European Archives of Oto-Rhino-Laryngology (2020) 277:2581–2587
https://doi.org/10.1007/s00405-020-06078-5

HEAD AND NECK

Volumetric and morphological analysis of condyle and glenoid fossa on computed tomography

Gozde Serindere[1] · Ceren Aktuna Belgin[1] · Mehmet Serindere[2]

Received: 23 March 2020 / Accepted: 20 May 2020 / Published online: 25 May 2020

Abstract

Aim The aim of this study was to evaluate temporomandibular joint (TMJ) condyle and glenoid fossa morphology with measurements on Computed Tomography (CT) and volumetric analysis using InVesalius software program.

Materials and methods 250 condyles in 125 patients (mean age: 40.64) was evaluated on CT. Length, width, and height of the condyle, condylar volume, the thickness of glenoid fossa (TGF), condyle surface area, anterior space (AS), superior space (SS), and posterior space (PS) were measured in this study. Two left and right sides of the jaw have been measured. Linear measurements were performed with the image analysis program (Image J, 1.4 v version, National Institutes of Health, Bethesda, MD). Volume and surface area measurements were performed with InVesalius software (CTI, Campinas, São-Paulo, Brazil).

Results To compare the dimensions of the condyle between males and females, there was only a significant difference in left AS and SS and no significant difference was found between males and females in other measured factors. There was a significant difference between the age groups and left SS. A significant difference was also found between the age groups and condylar height, condyle surface area, and condylar volume on both right and left sides.

Conclusion Evaluation of condylar morphology is important to assess the TMJ anomalies and bony changes. This study showed no significant differences between gender and all measured factors except in the left AS and SS. However, age factor had a major effect on the morphology.

Keywords Computed tomography · Glenoid fossa · Mandibular condyle · Volume assessment

Introduction

The condyle is an important area of the temporomandibular joint (TMJ) and is the primary growth center of the mandible. It has the special talent of multidirectional growth and adaptive remodeling. Therefore, it can reply to the continuous stimuli adeptly by the way of the bone remodeling and affect the final mandible dimension in the adults [1]. When abnormal TMJ loading or sustained physical stress exceeds the adaptive capacity and thus, the changes of dysfunctional remodeling happen in the mandibular bone. Some morphological changes occur such as decreased mandibular growth, condylar volume, ramus height, and progressive mandibular retrusion [2–4].

Detailed radiographic assessment of TMJ is important for diagnosing some anomalies and adaptive changes. However, there are some limitations while obtaining an image of the TMJ area using conventional radiographic methods that have little capacity to discover anything more than gross osseous changes [5].

Computed Tomography (CT) is the best preference for evaluation and treatment of complications during dental and craniofacial surgery and several other scientific fields [6]. After the development of craniofacial radiological imaging systems such as CT technology, to evaluate the anatomy and anatomical variations has progressed. Nowadays, some 3D software programs were developed to diagnose and make treatment planning in orthognathic surgery [7].

In this study, the InVesalius 3.0 software (CTI, Campinas,São Paulo, Brazil) was used to perform the

✉ Gozde Serindere
gozdeserindere@mku.edu.tr

[1] Department of Dentomaxillofacial Radiology, Faculty of Dentistry, Hatay Mustafa Kemal University, Hatay, Turkey

[2] Department of Radiology, Antakya State Hospital, Hatay, Turkey

measurements of condylar volume and surface area. The aim of this software is to process the CT scans with reconstructing them into 3D models and to perform the volumetric analysis [8].

The aim of this study was to evaluate TMJ condyle and glenoid fossa morphology with measurements on CT and volumetric analysis using InVesalius software program.

Materials and methods

This study was approved by the Institutional Review Board of Hatay Mustafa Kemal University (26/12/2019-Decision number: 21). The image of patients admitted to the Department of Dentomaxillofacial Radiology with several reasons (implant or impacted third molar surgery, cysts, and tumors that do not affect the condyle and the glenoid fossa region, etc.) were selected from the database. The patients who had a history of TMJ surgery or joint disease, facial growth disorders, history of trauma or fracture, TMJ tumors, missing teeth in maxillary or mandibular dental arches (except third molar), any systemic diseases that can affect the TMJ morphology such as rheumatoid arthritis and low-quality images were excluded from the study. The CT images of 125 patients (59 males and 66 females, mean 40.64 years) who were excluded from these criteria were included in the study. Patients were divided into six age groups (18–29 years, 30–39 years, 40–49 years, 50–59 years, 60–69 years, and ≥ 70 years) and by sex. The right and left TMJs of each patient were calculated separately; in total, 250 TMJs were recorded.

Based on the study of Hilgers [9] and Al-koshab et al. [10], the condylar size (length, width, height), the thickness of glenoid fossa (TGF), condylar volume and surface area measurements was performed (Fig. 1). A sagittal image in which the condyle and glenoid fossa were clearly noticed, was selected. From this image, the condylar length was measured. The condylar length was measured from the line extending from the posterior mandibular condyle point to the anterior mandibular condyle point. In the coronal plane, the

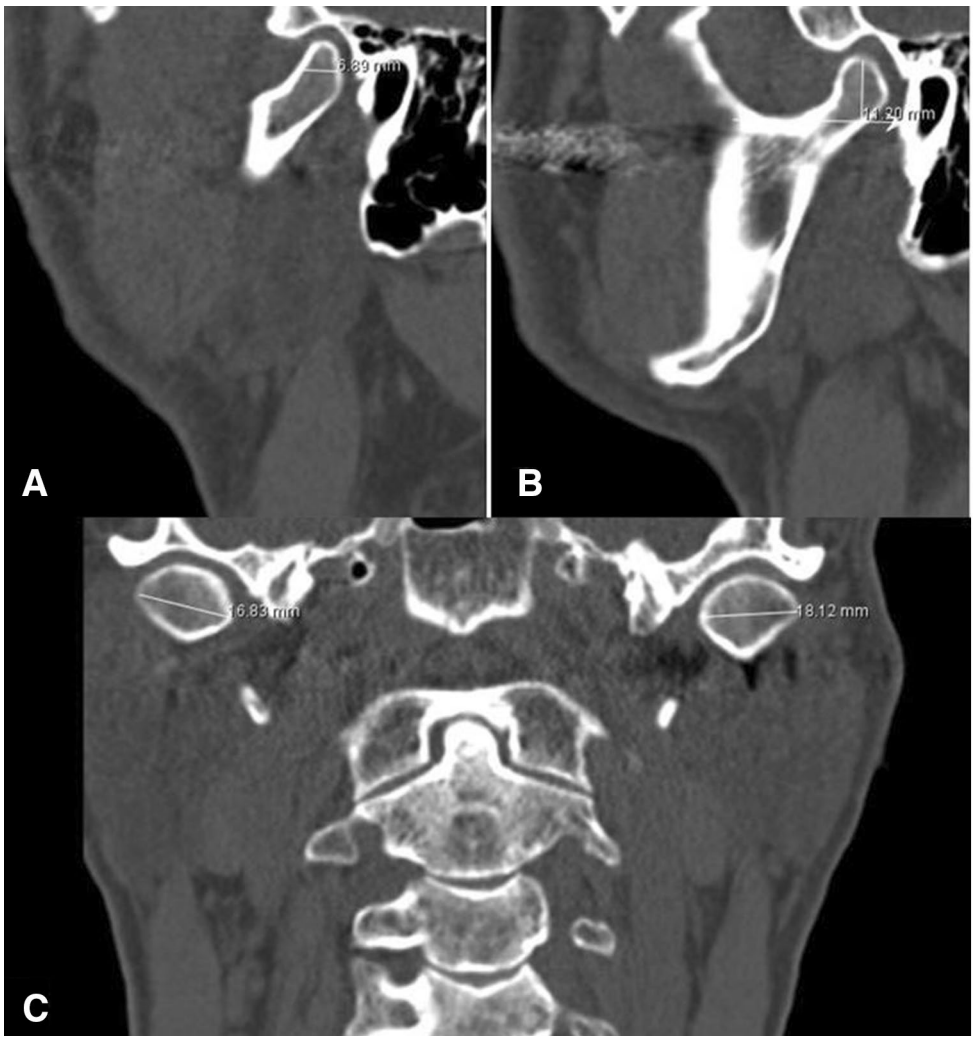

Fig. 1 The measurement methods of condylar size. **a** Sagittal scan demonstrating condylar length. **b** Sagittal scan demonstrating condylar height. **c** Coronal scan demonstrating condylar width

condyle width was the linear distance between the medial and lateral mandibular poles. The condyle height was measured as a linear distance perpendicular to a line formed between the mandibular condyle superior and the lowest point of the sigmoid notch perpendicular to the tangent of the posterior surface of the ramus in the sagittal plane. The angle of the condyle head was corrected to explain the medial to the lateral angulation of the condyle head relative to the intermeatal baseline.

The thinnest bone that forms the glenoid fossa roof was defined and measured in the sagittal plane. The condyle position was described by measuring joint spaces. The anatomical landmarks and the linear measurements of the space between the condyle and glenoid fossa were determined. The true horizontal line tangent to the glenoid fossa roof was used as the reference plane. The superior space (SS) was measured as a distance from the top of the condyle to the superior fossa. A tangent line was drawn from the superior fossa to the most prominent anterior and posterior area of the condyle to measure the anterior space (AS) and posterior space (PS). The distance from the anterior condyle to the corresponding glenoid fossa bone was measured as the AS and the PS was measured with describing distance from the posterior condyle to the corresponding glenoid fossa (Fig. 2).

Linear measurements were performed with the image analysis program (Image J, 1.4 v version, National Institutes of Health, Bethesda, MD) and volume and surface area measurements were performed with InVesalius software (CTI, Campinas, SãoPaulo, Brazil). According to the study of Bayram et al. [11], condylar volume and surface were measured by drawing an imaginary line tangent to the distal slope of the coronoid process. The volume and surface above this line were measured with InVesalius software (Fig. 3).

All image evaluation and measurement procedures were performed by two Dentomaxillofacial Radiology specialists (GS and CAB). Two weeks later, 20% of the samples were randomly selected to test the interobserver reliability and the measurement was repeated. The average of the results of both observers was used for statistical analysis.

Statistical analysis

Two-way ANOVA and t-student test were used to study the difference between the age and gender groups. When the data has no normal distribution, the Mann–Whitney test is used to study the difference between the gender groups, and the Kruskal Wallis test was used to study the difference among the age groups. Besides, the Paired *t* test and Wilcoxon test were used to study the difference in TMJ between the left and right sides. The significance level in this study is 0.05. The reliability was estimated by Intraclass Correlations

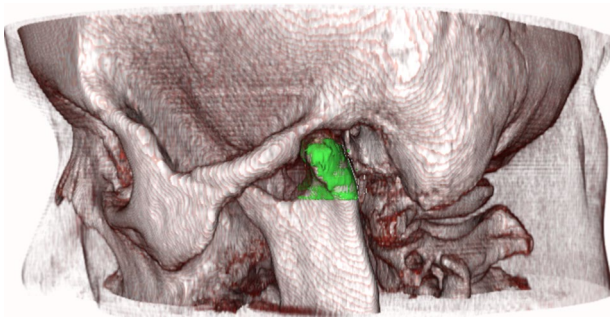

Fig. 3 Volumetric analysis using InVesalius software

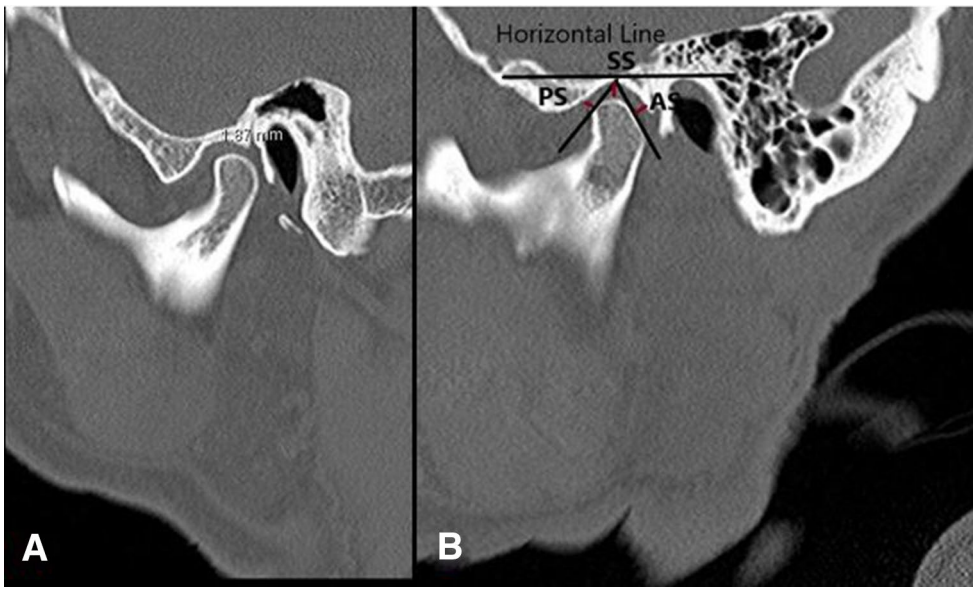

Fig. 2 Sagittal scans demonstrating the measurement of glenoid fossa thickness (**a**) and the joint spaces (**b**)

(ICC) for all observations. All statistical results have been obtained in this study with Statistical Package for the Social Sciences (SPSS) version 21.0 (SPSS Inc., Chicago, IL).

Results

Interobserver ICC values for all observers were excellent as above 0.995 (for right condyle surface area) and 0.996 (for left condyle surface area) indicating high reliability in all measurements.

A comparison of the dimensions of the condyle between males and females were given in Table 1. There was only significant difference in AS and only on the left side with mean of 2.17 mm among the men and mean of 1.90 mm among the women, SS and only on the left side with mean of 3.03 mm among the men and mean of 2.69 mm among the women and no significant difference was found between the women and men in other measured factors.

Table 1 Comparison the dimensions of the condyle between males and females

	Male, $N=59$, mean (SD)	Female, $N=66$, mean (SD)	p
Condylar length (mm)			
R	7.52 (1.12)	7.71 (1.14)	0.366
L	7.31 (1.36)	7.57 (1.15)	0.274
Condylar width (mm)			
R	15.99 (2.81)	16.08 (2.51)	0.950
L	15.72 (2.90)	16.08 (2.39)	0.517
Condylar height (mm)			
R	17.79 (3.14)	17.45 (2.98)	0.603
L	17.77 (4.05)	17.52 (3.31)	0.533
Anterior space (mm)			
R	2.01 (0.69)	2.18 (1.46)	0.5
L	2.17 (0.73)	1.90 (0.72)	**0.019***
Superior space (mm)			
R	2.82 (0.91)	2.83 (1.31)	0.53
L	3.03 (0.91)	2.69 (0.93)	**0.043***
Posterior space (mm)			
R	1.82 (0.55)	1.73 (0.64)	0.23
L	1.90 (0.69)	1.74 (0.52)	0.22
Thickness of Glenoid fossa (mm)			
R	1.24 (0.41)	1.21 (0.51)	0.316
L	1.19 (40)	1.17 (0.47)	0.183
Condylar surface area (mm^2)			
R	15,781.80 (113,704.48)	935.98 (156.63)	0.453
L	16,047.49 (115,880.77)	923.91 (147.97)	0.58
Condylar volume (mm^3)			
R	1582.14 (360.15)	1546.94 (286.72)	0.692
L	1587.29 (336.90)	1526.04 (282.55)	0.2

*Indicated with bold were found statistically significant

A comparison of the dimensions of the condyle between age groups was given in Table 2. There was a significant difference among the age groups in the left SS. A significant difference was also found among the age groups in the condylar height, condyle surface area, and condylar volume on both right and left sides ($p<0.05$).

A comparison of the dimensions of the condyle between left and right sides were given in Table 3 and no statistically significant difference was found in any of the measurements on the right and left sides ($p>0.05$).

Discussion

The mandibular condyle and glenoid fossa morphology vary majorly according to age and gender [12]. As one of the most important joints of the body, TMJs should be worked bilaterally. The TMJ is one of the parts of dentomaxillofacial functional system with the maxillofacial bones, muscles, nerves, and blood vessels. The radiological evaluation of TMJ anatomy is important to research the TMJ morphology for the diagnosis and treatment planning of TMJ diseases [13].

With the development of qualitative analysis by using 3D imaging methods, a lot of quantitative measurements are performed benefiting from CT. Linear and angular measurements are performed in the cranial vault, brain, orbits and spinal canal [14]. The accuracy of parameters provided from CT images are also researched in the field of dentistry. Certain measurement is important in the orthodontic department and maxillofacial surgical practice, particularly complex craniofacial disorder cases. There are few studies that are studied in maxilla and mandible, although the accuracy of parameters is studied by using of CT images [15].

In the study of Al-koshab et al. [10], condylar length, width, and height were reported as 7.29 mm, 17.93 mm, and 18.25 mm in males, respectively while 7.11 mm, 17.04 mm and 17.22 mm in females, respectively. Condylar length, width, and height were 7.08 mm, 17.17 mm, and 17.88 mm in the left side, respectively while 7.31 mm, 17.27 mm, and 17.49 mm in the right side, respectively. TGF was found as 1.24 mm and 1.00 mm in the left and right side, respectively while 1.20 mm and 1.14 mm in males and females, respectively. AS, SS, and PS measurement was reported as 1.68 mm, 2.70 mm, and 1.96 mm in the left side, respectively while 1.79 mm, 3.00 mm and 2.14 mm in the right side, respectively. Condylar volume was found as 1450.89 mm^3 and 1460.69 mm^3 in the left and right side, respectively while 1613.87 mm^3 and 1339.65 mm^3 in males and females, respectively. In our study, the close results were found. Al-koshab et al. [10] reported that no significant gender differences were found in TGF and condylar length, but, condylar volume, width, height, and the joint spaces were

Table 2 Comparison the dimensions of the condyle between age groups

	Age						Sig*
	18–29, $N=39$, mean (SD)	30–39, $N=26$, mean (SD)	40–49, $N=23$, mean (SD)	50–59, $N=15$, mean (SD)	60–69, $N=17$, mean (SD)	≥ 70, $N=5$, mean (SD)	
Condylar length (mm)							
R	7.48 (1.21)	7.85 (1.24)	7.78 (0.94)	7.71 (1.04)	7.52 (1.20)	6.95 (0.74)	0.097
L	7.31 (1.41)	7.47 (1.00)	7.53 (1.40)	7.96 (1.53)	7.24 (0.81)	7.16 (0.74)	0.068
Condylar width (mm)							
R	15.44 (3.07)	16.19 (2.41)	16.17 (2.56)	17.03 (2.59)	16.58 (2.02)	14.38 (1.67)	0.022
L	15.22 (3.05)	16.69 (2.27)	15.28 (2.34)	16.83 (2.23)	16.84 (2.44)	14.21 (1.64)	0.058
Condylar height (mm)							
R	18.00 (3.34)	18.71 (2.85)	16.70 (2.56)	19.07 (2.41)	15.60 (2.67)	15.60 (1.55)	**0.11***
L	18.36 (3.26)	18.69 (3.52)	15.87 (4.52)	18.75 (3.08)	16.21 (3.23)	16.26 (2.26)	**0.16***
Anterior space (mm)							
R	2.18 (1.39)	2.44 (1.53)	2.01 (0.71)	2.19 (0.76)	1.56 (0.56)	1.74 (0.63)	0.366
L	2.22 (0.85)	2.18 (0.88)	1.82 (0.49)	1.89 (0.57)	1.70 (0.48)	2.11 (0.65)	0.019
Superior space (mm)							
R	2.63 (1.37)	2.84 (1.26)	2.93 (0.72)	3.17 (1.15)	2.76 (0.83)	2.92 (0.88)	0.007
L	2.47 (0.85)	2.76 (0.99)	3.34 (0.91)	2.80 (0.87)	3.12 (0.87)	3.28 (0.55)	**0.19***
Posterior space (mm)							
R	1.75 (0.53)	1.63 (0.70)	1.93 (0.60)	1.80 (0.32)	1.69 (0.67)	2.21 (0.88)	0.062
L	1.79 (0.66)	1.74 (0.57)	1.94 (0.53)	1.98 (0.63)	1.76 (0.66)	1.61 (0.67)	0.58
Thickness of Glenoid fossa (mm)							
R	1.25 (0.52)	1.16 (0.34)	1.28 (0.56)	1.17 (0.36)	1.29 (0.40)	1.12 (0.66)	0.38
L	1.20 (0.45)	1.05 (0.29)	1.23 (0.26)	1.14 (0.66)	1.25 (0.50)	1.26 (0.58)	0.01
Condylar surface area (mm^2)							
R	23,423.37 (139,844.41)	1006.99 (208.00)	887.30 (118.78)	919.84 (205.75)	846.86 (194.11)	921.05 (217.49)	**0.01***
L	23,835.18 (142,521.07)	984.57 (208.18)	884.01 (103.01)	884.66 (164.45)	845.99 (188.57)	925.02 (193.41)	**0.038***
Condylar volume (mm^3)							
R	1726.89 (327.37)	1543.53 (235.19)	1491.65 (214.52)	1526.79 (454.06)	1413.74 (315.00)	1343.97 (194.05)	**0.024***
L	1734.65 (303.61)	1535.37 (249.03)	1484.91 (220.07)	1461.50 (347.24)	1396.25 (342.63)	1397.31 (186.07)	**0.028***

*Indicated with bold were found statistically significant

Table 3 Comparison of the dimensions of the condyle between left and right sides

	TMJ side		Sig*
	Right, mean (SD)	Left, mean (SD)	
Condylar length (mm)	7.62 (1.13)	7.45 (1.25)	0.171
Condylar width (mm)	16.04 (2.64)	15.91 (2.64)	0.633
Condylar height (mm)	17.61 (3.05)	17.64 (3.66)	0.75
Anterior space (mm)	2.10 (1.16)	2.02 (0.74)	0.994
Superior space (mm)	2.82 (1.13)	2.85 (0.93)	0.606
Posterior space (mm)	1.77 (0.60)	1.82 (0.61)	0.7
Thickness of Glenoid fossa (mm)	1.23 (0.46)	1.18 (0.43)	0.39
Condylar surface area (mm^2)	7943.20 (78,119.66)	8062.24 (79,614.55)	0.08
Condylar volume (mm^3)	1563.55 (322.61)	1554.95 (309.65)	0.377

*Indicated with bold were found statistically significant

significantly greater among males. The relationship between right and left sides and AS, SS, and PS was researched by Al-koshab et al. [10], Wang [16] and Rodrigues [17]. They observed that there was no significant difference between left and right sides. Differently, in the present study, there was only a significant difference in left AS and SS.

The relationship between gender and the TGF was discussed by Honda [18], Ejima [19], and Kijima [20], all of them agreed that there was no significant difference in TGF between males and females, and this was also confirmed by this study. In our study, the value of SS was the greatest in both sexes, followed by AS and PS respectively. Finding SS as the greatist value in our study was similar to the results of Ikeda and Kawamura [21], Dalili [22], and Kinniburgh [23]. However, the PS value was higher in these studies, whereas the AS value was higher in our study. Al-koshab et al. [10], Dalili [22] and Kinniburgh [23] reported that males had larger joint spaces than females especially the SS and PS. In the study of Al-koshab et al. [10], condylar volume, width, and height in males were larger than in females. In our study, males did not provide an obvious superiority to females in terms of all parameters.

In the study of Tecco et al. [24], it was reported that the condylar volume was 691.26 ± 54.52 mm^3 in males and 669.65 ± 58.80 mm^3 in females. Males showed a higher condylar volume when compared with females and males also showed a higher condylar surface area than females, without statistical significance. Saccucci et al. [25] reported that condylar volume was 699.8 ± 63.07 mm^3 in males and 663.5 ± 81.3 mm^3 in females, however, the condylar surface was 423.24 ± 63.03 mm^2 in males and 389.76 ± 61.15 mm^2 in females with the significant higher results in males. In our study, higher values of condylar surface and volume were found in both genders. They were no significant relationship between gender and condylar surface and volume. Similar to our study, Liu et al. [13] reported that there was no significant relationship between condylar volume, surface, and left and right sides. They also reported no significant relationship between volume and surface among age groups. This result was inconsistent with the result of our study. According to the study of Liu et al. [13], condylar volume was 1976.135 mm^3 in males and 1867.607 mm^3 in females. The condylar surface was 963.084 mm^2 in males and 911.552 mm^2 in females. Condylar volume was 1903.680 mm^3 and 1923.804 mm^3 in the left and right side, respectively while the condylar surface was 926.983 mm^2 and 933.457 mm^2 in the left and right side, respectively. Condylar volume was significantly higher in males than females. And similar to our study result, it was reported that no significant differences were found in condylar volume and surface between right and left sides. In this study, it can be said that there were lower values than the study of Liu et al. [13] in most parameters. And again differently, no significant difference was found between the males and females in the measured factors except the left AS and SS. It can be said that the values in the parameters reported in most articles are higher in males, which is not compatible with the results of our study.

Similarly, in the study of Hasan et al. [26], the InVesalius software was used to perform the measurements. This software is free and as valuable as Mimics software that is very expensive. So authors may perform reliable measurements by using the InVesalius software which is free and cheap [26]. So, in this study, we preferred using the InVesalius software because of these advantages.

There are some limitations in this study. The3-D volumetric analysis depends on the segmentation suitability, the threshold of bone voxel values, and the exact suppression of the neighbouring tissue values to enhance the structure of interest. There are some factors that analysis depends on such as the software features, the spatial and contrast resolution of the image, the thickness and calcification or cortication degree of bone, and the technical skill of the operator [25].

In conclusion, to the best of our knowledge, this is the first detailed study that was investigated both condyle and glenoid fossa morphology and condylar volume and surface area. Further studies will be useful to evaluate these parameters and understand the relationships between them.

Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

Ethical statements The Ethics Committee of the Hatay Mustafa Kemal University Faculty of Dentistry approved this retrospective study. 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.

References

1. Zane Krisjane IU, Krumina G, Bieza A, Zepa K, Rogovska I (2007) Condylar and mandibular morphological criteria in the 2D and 3D MSCT imaging for patients with class II division 1 subdivision malocclusion. Stomatologija 9(3):67–71
2. Papadaki ME, Tayebaty F, Kaban LB, Troulis MJ (2007) Condylar resorption. Oral Maxillofac Surg Clin N Am 19:223–234. https://doi.org/10.1016/j.coms.2007.01.002
3. Mercuri LG (2008) Osteoarthritis, osteoarthrosis, and idiopathic condylar resorption. Oral Maxillofac Surg Clin N Am 20:169–183. https://doi.org/10.1016/j.coms.2007.12.007
4. Arnett GW, Milam SB, Gottesman L (1996) Progressive mandibular retrusion: part I—idiopathic condylar resorption. Am J Orthod Dentofacial Orthop 110:8–15. https://doi.org/10.1016/s0889-5406(96)70081-1

5. Brooks SL, Brand JW, Gibbs SJ, Hollender L, Lurie AG, Omnell KA et al (1997) Imaging of the temporomandibular joint: a position paper of the American Academy of Oral and Maxillofacial Radiology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 83:609–618. https://doi.org/10.1016/s1079-2104(97)90128-1
6. Nizam A, Gopal RN, Naing L, Hakim AB, Samsudin AR (2006) Dimensional accuracy of the skull models produced by rapid prototyping technology using stereolithography apparatus. Arch Orofac Sci 1:60–66
7. Quevedo LA, Ruiz JV, Quevedo CA (2011) Using a clinical protocol for orthognathic surgery and assessing a 3-dimensional virtual approach: current therapy. J Oral Maxillofac Surg 69:623–637. https://doi.org/10.1016/j.joms.2010.11.009
8. Verri FR, Junior JF, Almeida DA (2015) Biomechanical influence of crown-to-implant ratio on stress distribution over internal hexagon short implant: 3-D finite element analysis with statistical test. J Biomechan 48:138–145. https://doi.org/10.1016/j.jbiomech.2014.10.021
9. Hilgers ML, Scarfe WC, Scheetz JP, Farman AG (2005) Accuracy of linear temporomandibular joint measurements with cone beam computed tomography and digital cephalometric radiography. Am J Orthod Dentofacial Orthop 128:803–811. https://doi.org/10.1016/j.ajodo.2005.08.034
10. Al-koshab M, Nambiar P, John J (2015) Assessment of condyle and glenoid fossa morphology using CBCT in South-East Asians. PLoS ONE 10:e0121682. https://doi.org/10.1371/journal.pone.0121682
11. Bayram M, Kayipmaz S, Sezgin ÖS, Küçük M (2012) Volumetric analysis of the mandibular condyle using cone beam computed tomography. Eur J Radiol 81:1812–1816. https://doi.org/10.1016/j.ejrad.2011.04.070
12. Alomar X, Medrano J, Cabratosa J, Clavero JA, Lorente M, Serra I et al (2007) Anatomy of the temporomandibular joint. Semin Ultrasound CT MR 28(3):170–183. https://doi.org/10.1053/j.sult.2007.02.002
13. Liu Q, Wei X, Guan J, Wang R, Zou D, Yu L (2018) Assessment of condylar morphology and position using MSCT in an Asian population. Clin Oral Invest 22:2653–2661. https://doi.org/10.1007/s00784-018-2364-7
14. Waitzman AA, Posnick JC, Armstrong DC, Pron GE (1992) Craniofacial skeletal measurements based on computed tomography: part 1. Accuracy and reproducibility. Cleft Palate Craniofac J 29:112–117. https://doi.org/10.1597/1545-1569_1992_029_0112_csmboc_2.3.co_2
15. Periago DR, Scarfe WC, Moshiri M, Scheetz JP, Silveira AM, Farman AG (2008) Linear accuracy and reliability of cone beam CT derived 3-dimensional images constructed using an orthodontic volumetric rendering program. Angle Orthod 78:387–395. https://doi.org/10.2319/122106-52.1
16. Wang R, Ma X, Zhang W, Liu D (2007) Investigation of temporomandibular joint space of healthy adults by using cone beam computed tomography. Beijing da xue xue bao Yi xue ban = J Peking Univ Health Sci 39:503–506
17. Rodrigues AF, Fraga MR, Vitral RW (2009) Computed tomography evaluation of the temporomandibular joint in Class II Division 1 and Class III malocclusion patients: condylar symmetry and condyle-fossa relationship. Am J Orthod Dentofacial Orthop 136:199–206. https://doi.org/10.1016/j.ajodo.2007.07.033
18. Honda K, Kawashima S, Kashima M, Sawada K, Shinoda K, Sugisaki M (2005) Relationship between sex, age, and the minimum thickness of the roof of the glenoid fossa in normal temporomandibular joints. Clin Anat 18:23–26. https://doi.org/10.1002/ca.20054
19. Ejima K, Schulze D, Stippig A, Matsumoto K, Rottke D, Honda K (2013) Relationship between the thickness of the roof of glenoid fossa, condyle morphology and remaining teeth in asymptomatic European patients based on cone beam CT data sets. Dentomaxillofac Radiol 42:90929410. https://doi.org/10.1259/dmfr/90929410
20. Kijima N, Honda K, Kuroki Y, Sakabe J, Ejima K, Nakajima I (2014) Relationship between patient characteristics, mandibular head morphology and thickness of the roof of the glenoid fossa in symptomatic temporomandibular joints. Dentomaxillofac Radiol 36:277–281. https://doi.org/10.1259/dmfr/56344782
21. Ikeda K, Kawamura A (2009) Assessment of optimal condylar position with limited cone-beam computed tomography. Am J Orthod Dentofacial Orthop 135:495–501. https://doi.org/10.1016/j.ajodo.2007.05.021
22. Dalili Z, Khaki N, Kia SJ, Salamat F (2012) Assessing joint space and condylar position in the people with normal function of temporomandibular joint with cone-beam computed tomography. Dent Res J 9:607–612. https://doi.org/10.4103/1735-3327.104881
23. Kinniburgh RD, Major PW, Nebbe B, West K, Glover KE (2000) Osseous morphology and spatial relationships of the temporomandibular joint: comparisons of normal and anterior disc positions. Angle Orthod 70:70–80. https://doi.org/10.1043/0003-3219(2000)070%3c0070:OMASRO%3e2.0.CO;2
24. Tecco S, Saccucci M, Nucera R, Polimeni A, Pagnoni M, Cordasco G et al (2010) Condylar volume and surface in Caucasian young adult subjects. BMC Med Imaging 10:28. https://doi.org/10.1186/1471-2342-10-28
25. Saccucci M, Dattilio M, Rodolfino D, Festa F, Polimeni A, Tecco S (2012) Condylar volume and condylar area in class I, class II and class III young adult subjects. Head Face Med 8:34. https://doi.org/10.1186/1746-160X-8-34
26. Hasan HA, Alam MK, Yusof A, Matsuda S, Shoumura M, Osuga N (2016) Accuracy of three dimensional CT craniofacial measurements using mimics and Invesalius software programs. J Hard Tissue Biolo 25:219–224. https://doi.org/10.2485/jhtb.25.219