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Dimensional Changes of Temporomandibular Joint in Patients Affected by Temporomandibular Disorders: A Combination of Two-Dimensional and Three-Dimensional Evaluation

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ABSTRACT

Introduction: Temporomandibular disorders (TMDs) are frequently associated with degenerative changes involving bony components of temporomandibular joint (TMJ) which may result in morphologic and dimensional changes of them.
Aims: This study aimed to evaluate dimensional changes in TMJ in patients affected by TMD using CBCT and a three-dimensional (3D) rendering software.
Materials and Methods: CBCT images of 68 subjects (19 males and 49 females, age range, 20-50 years) were studied. 40 joints in RDC/TMD (Research Diagnostic Criteria for TMD) II group (disk displacement), 45 joints in RDC/TMD III group (osteoarthritis/osteoarthrosis) and 48 normal joints were included. Variables of length, width, and height of the condyle and slope of articular eminence were measured on CBCT images. Condylar volume was measured using a 3D model of the condyle, reconstructed by 3D rendering software. One-way ANOVA, GLM univariate and Pearson's/Spearman correlation coefficients tests were used for statistical analysis.
Results and Discussion: The average condylar volume, width, and height had the highest values in the normal group and the lowest one in RDC/TMD III. The difference of condylar height was statistically significant between RDC/TMD III and the normal group (P=0.01). Other studied variables were not significantly different among the three groups (P>0.05). There was a significant correlation between age and condylar volume in RDC/TMDII (P=0.049).
Conclusion: TMD, especially in the early stages, will not lead to significant dimensional changes in the condyle, but in more advanced stages it can lead to a decrease in the height of the condyle.

Key words: Temporomandibular joint, Cone-beam computed tomography, Three-dimensional image, Software

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INTRODUCTION

Temporomandibular disorder (TMD) is a heterogeneous disorder in which temporomandibular joints (TMJ), masticatory muscles or both are affected. The prevalence of this disorder is estimated to be 5%-12% [1]. In long-term stages of articular disk displacement without reduction, in addition to disc deformation, changes in morphology and dimensions of different parts of the joint may also happen. These changes may be asymptomatic in the early stages, but as time passes, clinical signs and symptoms such as pain and functional impairment are followed [2]. So, accurate and early diagnosis of bone abnormalities in TMJ is important.

The most common way to screen TMD is to use the Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD), which uses clinical and radiologic evaluations and considers pain-related disabilities, besides psychologic conditions in patient classifications [3].

Complete radiographic evaluation of TMJ structures is an essential tool in the diagnosis of the severity of pathologies and anomalies of joints and assessing the compensatory changes which follow these anomalies [4]. Recent advances in imaging by CBCT and developed various complementary software make it possible to produce three-dimensional (3D) models by CBCT. Using this method, in addition to linear quantitative measurement, it could also be possible to provide useful volumetric information by constructing real three-dimensional models [5].

Application of 3D models in various studies on TMJs provides good results and have potential benefits in the diagnosis of pathologies in this region [6,7]. Amira is one of 3D rendering software that provides different linear and volumetric measurements [8,9].

Since various parts of TMJs are altered during TMDs [4] and since diagnosis these changes can help physicians to take a positive step towards preventing the development of osteoarthritis, this study was designed to evaluate dimensional changes of TMJs in patients with TMDs using CBCT and Amira software.

METHOD

Study design

This study was approved by the Ethics Committee of Mashhad University of Medical Sciences (Project NO. IR.MUMS.REC.1391.603). In this cross-sectional study, CBCT images of 188 TMJs belonged to 99 subjects (30 males and 69 females; mean age, 36.6 ± 11.54; range, 20-50 years) available in the archive of Oral and Maxillofacial Radiology Department of the Dental School, Mashhad University of Medical Sciences, were evaluated. Studied population was divided into three groups, based on medical records and clinical examinations, performed by a prosthodontist (Table 1) [10,11]:

1. Normal group who had class I occlusion and normal TMJ and referred to dental school for posterior maxillary implant placement, including 48 joints (11 males and 20 females; mean age, 33.5 ± 9.68);
2. RDC/TMD II group (disk displacement with or without reduction), including 40 TMJs (6 males and 14 females; mean age, 34.8 ± 10.74); and
3. RDC/TMD III group (patients with arthralgia/ Osteoarthritis/osteoarthrosis), including 45 TMJs (7 males and 16 females; mean age, 39.4 ± 12.64).

In the present study, the subgroups for RDC/TMD subjects were not separated.

Exclusion criteria included the CBCT images with poor quality and low resolution, lack of accurate observation of mandibular condyle and glenoid fossa, history of trauma to the TMJ or previous treatments of the TMJ, systemic disorders involving the TMJ (such as rheumatoid arthritis and scleroderma), record of orthodontic treatment, orthographic surgery or significant jaw asymmetry.

Each joint was considered as one sample. For calculating the number of joints, in some subjects, due to the poor quality of some images, only one joint was accounted.

CBCT acquisition

CBCT scans were obtained using a Planmeca Promax 3D max (Helsinki, Finland) unit with maximum output of 54 to 84 kVP, total filtration equivalent of 2.5 mm aluminum, FOV (field of view) of 8 × 8 cm^2, matrix size of 512 × 512 pixels, scan time of 25 seconds, exposure time of 12 seconds and slice thickness equivalent to multiples

Table 1: Clinical signs and symptoms for TMD diagnosis

Group	Subgroup	Signs
RDC/TMD II	(a) Disk displacement with reduction	1. Loss of pain in TMJ
		2. Click on vertical opening and closing, occurs on 2/3 of examinations
		3. Click on vertical opening and closing occurs at a point at least 5 mm greater inter-incisal distance on opening than closing and doesn't exist on protrusive opening, on 2/3 of examinations
		4. Click on lateral movements on 2/3 of examinations
	(b) Disk displacement without reduction with limited opening	1. History of locking of the jaw and limitation on opening the jaw
		2. The absence of clicking in joint
		3. Maximum unassisted opening: 35 mm, assisted opening is 4 mm greater than unassisted one
		4. Contralateral excursion <7 mm and/or uncorrected deviation to ipsilateral side during the opening
	(c) Disk displacement without reduction without limited opening	1. History of locking or limitation on opening
		2. Maximum unassisted opening >35 mm, assisted opening is 5 mm or more over than unassisted one
		3. Contralateral excursion 7 mm
		4. Presence of joint sounds that don't include diagnostic criteria for disk displacement with reduction (in these cases MRI or arthrography reveals disk displacement without reduction)
RDC/TMD III	(a) Arthralgia	1. Pain in one or both joints during palpation
		2. Pain in joint during movements or without movement
		3. Crepitus is absent, but click may be present
	(b) Osteoarthritis	Pain as defined in arthralgia with crepitus in the joint or radiographic features of arthrosis (erosion, sclerosis, flattening, and osteophyte)
	(c) Osteoarthrosis	Without of arthralgia, but crepitus in the joint and radiologic signs of arthrosis exist

of 0.16 mm. All constructions and measurements were performed on a flat panel color active matrix TFT Medical Display (Nio Color 3MP, Barco, Kortrijk, Belgium) 27 inch diagonally, with 1280 × 1024-pixel screen resolution.

In CBCT images, variables of length, width, and height of the condyle and slope of articular eminence (Table 2) were measured using Romexis 2.4.2 software specific to CBCT machine (Table 3 and Figure 1). Table 4 compared each studied variable on the right and left sides.

Constructing three-dimensional model

In order to reconstruct three-dimensional models of condyles, samples files with DICOM (Digital Imaging and Communications in Medicine) format imported into Amira 5.2.2 software (Visage Imaging GmbH, Fürth, Germany).

The mandibular condyles were first segmented (determining the outer edge), manually in CBCT axial sections. In the segmentation stage, the upper limit of the condylar head was selected when the first white point of the condylar head appears in the upper articular space. The lower limit of the condyle was selected in the last section before sigmoid notch appearance (Figure 2). Finally, the volume of the three-dimensional structure of the condyle was measured and displayed in terms of the number of voxels and also in mm³ by the software (Figure 3).

Table 2: Definition of studied variables

Variable	Definition
Condylar Width	The greatest distance between the most medial (CoM) and the most lateral (CoL) points of condylar head in axial view
Condylar Length	The greatest distance between the most anterior (CoA) and the most posterior (CoP) points of condylar head in axial view
Condylar Height	The length of the line that is perpendicular to the CoA-CoP line from the anatomical point of CoS (the highest point of the condyle)
Slope of articular eminence	A line was drawn along with the anterior slope of glenoid fossa. The angle between mentioned line and true horizontal line (THL) was measured as the slope of articular eminence

Table 3: Comparison the mean of variables in each studied group

	Mean of studied variables ± standard deviation				
Group	**Volume (mm³)**	**Width**	**Length (mm)**	**Height (mm)**	**Slope of articular eminence (°)**
Normal (n=48)	1569.31 ± 537.3	18.79 ± 2.49	8.38 ± 1.28	5.84 ± 1.57	52.26 ± 11.52
RDC/TMDII (n=40)	1525.22 ± 541.1	18.72 ± 2.24	8.07 ± 1.03	5.51 ± 1.83	56.76 ± 8.90
RDC/TMDIII (n=45)	1533.55 ± 536.7	18.68 ± 2.30	8.21 ± 1.95	4.83 ± 1.43	54.40 ± 11.28
P-value*	0.833	0.971	0.517	0.011	0.15

*One-way ANOVA

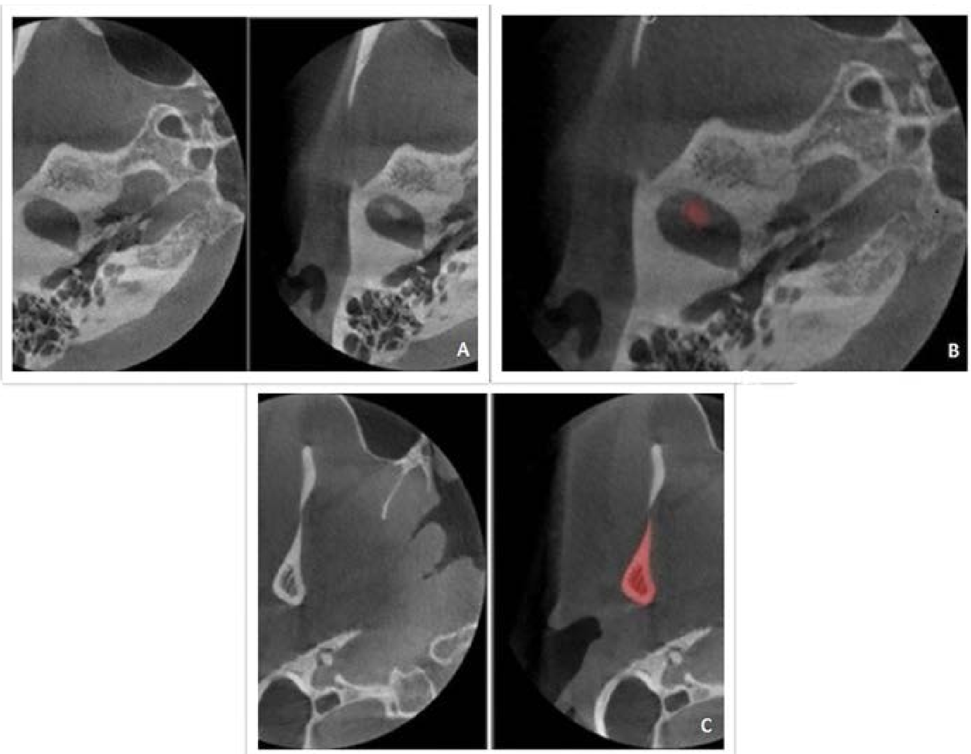

Figure 1: Dimensions of the condyle measured using Romexis software (A) Condylar width, (B) Condylar length, (C) Condylar height, (D) Slope of articular eminence

Table 4: Mean and standard deviation of studied variables on the right and left sides in each

		Mean of studied variables ± standard deviation				
Group	**Side**	**Volume (mm³)**	**Width (mm)**	**Length (mm)**	**Height (mm)**	**Slope of articular eminence (°)**
Normal	Right	1457.43 ± 533.42	18.43 ± 2.72	8.36 ± 1.25	5.60 ± 1.46	52.70 ± 11.39
	Left	1676.26 ± 541.53	19.20 ± 2.31	8.40 ± 1.34	6.26 ± 1.67	51.82 ± 11.61
RDC/TMDII	Right	1522.24 ± 547.31	18.73 ± 2.36	8.06 ± 1.10	5.39 ± 1.91	57.91 ± 9.11
	Left	1516.76 ± 536.82	18.75 ± 2.18	7.96 ± 1.02	5.73 ± 1.74	55.94 ± 8.17
RDC/TMDIII	Right	1553.76 ± 534.21	18.65 ± 2.43	8.41 ± 1.41	5.18 ± 1.62	54.83 ± 11.43
	Left	1444.35 ± 539.46	18.70 ± 2.21	8.02 ± 1.37	4.58 ± 1.54	54.56 ± 11.35

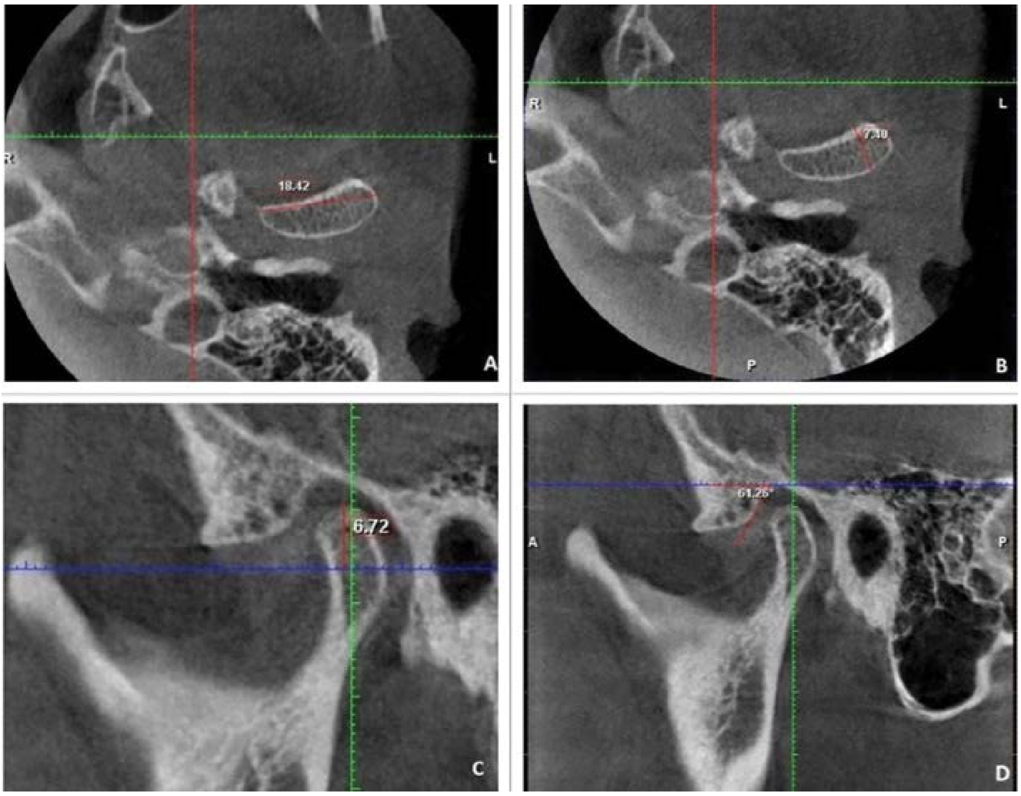

Figure 2: Segmentation of mandibular condyle by Amira software (A) Axial section before appearance of the first white region of condylar head (Left), condylar head appearance (Right), (B) Segmentation of the first region of condylar head, (C) The lower limit of the condyle was segmented in the last section before sigmoid notch appearance

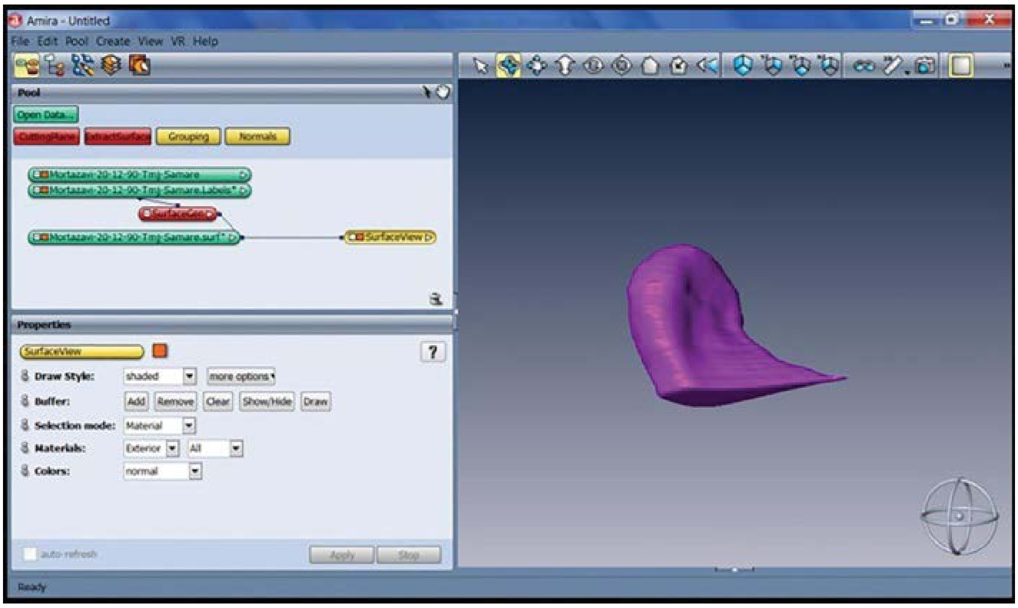

Figure 3: Reconstructed three-dimensional model of mandibular condyle

Each subject was assigned a code, regardless of the condition of the condyle. Then a postgraduate student of oral and maxillofacial radiology, supervised by two experienced radiologists, performed all linear and volumetric measurements twice with a one-month interval and considered the average of them.

Statistical Analysis

PASW Statistics 18 software was used to analyze the data. For comparison the average of the variables studied in three groups, ANOVA and Tukey post-hoc test (if needed) was used. The GLM Univariate was used to investigate the interaction of the involved side and RDC/TMD groups and Pearson correlation coefficient or its non-parametric equivalent (Spearman) was used to assess the correlation between the volume of the condyle and other variables. In all tests, the significance level of 5% was assumed.

RESULTS

Comparison of each condylar variable in the studied groups

Width

The mean value of condylar width was the highest in the normal group and was the lowest in the RDC/TMD III group. The average width of the condyle was not significantly different among the three groups (P=0.97). There was no significant difference in the average condylar width between right and left sides (P=0.49). The involved side and the type of RDC/TMD group had no interaction on the condylar width (P=0.67).

Height

As for condylar width, the mean value of condylar height was the highest in the normal group and was the lowest in the RDC/TMD III group. Condylar height difference between normal and RDC/TMD III groups was statistically significant (P=0.009). There was no significant difference in the average condylar width between the two sides (P=0.65). The involved side and the type of RDC/TMD group had no interaction on the height (P=0.79).

Length

The maximum and minimum mean values of condylar length were related to the normal group and RDC/TMD II group, respectively. The average length of the condyle was not significantly different among the three groups (P=0.51). There was no significant difference in the average condylar length between the two sides (P=0.58). The involved side and the type of RDC/TMD group had no interaction on the condylar length (P=0.27).

The slope of the articular eminence

The average slope of the articular eminence was not significantly different among the three groups (P=0.15). Also, there was no significant difference in the average slope of articular eminence between the two sides (P=0.58). The involved side and the type of RDC/TMD group had no interaction on the slope of articular eminence (P=0.88).

Volume

The average condylar volume was not significantly different among the three groups (P=0.83). Also, there was no significant difference in the average condylar volume, between the two sides (P=0.74). The involved side and the type of RDC/TMD group had no interaction on the condylar volume (P=0.36).

Evaluation of correlation between quantitative variables of the study

Correlation coefficients between condylar volume and other condylar dimensions (width, length, and height of the condyle) were statistically significant in all three groups (P<0.05). Also, it is noteworthy that there was a significant correlation (P=0.001) between the slope of the articular eminence and condylar volume in the normal group.

Pearson correlation coefficient was statistically significant between length and height of the condyle, in RDC/TMD II group (P<0.05) and between the slope of the articular eminence and condylar width in RDC/TMD III group (P<0.05).

There was a significant correlation between age and volume of the condyle only in the RDC/TMD II group (P=0.049) (r=0.31) and there was no significant correlation between age and other variables in all three groups (P>0.05).

DISCUSSION

In our study, the mean value of the condylar width was the highest in the normal group and was the lowest in the RDC/TMD III group. The results for the condyle height were similar. The maximum and minimum mean values of condylar length were related to normal group and RDC/TMD II group respectively. The results showed no significant differences in the variables of the length and width among the three groups that could be due to the small sample size of this study. The condyle height was significantly different between the normal group and RDC/TMD III group. According to the study of Yáñez-Vico et al. [12], patients with TMD had less condylar height compared to the normal group. Lower height of the condyle in RDC/TMD III group could be defined due to degenerative changes in the joints suffering from osteoarthritis.

de Leeuw et al. [13] reported that the shortening of the internal-external dimension of the condyle in patients suffering from osteoarthritis is evident. It appears that the progressive remodeling of the condyle in its posterolateral corner may cause resorption and thus leads to a reduction in internal-external dimension of the condyle.

According to Kurita et al. [14] the anterior-posterior dimension of the condyle, in more advanced stages of TMJ disorders, becomes bigger. This phenomenon happens when the disc is severely and permanently dislocated and deformed which is sometimes associated with evidence of perforation. Proliferative degenerative changes of the condyle including flattening, spurring and eburnation may responsible for the lengthening of the anterior-posterior dimension of the condyle in the advanced stages of TMD [14]. This is in accordance with the higher mean of the anterior-posterior dimension of the condyle in RDC/TMD III group comparing to the RDC/TMD II group in our study.

Condylar volume changes mostly can be seen with 3 conditions: Arthritis, asymmetry and anterior disk displacement [15]. In the present study, the lowest mean of condylar volume calculated belonged to RDC/TMD III group, and the highest value belonged to the normal group. There was no significant difference in condylar volume in RDC/TMD II group compared to the normal group that didn't match the findings of Ali et al. [16] and Legrell et al. [17] studies. The lower condyle volume in RDC/TMDIII group can be related to degenerative changes of bone due to osteoarthritis.

In Gang et al. [18] study (similar to this study), there was no significant difference between right and left condylar volume. Another study [12] showed the asymmetry in width, height, and length of the condyle (and so asymmetry in the volume) is a common finding in patients with TMD. Their results revealed a statistically significant difference in vertical, mediolateral, and sagittal condyle asymmetry among normal control group and the TMD group. Asymmetry in joints affected by TMD can be due to different stages of TMD on two sides.

In this study, the average slope of the articular eminence was highest in RDC/TMD II and it was lowest in RDC/TMD III. In Ozkan et al. [19] and Gökalp et al. [20] studies, the slope of articular eminence in a group with reduced dislocated disk was higher than unreduced one. The movement of the disk against a large sloping articular eminence, during the opening of the mouth, may eventually cause loosening of the ligaments connecting the disk to the condyle and cause the disk to gradually move anterior to the condyle. Some suggested that articular eminence anatomy may make the joint more susceptible to disk displacement, while others believe that displacement of the disk may lead to changes in the shape of the joint structures, including flattening of articular eminence. Bone changes involving remodeling and osteoarthrosis are the most important factors affecting the articular eminence. Therefore, the gradual flattening of the articular eminence can be a reflection of the progression of disk displacement with reduction to without reduction situation [14,19].

There was a significant correlation between age and condylar volume in the RDC/TMD II group in our study. Results of the study of Mathew et al. [21] showed an increase of radiographic abnormalities in the morphology of mandibular condyle by increasing the age. In their study, the prevalence of changes in the morphology of the condyle in people over 40 years was reported significantly higher than those less than 40 years old. With increasing age and prolonged TMD, bone remodeling in response to it may increase and lead to changes in the volume of the condyles. But Isberg et al. [22] found no correlation between the age and an increase in bone deformities. Karlo et al., [23] evaluated changes in the size and shape of the mandibular condyle in children with a mean age of 7 years. The results showed that measurements of anterior-posterior and internal-external dimensions of the condyle are significantly associated with age in growth age. This reason could be due to lack of the full growth of condyle in the age range of these patients.

In the present study, in order to measure the volume of the condyle, Amira software was used to reconstruct three-dimensional images. Like this study, Chirani et al. [24] used Amira software, in their study of the movements of TMJ, to reconstruct three-dimensional MRI images. These images provided more anatomical, functional and understandable description of the TMJ.

According to the studies, Amira software has 4% and 5% error in the measurements of the Phantom and dry skull, respectively [25]. The accuracy of volumetric measurements using Amira software is depended on the accuracy of segmentation performed manually. In this study, all measuring and all processes were repeated twice to increase the accuracy of the results. However, it should be noted that it is inevitable to have a minimum amount of error when using such software.

CONCLUSION

In conclusion, any of the dimensions of the condyle were not significantly affected by TMD, excepted for the height. Condylar height in the RDC/TMD III group was significantly less than the normal group. Early diagnosis and treatment of TMD may prevent the development of dimensional changes and subsequent functional problems in the condyle.

We recommend further studies with larger sample size and separation of RDC/TMD subgroups. In addition, equal sex distribution in each group in future studies makes it possible to evaluate the effect of sex on TMJ morphology in TMDs.

CONFLICT OF INTEREST

All authors declare that there is no conflict of interest.

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