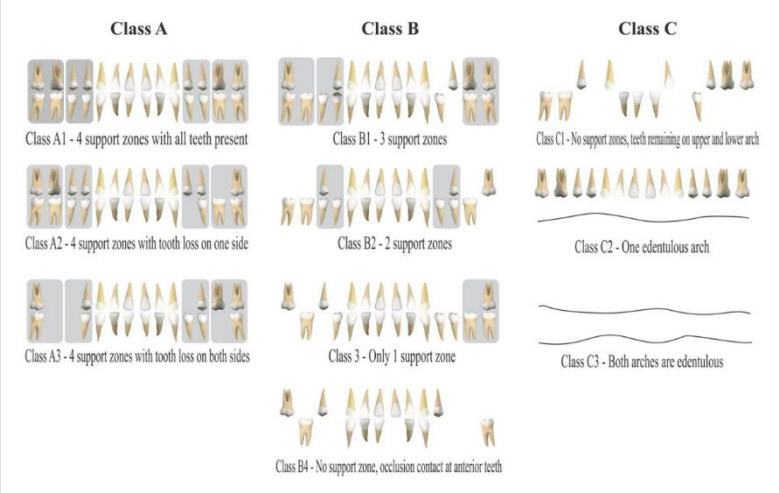


*Figure 2: Eichner index classification; A1) four support areas, no missing teeth; A2) four support areas, missing teeth on one side of the jaw; A3) four support areas, missing teeth on both sides of the jaw. B1) three support areas; B2) two support areas; B3) one support area; B4) only anterior contact; no tooth support in the molar region. C1) at least one tooth without support area in mandible and maxilla; C2) at least one tooth without support area in mandible or maxilla, C3) complete edentulism on both sides of the jaw.*

### *Statistical analysis*

The normality of the study group's data was assessed using the Kolmogorov-Smirnov test, confirming a normal distribution. Correlations among continuous variables were assessed using Pearson test, whereas differences based on age and gender were analyzed using Student's t-test. Furthermore, Paired t-test was employed to compare the left and right sides of the TMJ. A significance level of $p < 0.05$ was set. All statistical analyses were performed using SPSS Statistics 29.0 (IBM Corp, Armonk, NY).

## Results

We observed a strong correlation (0.87-0.92) among all repeated measurements, suggesting reliable intra- and inter-observer consistency in the assessments. The mean volume of the right condyle was 1520.6 ± 409.7 $mm^3$, and for the left condyle, it was 1492.5 ± 412.7 $mm^3$. There was no statistically significant difference between the mean volumes of the right and left condyles ($p>0.05$). The comparison of condyle volumes between males and females is presented in Table 1. Although the mean condyle volume was higher in males compared to females, this difference was not statistically significant ($p>0.05$). Eichner index distribution of the patients was 44.8% in group A, 33.6% in group B and 21.6% in group C. While a significant difference was detected between Eichner index and age and condyle volumes, no statistically significant relationship was found with gender. A statistically significant negative correlation was observed between age and condyle volume ($p<0.05$). Age and Eichner index had a statistically significant positive correlation ($p<0.05$). A statistically significant negative correlation was observed between condyle volume and Eichner index ($p<0.05$). Correlations between variables are shown in Table 2.

*Table 1.* The comparison of condyle volumes between males and females is demonstrated.

| | Female (n=125) | | Male (n=107) | |
|---|---|---|---|---|
| **Volume ($mm^3$)** | **Right** | **Left** | **Right** | **Left** |
| Mean±S.D. | 1493.1±386.7 | 1497.7±401.8 | 1552.8±434.6 | 1486.5±426.9 |
| Min.-Max. | 814-2373 | 751-2331 | 827-2586 | 689-2664 |

*S.D.: Standard Deviation, Min.: Minimum, Max.: Maximum*

*Table 2.* Correlations between variables are displayed

| | Pearson Correlation-P | | | |
|---|---|---|---|---|
| | **Age** | **Left Condyle Volume** | **Right Condyle Volume** | **Eichner index** |
| **Age** | ------ | -0,820 - p<0.001 | -0,853 - p<0.001 | 0.816 - p<0.001 |
| **Left Condyle Volume** | -0,820 - p<0.001 | ------ | 0,901- p<0.001 | -0,824 - p<0.001 |
| **Right Condyle Volume** | -0,853 - p<0.001 | 0,901- p<0.001 | ------ | -0,837- p<0.001 |
| **Eichner index** | 0.816 - p<0.001 | -0,824 - p<0.001 | -0,837- p<0.001 | ------ |

*P < 0.05*

## Discussion

Physiologic and pathologic changes as a result of changing mechanical and functional forces cause life-long remodeling processes thanks to the adaptability of the bone and soft tissue structures of the TMJ.[1,20,21] Changes in the number of teeth with age and changes in masticatory function may cause changes in the morphologic and histologic structure as well as volume of condyle.[20-22] Alexiou *et al.*[23] have reported that the degree of bone changes in the mandibular condyle progressively increases with age. In the present study, we concluded that condyle volume decreases with age and that edentulism is associated with a decrease in condyle volume.

Radiologic examination of TMJ and condyle anatomy is important for investigating TMJ anatomical morphology in the identification and therapeutic planned treatment of TMJ diseases.[13] CBCT is an important imaging tool widely used for the evaluation of the condyles, involves a lower radiation dose than computed tomography (CT) and provides images in a relatively short time.[13,24] Several studies have been performed on CBCT to establish segmentation of condyles.[1,14,15,17] Various techniques are employed to obtain volumetric data of regions of interest. In this study, we utilized semi-automated segmentation of mandibular condyles with the open-access software ITK-SNAP. Semi-automated segmentation merges the efficiency and consistency of automated segmentation with the ability to manually designate the region of interest, thereby reducing user-dependent errors and saving time.[25,26] Semi-automatic segmentation was chosen in this study due to the fact that it integrates automated and manual segmentation of the regions of interest. Semi-automatic segmentation is guided by the user and has an crucial role in the precise assessment of the volume measured.

Bayram *et al.*[17] performed volume measurement of the mandibular condyle using the Cavalieri principle on CBCT images of 5 dry mandibles. Safi *et al.*[1] measured the condyle volume from CBCT images of 195 patients using ITK SNAP software (Penn Image Computing and Science Laboratory). Şallı *et al.*[15] utilized CBCT images of 345 patients and measured the condyle volume with ITK SNAP software. Tecco *et al.*[18] used Mimics 9.0 software (Materialise NV Technologielaan, Leuven, Belgium) to measure condylar volume and surface on CBCT images of 150 Caucasian young adults. Serindere *et al.*[14] performed volume and surface area measurements on CT images of 125 patients using InVesalius software (CTI, Campinas, SãoPaulo, Brazil). In the current study, the condyle volume of 232 patients was analyzed using CBCT and ITK SNAP software similar to Safi *et al.*[1] and Şallı *et al.*[15].

Bayram *et al.*[17] reported that the mean condyles volume varied between 1378 and 2877 $mm^3$ in their study. Saccuci *et al.* [6] analysed the mandibular condyle volumes of 200 young patients aged 15 to 29 years and found that the mean right and left condyle volumes were 2464-2606 $mm^3$, respectively. Safi *et al.*[1] detected the mean right condyle volume as 2326 and the mean left condyle volume as 1982 $mm^3$ in 107 young patients aged 18-25 years; the mean right condyle volume as 2324 and the mean left condyle volume as 2227 $mm^3$ in 88 patients aged 46-55 years. Şallı *et al.*[15] observed the mean right and left condyle volume of 84 young patients aged 18-25 years as 1730.2-1754.6 $mm^3$, and the mean right and left condyle volume of 261 patients aged 45-70 years as 1703.6-1682.9 $mm^3$, respectively. Serindere *et al.*[14] found that the mean right and left condyle volume was 1565-1557 $mm^3$ in 125 patients between 18-70 years of age. Tecco *et al.*[18] determined the mean right and left condyle volume as 693.6-666.9 $mm^3$ in 150 young individuals aged 15-29 years, respectively. Most of the studies in the literature focus exclusively on the young population. In their present study, the mean right and left condyle volumes in 232 patients aged 18-76 years were 1520.6-1492.5 $mm^3$, respectively. It is similar to the results of Serindere *et al.*[14] who had a similarly wide age range to the current study.

Tecco *et al.*[18], Safi *et al.*[1] and Saccucci *et al.*[6] reported that the volume of the right condyle was greater than that of the left, with statistically significant differences between the condylar volumes of the two sides. Conversely Şallı *et al.*[15], Liu *et al.*[27] and Serindere *et al.*[14] observed that although the volume of the right condyle was larger than the left, there was no statistically significant disparity between the two sides. Our study's

findings align with those of Şallı *et al.*[15], Liu *et al.*[27] and Serindere *et al.*[14] indicating a higher volume in the right condyle but no significant difference compared to the left. This variation in right and left condyle volumes across the literature is believed to stem from inherent asymmetry in human body structures and differences in chewing habits.[1,18]

There are studies showing that decreases in condylar bone volume and trabecular bone are observed in females, particularly in the postmenopausal period, with osteoporosis which develops due to estrogen deficiency.[18,27-29] Safi *et al.*[1] found that males exhibited significantly greater condyle volumes than females in both young and elderly age groups. It was concluded by Tecco *et al.*[18] that the difference between condyle volumes in males and females was statistically significant, with males having larger condyle volumes than females. In the study of Şallı *et al.*[15] condyle volumes were observed to be larger in male patients than in females. In the study of Serindere *et al.*[14] condyle volume was significantly higher in males than in females. In comparison to the literature, condyle volume was higher in males than females in this study, however this difference was not statistically significant contrary to the literature.

Although numerous studies have investigated age-related morphological and morphometric alterations in TMJ, there remains contention surrounding the direct correlation between remodeling and age.[1,23]Alexiou *et al.*[23] suggested that the extent of bony changes in the mandibular condyle escalates with advancing age. Safi *et al.*[1] observed that condyle volume of the older group was lower than the younger group, however, this difference was not statistically significant. Şallı *et al.*[15] found that condyle volume of the elderly group was lower than the younger group, but this did not constitute a significant difference. Serindere *et al.*[14] concluded that condyle volume decreased with increasing age and this resulted in a statistically significant difference. In concordance with the literature, in our study, it was detected that condyle volume showed a negative and significant correlation with age.

Cartilage growth of the mandibular condyle and mandibular morphology are affected by mastication.[6,18,30] Loss of occlusal support leads to a decrease in masticatory function and thus to a change in mechanical forces. Moreover, loss of occlusal support can be the reason for bony changes in condyle.[18,30] Previous research has indicated that the most important morphological changes in TMJ structures are associated with conditions involving early occlusal contacts and tooth loss.[18] Loss of posterior teeth constitutes a significant etiological factor in functional alterations of the stomatognathic system.[18,31] In the current study, the tooth support status of our study group was classified according to the Eichner index, a classification system based on the occlusal support of natural posterior teeth. In the findings of Safi *et al.*[1], Ahmed *et al.*[31] and Şallı *et al.*[15], there was no correlation between Eichner index and condylar volume. In contrary to the literature, a statistically significant difference was determined between posterior occlusal support and condylar volume on both sides in this study.

In the literature, the relationship between orthodontic anomalies and condylar volume has been evaluated; *Saccucci et al.*[32] investigated the condylar volumes of skeletal S1, S2 and S3 patients with healthy TMJ using CBCT; a larger condylar volume was observed in skeletal class III subjects than in skeletal class II and skeletal class I subjects. In the study of *Ceratti et al.*[33] comparing vertical growth pattern and condylar volume changes, it was determined that individuals with hyperdivergence had relatively larger condylar volumes than those with hypodivergence. Similarly, smaller condyles were detected in individuals with increased total gonial angles showing post-rotation growth pattern compared to individuals with horizontal growth pattern in which total gonial angle was larger. There are also studies showing that TMJ morphology has a strong correlation with skeletal morphology.[5] It is known that there are differences in the force vector against the condyle during mastication in different individuals.

Changes in the shape and severity of orthodontic anomalies are likely to result in imbalances in masticatory force and differences in the force to the condyle.[32,34] The evaluation of the three-dimensional structure of the condyle head allows us to have clinical information about how force distributions should be made in the planning of orthodontic and orthognathic surgical treatments.

The decrease in condylar volume that occurs with age is particularly important in trauma, surgical interventions to the maxillofacial region and TMJ in elderly patients. Furthermore, we consider that the rehabilitation of mastication with the replacement of missing teeth can prevent this volume loss and minimise the complications that may occur in elderly patients.

There are several limitations of this study. Magnetic resonance imaging (MRI) is the ultimate method for examining the TMJ and diagnosing TMJ diseases; it acquires multiple static images in series, providing excellent routine static images.[35,36] It also allows analysis of disc position and condyle movement during the dynamic process of mouth opening and closing.[35,36] Additionally, the current clinical symptoms of the patients regarding TMJ are not known since this is a retrospective study, and the changes occurring on the MRI have not been reviewed. The changes in the TMJ of the patients before and after edentulism could not be investigated in the study. Further studies in larger populations are needed to include patients' systemic diseases and examine their effects on volumetric change, to evaluate the clinical symptoms occurring in the TMJ, and to analyze the changes that occur after masticatory rehabilitation.

## Conclusions

Whereas significant differences were found between age, condyle volume and Eichner index, no significant difference was found between genders, in spite of the volumetric difference observed. Volumetric measurement of the mandibular condyles and their analysis in

comparison with the Eichner index is an important feature derived from CBCT to assess abnormalities and bony changes affecting the TMJ in relation to occlusal support and to examine and prevent complications. Relying on CBCT images, ITK-SNAP software has enabled substantial and beneficial segmentation methods to assess condyle volumes in three dimensions.

## Conflict of Interest

There were no conflict of interest.

## Funding

The authors declared that this study did not receive any financial support.

## Ethics

Human and animal rights statement All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1964 and later versions.

## Ethical Statement

Ethical approval was obtained from Lokman Hekim University Non-interventional Clinical Research Ethics Committee (Protocol No: 2024/76).

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