INTERNATIONAL DENTAL JOURNAL 72 (2022) 797–804

Scientific Research Report

Analysis of the Volumetric Asymmetry of the Mandibular Condyles Using CBCT

Shishir Ram Shetty [a*], *Saad Al-Bayatti* [a], *Sausan AlKawas* [a], *Wael Talaat* [a], *Sangeetha Narasimhan* [a], *Kamis Gaballah* [a], *Natheer Al-Rawi* [a], *Mohammed Alsaegh* [a], *Ananya Madiyal* [b], *Preethi Balan* [c], *Vinayak Kamath* [d]

[a] *College of Dental Medicine, University of Sharjah, Sharjah, United Arab Emirates*
[b] *AB Shetty Memorial Institute of Dental Sciences, Nitte (deemed to be university), India*
[c] *Singapore Oral Microbiomics Initiative, National Dental Research Institute Singapore, National Dental Center, Singapore*
[d] *Goa Dental College and Hospital, Goa, India*

ARTICLE INFO

Article history:
Received 6 May 2022
Received in revised form
21 June 2022
Accepted 24 June 2022
Available online 2 August 2022

Key words:
Mandibular condyle
Volume
Segmentation
Gender
Age
Edentulous

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.[1] Several imaging modalities have been developed to detect the morphologic changes in condyles.[2] In years, cone beam computed tomography (CBCT) has been effectively used to study morphologic changes of the condyle with significantly lower doses of radiation.[3] Several conditions associated with the alteration in condylar morphology such as hypertrophy, hypotrophy, erosion, and osteophyte formation have been effectively detected using CBCT.[4]

Although most physiologic and pathologic changes alter the volume of the condyle, few studies have concentrated on volumetric analysis.[5] These studies have analysed the condylar volume in relation to age, gender, dental status, and type of malocclusion.[6-8] Studies have revealed that there is a volumetric asymmetry between the right and left condyles in experimental rats.[9] The researchers attributed similar condylar volumetric asymmetry in experimental rats to unilateral chewing habits.[9] There are very few studies that have investigated the volumetric asymmetry of the condyles in humans.[5]

* *Corresponding author*. Department of Oral and Craniofacial Health Sciences College of Dental Medicine, University of Sharjah, Sharjah, United Arab Emirates.
E-mail address: shishirshettyomr@gmail.com (S.R. Shetty).
https://doi.org/10.1016/j.identj.2022.06.019
0020-6539/

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; doi 10.6084/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 $\times$ 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.

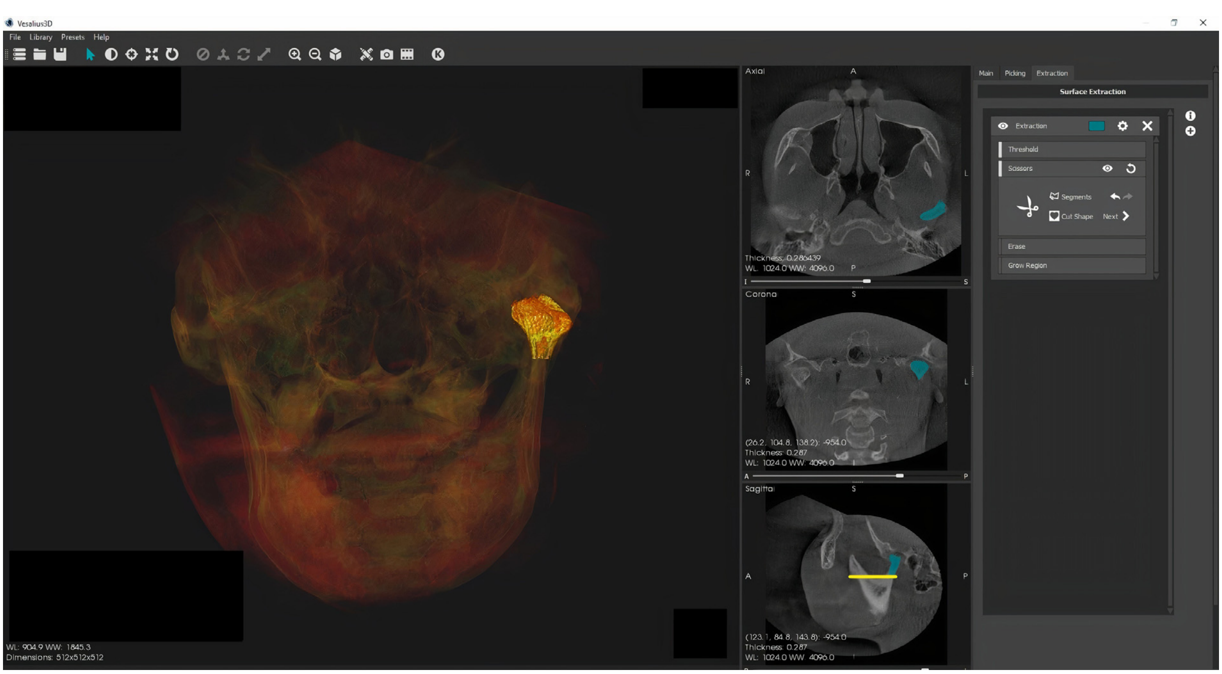

Fig. 1 – Segmentation of the condyle using Vesalius 3D software. The scissor and eraser tools were used in the 3D, axial, coronal, and sagittal views for the segmentation.

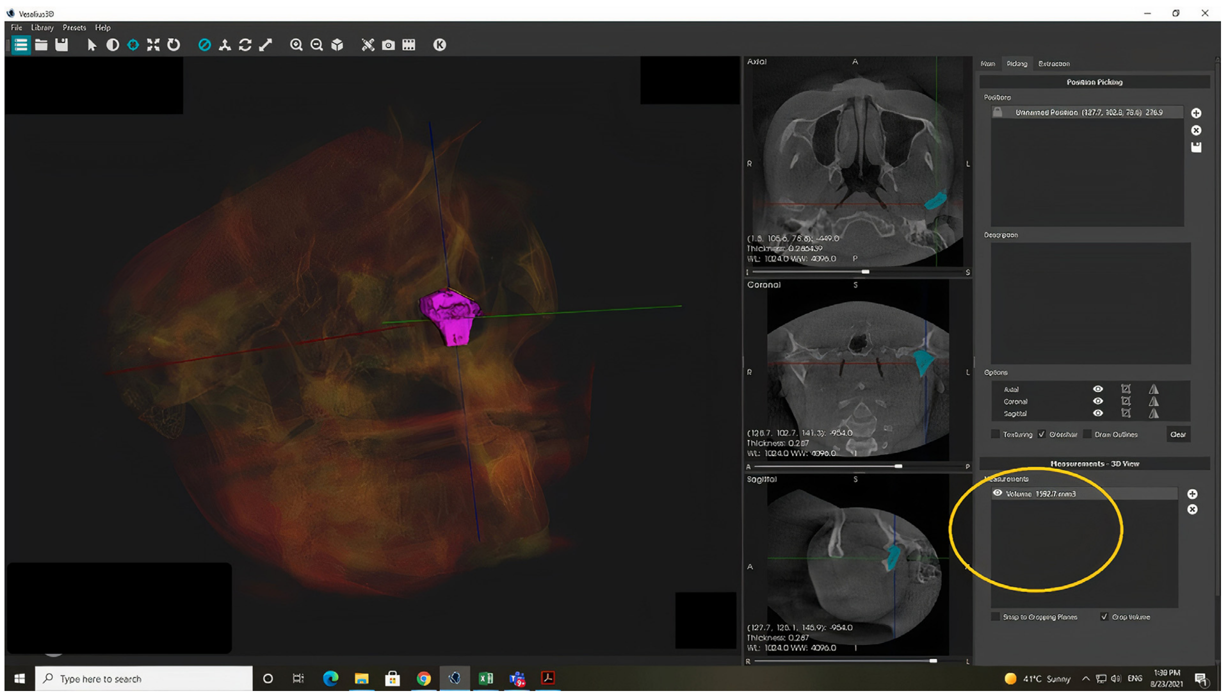

Fig. 2 – The picking functionality of the Vesalius 3D software used for volume detection. The yellow circle shows the volume of the segmented area (pink).

After completion of the segmentation, the volume of the segmented condyle (in mm^3) 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 dentate. 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

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	1787.60		
	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.

volumetric asymmetry were 1552.00 ± 173.33 mm^3, 1458.97 ± 245.58 mm^3, and 103.48 ± 102.15 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 when compared to dentate 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 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 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 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 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.

Table 3 – Comparison of the right condylar volume, left condylar volume, and volumetric asymmetry amongst dentate, partially edentulous, and completely edentulous patients.

Volume		N	Mean	SD	Minimum	Maximum	ANOVA	
							F	P value
Right condyle	**Completely edentulous**	15	1288.76	178.71	1121.80	1566.40	29.74	<.01*
	Partially edentulous	45	1536.58	199.45	1100.30	1787.60		
	Dentate	90	1603.58	105.43	1278.20	1802.10		
Left condyle	**Completely edentulous**	15	1039.52	201.22	901.60	1420.10	66.49	<.01*
	Partially edentulous	45	1364.90	245.38	811.30	1634.70		
	Dentate	90	1575.91	129.91	1134.90	1777.20		
Volumetric Asymmetry	**Completely edentulous**	15	249.24	99.54	146.30	432.20	85.25	<.01*
	Partially edentulous	45	171.68	104.85	20.90	380.70		
	Dentate	90	45.08	33.09	10.20	143.30		

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

Table 4 – Pairwise comparison of the right condylar volume, left condylar volume, and volumetric asymmetry amongst dentate, partially edentulous, and completely edentulous patients.

Volume	(I) dental status	(J) dental status	Mean difference (I–J)	SE	P value	95% confidence interval	
						Lower bound	Upper bound
Right condyle	**Completely edentulous**	**Partially edentulous**	−247.82	43.90	<.01*	−351.76	−143.89
		Dentate	−314.82	41.06	<.01*	−412.04	−217.59
	Partially edentulous	**Dentate**	−66.99	26.88	.04*	−130.64	−3.35
Left condyle	**Completely edentulous**	**Partially edentulous**	−325.38	53.41	<.01*	−451.85	−198.92
		Dentate	−536.39	49.96	<.01*	−654.69	−418.09
	Partially edentulous	**Dentulous**	−211.01	32.71	<.01*	−288.45	−133.57
Volumetric asymmetry	**Completely edentulous**	**Partially edentulous**	77.56	20.86	.01*	28.16	126.96
		Dentate	204.16	19.52	<.01*	157.95	250.37
	Partially edentulous	**Dentate**	126.60	12.78	<.01*	96.35	156.85

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.[5] 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.[11,13,14] 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.[11]

In our study, we used Vesalius 3D software for volumetric evaluation of the condyles. Similar external source semi-

Table 5 – Comparison between right condylar and left condylar volume according to side of edentulousness amongst partially edentulous patients.

Partially edentulous	Volume	N	Mean	SD	Mean difference	95% confidence interval of the difference		t	df	P value
						Lower	Upper			
Right	**Right**	24	1449.19	205.30	105.31	75.94	134.69	7.42	23	<.001*
	Left	24	1554.50	170.25						
Left	**Right**	16	1471.82	230.77	249.56	207.47	291.66	12.64	15	<.001*
	Left	16	1222.26	249.27						
Bilateral	**Right**	5	1682.90	203.31	275.23	119.81	430.64	5.64	3	.01*
	Left	5	1407.68	280.84						

Paired *t* test.

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

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		6.42	<.01*	206.94	391.21
Age	1.53	0.41	0.25	3.71	<.01*	0.72	2.35
Gender	−28.01	11.67	−0.13	−2.40	.07 (NS)	−51.08	−4.95
Dental status	−91.85	10.54	−0.61	−8.71	<.01*	−112.69	−71.02

$F(3, 146) = 68.41$. $P < .01$. $R^2 = 0.59$.

* $P < .05$, statistically significant. $P > .05$ nonsignificant (NS).

automated softwares were used by Lin et al. and Mendoza et al.[15-17] There is an overall agreement amongst the published studies regarding the validity of the semi-automated software in condylar volume estimation.[15,16-18]

Standardisation of the anatomic boundaries is an important factor during the volumetric analysis to maintain uniformity in all study samples.[19] Our study used the technique adapted by Lo Giudice et al. to standardise the condylar boundaries.[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 Cavgnetto et al. in their research study on juvenile arthritis patients.[20] Few other researchers have used a plane parallel to the Frankfurt horizontal passing through the most caudal point of the mandibular notch.[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.[5] Two other studies reported higher mean right condylar volume than left condylar volume, although the difference was not statistically significant.[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.[25] 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.[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.[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.[27] Few volumetric analysis studies conducted in the Italian, Spanish, Turkish, Korean, and Malaysian populations revealed similar results.[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.[30] 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.[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.[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.[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.[32] Another recently published study reported significant asymmetry between the medio-lateral dimensions of right and left condyles in participants in older age groups.[33] Researchers have found that mandibular condyles are more likely to remodel at or above the age of 40 years.[34] Degenerative changes resulting from the ageing process also lead to dimensional alterations.[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.[36] They found that the similarities between the right and left condylar shapes were significantly higher in 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 based on the nature and duration of edentulousness, therefore leading to asymmetry.[40] Studies have suggested that there is a possible association between grades of condylar erosion and number of missing posterior teeth. Age-related osteoarthritis-associated bone changes coupled with the loss of teeth had been associated with the morphologic alterations of the condyles.[41,42]

A recently conducted study revealed that the volumetric analysis of the condyle overcomes the limitation of the previous studies, which have analysed the linear dimensions or morphologic variations.[43] Therefore, the results obtained from the present study would be useful for further research on morphologic alterations on the mandibular condyles in health and disease.[44,45] Since the present study was cross-sectional and mainly focused on CBCT analysis, the duration of the study participants being partially or completely edentulous was not determined. To overcome this limitation, the duration of edentulousness can be determined in future studies.

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 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.

Author contributions

SRS: conception and design; 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.

REFERENCES

1. Alexiou K, Stamatakis H, Tsiklakis K. Evaluation of the severity of temporomandibular joint osteoarthritic changes related to age using cone beam computed tomography. Dentomaxillofac Radiol 2009;38:141–7. doi: 10.1259/dmfr/59263880.
2. Talmaceanu D, Lenghel LM, Bolog N, et al. Imaging modalities for temporomandibular joint disorders: an update. Clujul Med 2018;91(3):280–7. doi: 10.15386/cjmed-970.
3. Abu-Taleb NS, ElBeshlawy DM. Low-dose cone-beam computed tomography in simulated condylar erosion detection: a diagnostic accuracy study. Oral Radiol 2021;37(3):427–35. doi: 10.1007/s11282-020-00474-7.
4. Larheim TA, Abrahamsson AK, Kristensen M, et al. Temporomandibular joint diagnostics using CBCT. Dentomaxillofac Radiol 2015;44(1):20140235. doi: 10.1259/dmfr.20140235.
5. Tecco S, Saccucci M, Nucera R, et al. Condylar volume and surface in Caucasian young adult subjects. BMC Med Imaging 2010(10):28. doi: 10.1186/1471-2342-10-28.
6. Serindere G, Aktuna Belgin C, Serindere M. Volumetric and morphological analysis of condyle and glenoid fossa on computed tomography. Eur Arch Otorhinolaryngol 2020;277(9):2581–7. doi: 10.1007/s00405-020-06078-5.
7. Safi AF, Kauke M, Grandoch A, Nickenig HJ, Zöller JE, Kreppel M. Volumetric analysis of 700 mandibular condyles based upon cone beam computed tomography. J Craniofac Surg 2018;29(2):506–9. doi: 10.1097/SCS. 0000000000004136.
8. Lentzen MP, Riekert M, Buller J, et al. A volumetric study of mandibular condyles in orthognathic patients by semiautomatic segmentation. Oral Maxillofac Surg 2022;26(2):205–12. doi: 10.1007/s10006-021-00976-6.
9. Nakano H, Maki K, Shibasaki Y, Miller AJ. Three-dimensional changes in the condyle during development of an asymmetrical mandible in a rat: a microcomputed tomography study. Am J Orthod Dentofac Orthop 2004;126:410–20. doi: 10.1016/j.ajodo.2004.04.016.
10. Kim JJ, Lagravere MO, Kaipatur NR, Major PW, Romanyk DL. Reliability and accuracy of a method for measuring temporomandibular joint condylar volume. Oral Surg Oral Med Oral Pathol Oral Radiol 2020;131(4):485–93. doi: 10.1016/j.oooo.2020.08.014.
11. Méndez-Manjón I, Haas Jr OL, Guijarro-Martínez R, Belle de Oliveira R, Valls-Ontañón A, Hernández-Alfaro F. Semi-automated three-dimensional condylar reconstruction. J Craniofac Surg 2019;30(8):2555–9. doi: 10.1097/SCS.0000000000005781.
12. Bayram M, Kayipmaz S, Sezgin OS, Küçük M. Volumetric analysis of the mandibular condyle using cone beam computed tomography. Eur J Radiol 2012;81:1812–6. doi: 10.1016/j.ejrad.2011.04.070.
13. da Silva RJ, Valadares Souza CV, Souza GA, et al. Changes in condylar volume and joint spaces after orthognathic surgery. Int J Oral Maxillofac Surg 2018;47(4):511–7. doi: 10.1016/j.ijom.2017.10.012.
14. Lim YN, Park IY, Kim JC, Byun SH, Yang BE. Comparison of changes in the condylar volume and morphology in skeletal

class III deformities undergoing orthognathic surgery using a customized versus conventional miniplate: a retrospective analysis. J Clin Med 2020;9(9):2794. doi: 10.3390/jcm9092794.

15. Lin H, Zhu P, Lin Y, et al. Mandibular asymmetry: a three-dimensional quantification of bilateral condyles. Head Face Med 2013;9:42. doi: 10.1186/1746-160X-9-42.
16. Mendoza LV, Bellot-Arcís C, Montiel-Company JM,, et al. Linear and volumetric mandibular asymmetries in adult patients with different skeletal classes and vertical patterns: a cone-beam computed tomography study. Sci Rep 2018;8:12319. doi: 10.1038/s41598-018-30270-7.
17. Mostafavi M, Saeedi Vahdat A, Javadian L, Ghaznavi A. Analysis of condylar volume in relation to craniofacial morphology using cone beam computed tomography. J Cont Med Sci 2018;4(4):202–6. doi: 10.22317/jcms. v4i4.485.
18. Lo Giudice A, Quinzi V, Ronsivalle V, et al. Evaluation of imaging software accuracy for 3-dimensional analysis of the mandibular condyle. A comparative study using a surface-to-surface matching technique. Int J Environ Res Public Health 2020;17(13):4789. doi: 10.3390/ijerph17134789.
19. Jung J, Kim JH, Lee JW, Ohe JY, Choi BJ. Three-dimensional volumetric analysis of condylar head and glenoid cavity after mandibular advancement. J Craniomaxillofac Surg 2018;46 (9):1470–5. doi: 10.1016/j.jcms.2018.06.001.
20. Cavagnetto D, Abate A, Caprioglio A, Cressoni P, Maspero C. Three-dimensional volumetric evaluation of the different mandibular segments using CBCT in patients affected by juvenile idiopathic arthritis: a cross-sectional study. Prog Orthod 2021;22(1):32. doi: 10.1186/s40510-021-00380-6.
21. Santander P, Quast A, Olbrisch C, et al. Comprehensive 3D analysis of condylar morphology in adults with different skeletal patterns - a cross-sectional study. Head Face Med 2020;16 (1):33. doi: 10.1186/s13005-020-00245-z.
22. Saccucci M, D'Attilio M, Rodolfino D,, et al. Condylar volume and condylar area in class I, class II and class III young adult subjects. Head Face Med 2012;8:34. doi: 10.1186/1746-160X-8-34.
23. Rodrigues AF, Fraga MR, Vitral RF. Computed tomography evaluation of the temporomandibular joint in Class I malocclusion patients: condylar symmetry and condyle-fossa relationship. Am J Orthod Dentofac Orthop 2009;136:192–8. doi: 10.1016/j.ajodo.2007.07.032.
24. Altan Şallı G, Öztürkmen Z. Semi-automated three-dimensional volumetric evaluation of mandibular condyles. Oral Radiol 2021;37(1):66–73. doi: 10.1007/s11282-020-00426-1.
25. Schmidt BL, Pogrel MA, Necoechea M, Kearns G. The distribution of the auriculotemporal nerve around the temporomandibular joint. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1998;86:165–8. doi: 10.1016/s1079-2104(98)90119-6.
26. Fanghanel J, Gedrange T. On the development, morphology and function of the temporomandibular joint in the light of the orofacial system. Ann Anat 2007;189(4):314–9.
27. Nota A, Caruso S, Ehsani S, Baldini A, Tecco S. Three-dimensional volumetric analysis of mandibular condyle changes in growing subjects: a retrospective cross-sectional study. Cranio 2020;38(5):320–6. doi: 10.1080/08869634.2018.1537088.
28. Ahn SJ, Chang MK, Choi JH, Yang IH, An JS, Heo MS. Relationships between temporomandibular joint disk displacements and condylar volume. Oral Surg Oral Med Oral Pathol Oral Radiol 2018;125(2):192–8. doi: 10.1016/j.oooo.2017.11.001.
29. Al-Koshab M, Nambiar P, John J. Assessment of condyle and glenoid fossa morphology using CBCT in South-East Asians. PLoS ONE 2015;10(3):e0121682. doi: 10.1371/journal. pone. 0121682.
30. Alam MK, Ganji KK, Munisekhar MS, et al. A 3D cone beam computed tomography (CBCT) investigation of mandibular condyle morphometry: gender determination, disparities, asymmetry assessment and relationship with mandibular size. Saudi Dent J 2021;33(7):687–92. doi: 10.1016/j.sdentj.2020.04.008.
31. Mathew AL, Sholapurkar AA, Pai KM. Condylar changes and its association with age, TMD, and dentition status: a cross-sectional study. Int J Dent 2011;2011:413639. doi: 10.1155/2011/413639.
32. Iturriaga V, Navarro P, Cantin M, Fuentes R. Prevalence of vertical condilar asymmetry of the temporomandibular joint in patients with signs and symptoms of temporomandibular disorders. Int J Morphol 2012;30(1):315–21.
33. Khounganian RM, AlDosimani MA, AlZahrani AH, et al. Age related variations of the mandibular condyle in a sample of Saudi population. J Edu Res Review 2021;9(1):6–12. doi: 10.33495/jerr_v9i1.20.213.
34. Yun JM, Choi YJ, Woo SH,, et al. Temporomandibular joint morphology in Korean using cone-beam computed tomography: influence of age and gender. Maxillofac Plast Reconstr Surg 2021;43:21. doi: 10.1186/s40902-021-00307-5.
35. Daniel C, Eduardo E, Carlos M, Rodrigo M, Gustavo M. Association between disk position and degenerative bone changes of the temporomandibular joints: an imaging study in subjects with TMD. Cranio 2011;29:117–26. doi: 10.1179/crn.2011.020.
36. Singh B, Kumar NR, Balan A, et al. Evaluation of normal morphology of mandibular condyle: a radiographic survey. J Clin Imaging Sci 2020;17(10)):51. doi: 10.25259/JCIS_84_2020.
37. Csadó K, Márton K, Kivovics P. Anatomical changes in the structure of the temporomandibular joint caused by complete edentulousness. Gerodontology 2012;29(2):111–6. doi: 10.1111/j.1741-2358.2011. 00498.x.
38. Xu W, Lu H, Shi Q, Gu Z. Research on condylar morphology in patients with prolonged unilateral posterior teeth loss with cone beam computed tomography. Hua Xi Kou Qiang Yi Xue Za Zhi 2016;34(2):162–5. doi: 10.7518/hxkq.2016.02.011.
39. Yalcin ED, Ararat E. Cone-beam computed tomography study of mandibular condylar morphology. J Craniofac Surg 2019;30 (8):2621–4. doi: 10.1097/SCS.0000000000005699.
40. Thiesen G, Gribel BF, Pereira KC, Freitas MP. Is there an association between skeletal asymmetry and tooth absence? Dental Press J Orthod 2016;21(4):73–9. doi: 10.1590/2177-6709.21.4.073-079.oar.
41. Pullinger AG, Seligman DA, Gornbein JA. A multiple logistic regression analysis of the risk and relative odds of temporomandibular disorders as a function of common occlusal features. J Dent Res 1993;72(6):968–79. doi: 10.1177/00220345930720061301.
42. Bertram F, Hupp L, Schnabl D, Rudisch A, Emshoff R. Association between missing posterior teeth and occurrence of temporomandibular joint condylar erosion: a cone beam computed tomography study. Int J Prosthodont 2018;31(1):9–14. doi: 10.11607/ijp.5111.
43. Kim JY, Kim BJ, Park KH, Huh JK. Comparison of volume and position of the temporomandibular joint structures in patients with mandibular asymmetry. Oral Surg Oral Med Oral Pathol Oral Radiol 2016;122(6):772–80. doi: 10.1016/j.oooo.2016.08.017.
44. Ueda M, Yonetsu K, Ohki M, et al. Curvature analysis of the mandibular condyle. Dentomaxillofac Radiol 2003;32(2):87–92. doi: 10.1259/dmfr/23859709.
45. Hedge S, Praveen BN, Shetty SR. Morphological and radiological variations of mandibular condyles in health and diseases: a systematic review. Dentistry 2013;3:154. doi: 10.4172/2161-1122.1000154.