Analysis of the Volumetric Asymmetry of the Mandibular Condyles Using CBCT

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ABSTRACT

Objectives: The aim of this study was to analyse volumetric asymmetries between the right and left condyles in relation to age, gender, and dental status.

Materials and methods: A retrospective analysis of 150 cone beam computed tomography (CBCT) scans was conducted. A single investigator performed the volumetric analysis of the CBCT scans using Vesalius 3D software. The volumetric data were analysed in relation to the gender, age, and dental status.

Results: The mean right condylar volume was significantly higher ($P < .01$) than the left condylar volume. Right and left condylar volumes were significantly higher ($P < .01$) in male study participants when compared to female study participants. There was no significant difference ($P = .47$) in the volumetric asymmetry between the male and female study participants. The volumetric asymmetry was significantly higher ($P < .01$) in the older age groups when compared to the younger age groups. The volumetric asymmetry was significantly higher ($P < .01$) in the partially and completely edentulous patients when compared to the dentate study participants. The condylar volume on the side having a partially edentulous area was significantly lower than the condylar volume of the contralateral dentate side ($P < .001$).

Conclusions: The volumetric asymmetry between the right and left condyle significantly increases with age and edentulousness. The result of the study encourages the clinicians to perform volumetric evaluation of the condyles in cases of radiographically evident condylar asymmetries to obtain a more accurate diagnosis.

Introduction

The mandibular condyles undergo morphologic changes due to physiologic and pathologic processes throughout human life. Several imaging modalities have been developed to detect the morphologic changes in condyles. In years, cone beam computed tomography (CBCT) has been effectively used to study morphologic changes of the condyle with significantly lower doses of radiation. Several conditions associated with the alteration in condylar morphology such as hypertrophy, hypotrophy, erosion, and osteophyte formation have been effectively detected using CBCT. Although most physiologic and pathologic changes alter the volume of the condyle, few studies have concentrated on volumetric analysis. These studies have analysed the condylar volume in relation to age, gender, dental status, and type of malocclusion. Studies have revealed that there is a volumetric asymmetry between the right and left condyles in experimental rats. The researchers attributed similar condylar volumetric asymmetry in experimental rats to unilaterial chewing habits. There are very few studies that have investigated the volumetric asymmetry of the condyles in humans.
A recent study comparing CBCT based semi-automated segmentation volume with 3-dimensional printed models revealed that the segmentation was reliable and accurate.\(^{10}\) Although manual, semi-automated condylar segmentation procedures are tedious and time-consuming, they are more reliable and accurate when performed by experienced operators.\(^{11,12}\) With this background, the present study was conducted to analyse age-, gender-, and dental status-related alterations associated with volumetric asymmetry between right and left mandibular condyles.

**Materials and methods**

**Study design**

A retrospective analysis of 150 CBCT scans in the radiographic archives of University Dental Hospital, Sharjah (UDHS) was conducted. Randomly selected scans belonged to patients who reported to the UDHS clinics for various dental treatments from January 2019 to December 2022. This study was approved by the research ethics committee, University of Sharjah (Reference number: REC-20-09-21-01) and conformed with the principles of the Declaration of Helsinki. Informed written consent was obtained from all patients involved in the study. Supporting data are available at figshare; doi10.6084/m9.figshare.19334915.

CBCT scans of male and female study participants older than 20 years were included in the study. CBCT scans with artifacts affecting the region of interest (ROI) and scans that were not completely cover the ROI were excluded. CBCT scans of participants with clinical symptoms of temporomandibular joint (TMJ) disorders, history of TMJ disorders, TMJ trauma, and TMJ surgery were excluded from the study.

Sample size estimation using an analysis of variance (ANOVA) model revealed that an approximate 150 CBCT scans would deliver an 80% probability of detecting the differences in the condylar volumetric asymmetry with a confidence level of 95%.

**Image acquisition and condylar volume detection**

CBCT scans analysed in the study were obtained using the Galileos CBCT machine (Sirona Dental Systems). The scans were acquired using the following parameters: field of view 15 cm × 24 cm, voxel size 0.25 mm, voltage 120 kVp, tube current 7 mA, and scanning time of 14 seconds. After the application of inclusion and exclusion criteria, 150 randomly selected CBCT scans were selected for the study. A single investigator with 12 years of clinical experience in dentomaxillofacial radiology performed the volumetric analysis of the CBCT scans.

The scans of the study participants were exported and saved in the Digital Imaging and Communications in Medicine (DICOM). The scans were then imported into the Vesalius 3D software (PS-Medtech). The CBCT scans were then visualised using contrast settings to visualise the hard tissues. Each condyle was visualised in 4 views, namely 3-dimensional, axial, coronal, and sagittal (Figure 1). The segmentation procedure was carried out using scissors and erase tools to follow the condylar contours. To achieve standardisation in the segmentation procedure, condyles were segmented to the level of a horizontal line drawn from the deepest point in the sigmoid notch. Whilst the line was being drawn, the CBCT volume was positioned in the sagittal direction with Frankfurt plane maintained horizontally.

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Fig. 1 – Segmentation of the condyle using Vesalius 3D software. The scissor and eraser tools were used in the 3D, axial, coronal, and sagittal views for the segmentation.
After completion of the segmentation, the volume of the segmented condyle (in mm³) was determined using picking and measurement functionality on the software toolbar (Figure 2). The investigator reevaluated the condylar volumes of 10% of the CBCT scans after an interval of 1 month to assess the intra-observer agreement.

The right condylar volume, left condylar volume, and volumetric asymmetry (difference between the volumes of right and left condyles) were analysed in relation to the gender, age, and dental status of the study participants. The study participants were categorised into 3 groups (A, B, and C) based on their age. Study participants within the age range of 20 to 40 years were categorised into Group A. Those within the age range of 21 to 40 years were categorised into Group B, and those older than 40 years were categorised into Group C.

Study participants with a full complement of teeth excluding the maxillary and mandibular third molar were considered as “dentate.” Patients who underwent extraction or lost any of the permanent teeth due to reasons such as orthodontics and trauma but presented no obvious spacing of the dental arch during CBCT evaluation were classified as denitate. Similarly, those with dental implants and fixed prosthesis were considered as dentate.

Participants with 1 or more teeth missing in the maxillary or mandibular arches were considered as “partially edentulous.” Participants with either completely edentulous maxilla or completely edentulous mandible or completely edentulous maxilla and mandible were considered as “completely edentulous.” Based on the location of the partially edentulous area in relation to the dental midline, the areas were classified as right, left, or bilateral. Patients using partial or complete removable prosthesis were classified as “partially edentulous” and “completely edentulous,” respectively.

**Statistical analysis**

The study parameters were statistically analysed using IBM SPSS statistics (version 22, IBM Corp.). Paired t test was used to determine the difference between the right and left condyles of the study participants. ANOVA and Tukey post hoc test were used to compare the condylar volumes and volumetric asymmetry in relation to the age and dental status of the study participants. Pearson correlation was used to evaluate the correlation between age and volumetric asymmetry.

**Results**

The intraclass correlation coefficient between the first and second volumetric analysis by the investigator for 10% of the randomly selected samples was 0.93. A majority of the study participants (40.0%) belonged to the 41- to 60-year-old age group (Group B) followed by 33.3% in the 20- to 40-year-old group (Group A) and 26.7% in the group aged 61 years or older (Group C). Male study participants represented 63.3% of the study sample, whilst female study participants accounted for 36.7%.

The age of the study participants ranged from a minimum of 22 years to a maximum of 78 years. The mean right condylar volume, mean left condylar volume, and
volumetric asymmetry were $1552.00 \pm 173.33 \text{ mm}^3$, $1458.97 \pm 245.58 \text{ mm}^3$, and $103.48 \pm 102.15 \text{ mm}^3$, respectively.

The mean right condylar volume was significantly higher ($P < .01$) compared to the left condylar volume when compared using paired t test. Further, both right and left condylar volumes were significantly higher ($P < .01$) in male study participants when compared to female study participants using independent-sample t test. However, there was no significant difference ($P = .47$) in the volumetric asymmetry between the male and female study participants.

When the volume of the right and left condyles were evaluated considering the age groups of the study participants using ANOVA, both the right and left condylar volumes significantly decreased ($P < .01$) in the older groups (Group B and Group C) when compared to younger study participants (Group A; Table 1). The difference amongst the groups was further confirmed by pairwise comparison of the study groups using the Tukey post hoc test (Table 2). However, the volumetric asymmetry was significantly higher ($P < .01$) in the older age groups (Group B and Group C) when compared to the younger age groups.

When the volume of the right and left condyles were evaluated considering the dental status of the study participants using ANOVA, both the right and left condylar volumes significantly decreased ($P < .01$) in partially and completely edentulous study participants compared to dentulous study participants (Group A; Table 3). Furthermore, the individual difference amongst the groups was confirmed by pairwise comparison of the study groups using the Tukey post hoc test (Table 4). However, the volumetric asymmetry was significantly higher ($P < .01$) in the partially and completely edentulous compared to the dentulous study participants. A moderate positive correlation ($r = 0.61$, $P < .01$) was observed between the age of the study participants and the volumetric asymmetry.

There were 45 participants in the partially edentulous group. Amongst them, 24 had a partially edentulous area on the right side, 16 of them on the left side, and 5 of them on both sides. When the partially edentulous area was on the right side, the left condylar volume was significantly higher ($P < .001$) than the right condylar volume. Similarly, when the partially edentulous area was on the left side, the right condylar volume was significantly higher ($P < .001$) than the left condylar volume. However, when the partially edentulous areas occurred bilaterally, the right condylar volume was significantly higher ($P < .001$) than the left condylar volume (Table 5).

Regression analysis revealed that the age and dental status of the study participants had a significant influence ($P < .01$) on the volumetric asymmetry of the mandibular condyles. In contrast, the gender of the study participants had no significant influence ($P = .07$) on the volumetric asymmetry of the study participants (Table 6).

### Table 1 – Comparison of the right condylar volume, left condylar volume, and volumetric asymmetry between age groups.

| Volume      | N  | Mean    | SD    | Minimum | Maximum | ANOVA | F      | P value |
|-------------|----|---------|-------|---------|---------|-------|--------|---------|
| Right condyle |    |         |       |         |         |       |        |         |
| Group A     | 50 | 1668.33 | 64.47 | 1543.10 | 1802.10 | 66.23 | <.01*  |         |
| Group B     | 60 | 1579.72 | 126.12| 1320.90 | 1782.60 |       |        |         |
| Group C     | 40 | 1364.99 | 176.32| 1100.30 | 1566.40 |       |        |         |
| Left condyle |    |         |       |         |         |       |        |         |
| Group A     | 50 | 1647.71 | 75.09 | 1500.10 | 1777.20 | 120.21| <.01*  |         |
| Group B     | 60 | 1503.75 | 121.47| 1200.00 | 1674.00 |       |        |         |
| Group C     | 40 | 1155.86 | 240.87| 811.30  | 1500.20 |       |        |         |
| Asymmetry   |    |         |       |         |         |       |        |         |
| Group A     | 50 | 44.49   | 24.20 | 11.10   | 78.10   | 52.47 | <.01*  |         |
| Group B     | 60 | 82.20   | 87.61 | 10.20   | 288.00  |       |        |         |
| Group C     | 40 | 209.13  | 104.47| 62.90   | 432.20  |       |        |         |

* $P < .05$, statistically significant. $P > .05$, statistically nonsignificant. ANOVA, analysis of variance.

### Table 2 – Pairwise comparison of the right condylar volume, left condylar volume, and volumetric asymmetry between age groups.

| Volume      | (I) age group | (J) age group | Mean difference (I–J) | SE | $P$ value | 95% confidence interval | Lower bound | Upper bound |
|-------------|---------------|---------------|-----------------------|----|-----------|-------------------------|-------------|-------------|
| Right condyle | Group A       | Group B       | 88.61                 | 24.23 | <.01*    | 31.23                   | 145.99      |             |
|             | Group A       | Group C       | 303.34                | 26.85 | <.01*    | 239.78                  | 366.91      |             |
|             | Group B       | Group C       | 214.73                | 25.83 | <.01*    | 153.56                  | 275.90      |             |
| Left condyle | Group A       | Group B       | 143.95                | 29.16 | <.01*    | 74.91                   | 213.00      |             |
|             | Group A       | Group C       | 491.85                | 32.31 | <.01*    | 415.35                  | 568.34      |             |
|             | Group B       | Group C       | 347.89                | 31.09 | <.01*    | 274.29                  | 421.50      |             |
| Asymmetry   | Group A       | Group B       | –37.70                | 15.04 | .04*     | –73.32                  | –2.08       |             |
|             | Group A       | Group C       | –164.63               | 16.67 | <.01*    | –204.09                 | –125.18     |             |
|             | Group B       | Group C       | –126.93               | 16.04 | <.01*    | –164.90                 | –88.96      |             |

Tukey post hoc test.

* $P < .05$, statistically significant. $P > .05$, statistically nonsignificant.
Discussion

The present study was carried out to analyse the volumetric asymmetry between the right and left condyles of taking into consideration the gender, age, and dental status of the study participants. Although some studies have analysed the volumetric changes in the condyles with respect to these parameters, not many have analysed the asymmetry (difference) in volumes of right and left condyles considering these parameters. This area of research remains vastly unexplored.

Since the segmentation process in our study is semi-automated, the examiner has an important role. In the present study, a single examiner performed the volumetric analysis of the mandibular condyles. The single examiner concept was used by da Silva et al., Kim et al., and Lim et al. In the present study, the intra-examiner reliability was 0.93. Studies have reported excellent intra-examiner reliability for volumetric assessment of condyles using CBCT.

In our study, we used Vesalius 3D software for volumetric evaluation of the condyles. Similar external source...
automated softwares were used by Lin et al. and Mendoza et al.\textsuperscript{15-17} There is an overall agreement amongst the published studies regarding the validity of the semi-automated software in condylar volume estimation.\textsuperscript{15,16,18}

Standardisation of the anatomic boundaries is an important factor during the volumetric analysis to maintain uniformity in all study samples.\textsuperscript{19} Our study used the technique adapted by Lo Giudice et al. to standardise the condylar boundaries.\textsuperscript{18} The inferior boundary of segmentation was extended to till a horizontal line that passed through the deepest point on the sigmoid notch. The same anatomic boundaries were used by Cavagnetto et al. in their research study on juvenile arthritis patients.\textsuperscript{20} Few other researchers have used a plane parallel to the Frankfurt horizontal passing through the most caudal point of the mandibular notch.\textsuperscript{21,22}

It noteworthy that the volume of the condyle is approximately 3 to 4 times greater with the former method when compared to the latter method because of the difference in the boundaries of segmentation.

In our study, the mean volume of the right condyle was significantly higher than the mean volume of the left condyle. A similar difference was observed by Tecco et al. in their study.\textsuperscript{5} Two other studies reported higher mean right condylar volume than left condylar volume, although the difference was not statistically significant.\textsuperscript{16,23,24} However, the sample size in the study by Rodrigues et al was considerably lower compared to the present study and the study by Tecco et al. In another study by Schmidt et al., 8 cadaveric heads showed marked mandibular condylar asymmetry.\textsuperscript{30} No apparent reason has been stated for the volumetric asymmetry, although most researchers attribute it to preferential one-sided mastication in study patients with malocclusion.\textsuperscript{5} Researchers have stated that significant morphologic changes and asymmetries of the TMJ and condyles in specific could be attributed to dental causes like loss of dentition and malocclusion.\textsuperscript{26}

In the present study, the right and left condylar volumes in the male study participants were significantly higher than in the female study participants. A recently published study revealed similar differences between the condylar volumes of male and female study participants.\textsuperscript{27} Few volumetric analysis studies conducted in the Italian, Spanish, Turkish, Korean, and Malaysian populations revealed similar results.\textsuperscript{5,10,24,28,29} To the best of our knowledge, there are no published studies in the Middle Eastern population analysing volumetric differences between male and female participants.

Therefore, the gender-based volumetric analysis of our study would provide critical regional data for any large-scale analysis in the future. Studies evaluating the linear measurements have reported that condylar size showed gender-based variation.\textsuperscript{20} It has been observed that both right and left condyles in male participants have larger medio-lateral and antero-posterior dimension compared to female participants.\textsuperscript{30}

Though the volumetric difference between the male and female patients in our study was similar to the Italian, Spanish, Turkish, Korean, and Malaysian populations, the volumetric asymmetry between the right and left condyles was not reported in these studies.\textsuperscript{5,10,24,28,29} In our study, there was no significant difference in the volumetric asymmetry between male and female participants. Another similarity between the results of these studies and our study was the larger volume of the right condyle compared to the left. These findings suggest that gender- and side-based variations in condylar volume are similar in individuals of different ethnicities.

In the present study, participants were classified into 3 age groups based on the method used by Mathew et al.\textsuperscript{31} We observed a significant increase in the volumetric asymmetry in older age groups (groups B and C) compared to the younger age group. A moderate positive correlation between volumetric asymmetry and the age of the participants was observed in our study. Iturriaga et al. found higher vertical asymmetry between the condyles of individuals in higher age groups. They found the vertical height of the condyles to be more symmetric in younger individuals.\textsuperscript{32} Another recently published study reported significant asymmetry between the medio-lateral dimensions of right and left condyles in participants in older age groups.\textsuperscript{33} Researchers have found that mandibular condyles are more likely to remodel at or above the age of 40 years.\textsuperscript{34} Degenerative changes resulting from the ageing process also lead to dimensional alterations.\textsuperscript{35} These dimensional changes may not occur in an identical manner in the right and left condyle, which is the probable reason for asymmetries in linear measurements. Though several studies have reported asymmetries in the linear dimensions of the condyle with advancing age, there are no data available on the volumetric asymmetry between the right and left condyles in relation to age.

In the present study, the volumetric asymmetry was significantly greater in partially and completely edentulous participants compared to dentulous participants. Though there are no studies evaluating volumetric asymmetries in dentulous, partially edentulous, and completely edentulous participants, a study by Singh et al. explored the dental status of the study participants in relation to asymmetries in condylar shapes.\textsuperscript{36} They found that the similarities between the right and left condylar shapes were significantly higher in

### Table 6 – Regression analysis for age, gender, and dental status with volume asymmetry.

|                        | Unstandardised coefficients | Standardised coefficients | t    | P value | 95% confidence interval for B |
|------------------------|-----------------------------|---------------------------|------|---------|------------------------------|
|                        | B   | SE   | Beta |       | Lower bound | Upper bound |
| (Constant)             | 299.08 | 46.62 |      |       |                |              |
| Age                    | 1.53 | 0.41 | 0.25 | 6.42 | <.01* | 206.94 | 391.21 |
| Gender                 | -28.01 | 11.67 | -0.13 | 3.71 | <.01* | 0.72 | 2.35 |
| Dental status          | -91.85 | 10.54 | -0.61 | -2.40 | .07 (NS) | -51.08 | 4.95 |

f(3, 146) = 68.41. P < .01. R² = 0.59.

* P < .05, statistically significant. P > .05 nonsignificant (NS).
dentulous study participants when compared to partially edentulous and completely edentulous patients. Though it is difficult to draw parallels between the volume changes and morphologic changes of the mandibular condyles, the outcomes of the 2 studies seem to be similar. In their radiographic study, Csado et al. found that the flattening of the articular eminence significantly correlated with age in completely edentulous study participants.37 They stated that the loss of physiologic vertical dimension leads to irreversible deformation of the condyles, resulting in flattening.37 In our study, the condylar volume on the side of edentulousness was significantly lower than on the dentate side when the right and left sides were compared in partially edentulous patients. Similar results were observed by in studies conducted by Xu et al. and Yalcin et al.38,39 This deformation may occur disproportionately in the mandible’s right and left sides. Further studies on the morphologic changes in the condyle in relation to the age and status of dentition. For further research, fully automated condylar segmentation and volumetric analysis may be useful for further studies on the morphologic changes in the condyle in relation to the age and status of dentition. For further research, fully automated condylar segmentation and volumetric analysis will be the areas to look towards.

Conclusions

From the results of our study, we conclude that the volumetric asymmetry between the right and left condyle significantly increases with age and edentulousness. The results of the study also demonstrate the volumetric changes in the condyles of the edentulous side and therefore stress the importance of replacing lost teeth. Gender seems to have no significant effect on the volumetric asymmetry. The data obtained from the present study can be useful for further research on the morphologic changes in the condyle in relation to the age and status of dentition. For further research, fully automated condylar segmentation and volumetric analysis will be the areas to look towards.

Author contributions

SRS: conception and design, and data acquisition and drafting and revision. SAB: data acquisition and drafting and revision. SAK: data acquisition and drafting and revision. WMT: data acquisition and drafting and revision. SN: Data analysis and interpretation. NHR: data acquisition and drafting and revision. KG: drafting and revision. MAA: data acquisition and drafting and revision. AM: data acquisition and drafting and revision. PB: data acquisition and drafting and revision. VK: statistical analysis. All authors read and approved the final manuscript.

Conflict of interest

None disclosed.

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