Original Article

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Clinical evaluation of the temporomandibular joint anatomy using hologram models: a retrospective study

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Abstract

Objectives: Temporomandibular joint (TMJ) is the only synovial joint in head region and is exposed to very strong pressure, especially during chewing. Disorders of this joint are quite common and occur with severe pain. Recent studies focused on the ideal surgical procedures to manage disorders and pathologies of TMJ. The number of studies on prosthesis implantations for the condylar process is also increasing; therefore, the three-dimensional anatomical organization of the TMJ becomes important.

Methods: Computed tomography images of 160 healthy individuals (82 women, 78 men) submitted to the Radiology Department of Balıkesir University Hospital from 2016 and to the first three months of 2018 were evaluated retrospectively to describe the detailed three-dimensional anatomical organization of this joint. The anterior, posterior and superior articular spaces between the condylar process and the temporal bone were measured. Anteroposterior condyle diameter and condyle height were also evaluated. Data were compared for age and gender.

Results: The mean value of superior articular distance was measured as 2.39 mm, anterior articular distance 1.83 mm, posterior articular distance 1.99 mm and diameter of the condylar process 10.38 mm. Statistical results indicated that there were gender differences among the parameters.

Conclusion: The results of the present study point out to the importance of the gross anatomy of the TMJ and revealed the differences between genders and individuals. These data may guide surgeons for planning the ideal surgical protocols during managing of joint disorders.

Keywords: computed tomography; mandibular surgery; radiologic anatomy; temporomandibular joint

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Introduction

The temporomandibular joint (TMJ) is a condylar-type synovial joint in the head region between the mandibular fossa, the articular tubercle of the temporal bone, and the head of the mandible. Since the TMJ has complex anatomical properties and is exposed to severe workload in daily life, it is very sensitive to pathological changes.[1]

TMJ disorders, which are seen very frequently, can cause serious morphological changes, are seen more in women than in men.[2,3] They occur with clinical signs such as limited jaw movement, pathological sounds coming from the joint, or the locking of the jaw as a result of degeneration in the trabecular bone tissue and the erosion of the joint disc. Although etiology has been implicated in many factors, the cause of TMJ disorders has not yet been fully elucidated.[4]

Studies that include patients with clinical symptoms in the TMJ region with the aim of explaining the biomechanical mechanisms of the etiologies of TMJ disorders have reached no definitive conclusions regarding the etiology. Another study that compared the condyle morphology of healthy individuals and patients suffering from TMJ disorders revealed morphological differences between genders, and age groups, and stated that three-dimensional imaging methods give more accurate results in the diagnosis compared to two-dimensional imaging.[5,6] Furthermore, it has been reported that using advanced imaging techniques during diagnosis can be beneficial and will form a more reliable differential diagnosis list.[1,7]

Surgical studies revealed changes in TMJ morphology following mandibular osteotomy operations. These studies also defined risk factors to prevent progressive condyle resorption, which was particularly likely in the post-operative period. Furthermore, their results indicated that morphological changes in the TMJ that were formed after surgery caused condyle resorption.[8,9]

A study that compared the morphometric properties of the TMJ using X-ray images reported differences among populations.[10] TMJ was studied in a Turkish population to investigate the effects of TMJ disorders on the joint morphometry;[11] however, morphometric properties of the TMJ in healthy individuals in the Turkish population were not well-described. Therefore, the main aim of the present study was to evaluate the anatomical organization of the TMJ using computed tomography (CT) images and hologramic images of healthy individuals in the Turkish population.

Materials and Methods

The ethical board of Balıkesir University approved this study (Decree Number: 171; Date: 12/27/2017). The study started upon gaining ethical approval and finished in July 2018. The study was performed according to the principles of the Helsinki Declaration (2008).

The CT image series of the temporal bones of 160 healthy individuals (82 women and 78 men) submitted to Radiology Department of Balıkesir University Hospital between 2016 and the first three months of 2018 were retrospectively evaluated. The mean age of the participants was 40.79 years (range: 12–75). The patients included in this study had no history of surgery or trauma against the head or mandible. Patients that had any bone deformation, TMJ disorders, surgery, or trauma history were excluded from the study.

A 64-slice CT scanner (Aquillon 64, Toshiba, Otawara, Japan) was used for image acquisition. Images were obtained in the axial plane from the frontal sinuses to the nasal floor. Continuous non-overlapping sections of temporal bone CT scan were obtained with acquisition parameters of 1 mm-slice thickness, 120 kV, and 200 mAs. The pixel spacing was 0.3×0.3 mm. Images were sent to the workstation (Aquarius Intuition edition version 4.4.6, TeraRecon, Foster City, CA, USA) for assessment. Reformatted images in the sagittal and coronal planes were constituted in addition to the axial plane with the same resolution characteristics. Images were evaluated with both bone and soft-tissue algorithms.

All CT images were obtained from the Picture Archiving and Communication System (PACS) at the University Hospital. Measurements were completed by radiology professor with a twenty-year experience, an anatomy professor with twenty six-year and experience and an anatomy specialist with six-year experience using Osirix-Lite version 9 (Pixmeo, SARL, Switzerland). Furthermore, ready-to-print three-dimensional images were obtained from the CT image series using Blender and Meshmixer software (Autodesk Inc, San Rafael, CA USA). These programs can be downloaded from the manufacturer's official websites for free. All parameters were measured from these ready-to-print three-dimensional images using free licensed Meshlab software that allows the spatial measurement of the distance between two selected points in three-dimensional images. There was no statistically significant difference between the measurements.

The Frankfurt horizontal plane, which lies from the inferior margin of the orbit to the superior margin of the external acoustic meatus, was determined. A parallel line to the Frankfurt horizontal plane from the most inferior point of the posterior border of the articular tubercle of the temporal bone to the anterior border of the condylar process of the mandible was drawn to measure the anterior articular space in sagittal sections. The posterior articular space was evaluated by drawing a parallel line to the Frankfurt horizontal plane from the most posterior point of the condylar process to the temporal bone in sagittal sections. The condylar process height was measured by drawing a parallel line to the posterior border of the condylar process from the tip of the condylar process to the deepest point of the mandibular notch. The diameter of the condylar process was evaluated by drawing a parallel line to the Frankfurt horizontal plane from the most anterior to the most posterior point of the head of the mandible in sagittal sections. The angle between the Frankfurt horizontal plane and the posterior border of the condylar process was also examined in sagittal sections (**Figure 1**). Finally, the superior articular space was measured by drawing a vertical line between the tip of the condylar process and the mandibular fossa in axial sections (**Figure 2**). All parameters were measured in three-dimensional images using Meshlab software (Autodesk Inc, San Rafael, CA USA) (**Figures 3** and **4**).

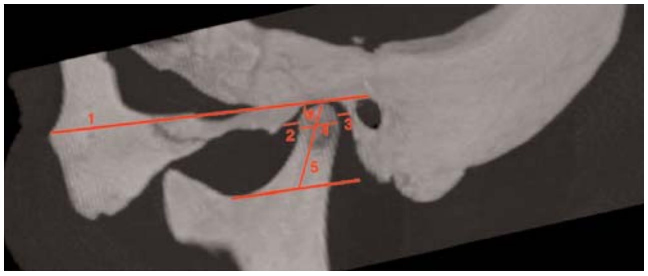

Figure 1. Radiological measurements in sagittal images. **Line 1:** Frankfurt horizontal plane; **Line 2:** anterior articular space; **Line 3:** posterior articular space; **Line 4:** condylar diameter; **Line 5:** condylar height; **Red star:** condylar angle. [Color figure can be viewed in the online issue, which is available at www.anatomy.org.tr]

Statistical analyses were performed using IBM SPSS Statistics for Windows (Version 21, Armonk, NY, USA). Determining the normal or non-normal distribution of all measurements was evaluated using the Kolmogorov–Simirnov and Shapiro-Wilk tests. Descriptive analyses were performed to demonstrate all variables' mean values and standard deviations. Comparisons between genders and measurements were performed using Student's t test and the Mann-Whitney U test for normal and non-normal distributed measurements, respectively. The paired Student's t test was utilized to compare measurements between the right and left sides. While investigating the associations between age and the measured data, Spearman's rho test was used to calculate the correlation coefficients and their significance at the 5% Type-I error level. Measurements with p-value <0.05 were considered statistically significant.

Results

The detailed information of the morphometric measurements, including their mean values, standard deviations and minimum and maximum values are summarized in **Table 1**.

The distance between the condylar process and the mandibular fossa (the superior articular space) was as short as 0.41 mm in women and 0.4 mm in men. The superior articular space was longer in men than women on both sides (p<0.001). The lowest condyle height was 11.9 mm in women and 11.1 mm in men. There were statistically significant differences in the right (p=0.02) and left (p=0.01) condyle height between genders in favor of women.

The diameter of the condylar process was only statistically different on the right side and men had a wider condylar process (p=0.01). The condylar angles were wider in men on the right (p=0.02) and left (p<0.001) sides.

Figure 2. Measurement of superior articular space in axial images.

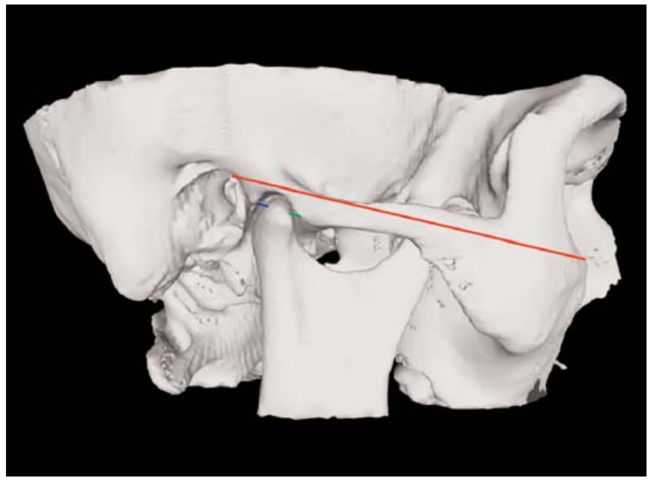

Figure 3. Lateral view from the right side of the virtual reality image that used for spatial measurements. **Red line:** Frankfurt horizontal line; **Blue line:** posterior articular space; **Green line:** anterior articular space.

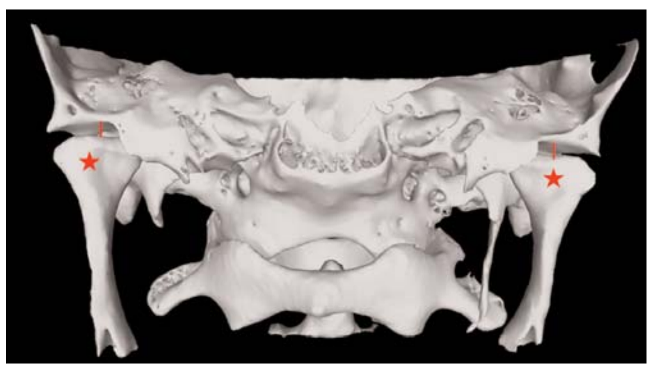

Figure 4. Anterior view of the coronal section of the virtual reality image. **Red lines:** superior articular space; **Red stars:** mandibular condyle.

The closest anterior articular space was 0.57 mm in women and 0.7 mm in men. The anterior articular space (p=0.002) and condylar height (p=0.001) were longer on the right side. However, the anterior articular space was not statistically different between genders for both sides (p=0.16 on the right and p=0.32 on the left side). In contrast, the diameter of the condylar process was larger on

Table 1

Results of morphological measurements. Mean values with standard deviations, minimum and maximum values (mm).

Parameter	Women		Men	
	Right	Left	Right	Left
Anterior articular space	1.83±0.73 (0.57–4.24)	1.71±0.8 (0.72–4.54)	2.03±0.86 (0.7–4.9)	1.74±0.67 (0.7–3.73)
Posterior articular space	1.98±1 (0.65–6.32)	1.9±1.08 (0.58–6.4)	2.07±0.9 (0.75–6.73)	2.05±0.87 (0.71–6.02)
Superior articular space	2±0.8 (0.6–4.14)	2.09±1.01 (0.41–6.66)	2.74±0.84 (0.4–5.03)	2.7±0.87 (0.65–5.78)
Condyle height	20.15±3.75 (13–29.8)	19.74±3.83 (11.9–28.5)	18.82±3.67 (11.5–28.7)	18.33±3.4 (11.1–25.7)
Anteroposterior condyle diameter	10±1.18 (6.8–12.4)	10.37±1.47 (6.36–13.9)	10.5±1.37 (7.1–15.1)	10.68±1.67 (7.2–15.6)
Angle of the condyle	70.04±5.4 (57–84.32)	69.32±6.29 (52.08–88.54)	72.18±6.16 (54.04–85.8)	72.16±6.13 (55.38–87.5)

the left side (p=0.01). There were no statistical differences between the right and left sides for other measurements.

The closest posterior articular space was measured as 0.58 mm in women and 0.71 in men. However, there was no statistically significant difference between genders for both sides (p>0.05).

Correlation analyses were also performed to evaluate the relationships between the variables. According to the correlation analyses results, the posterior articular spaces on either side narrowed with age (right: r=-0.28, p<0.001; left: r=-0.28, p<0.001). The superior articular space had a negative weak correlation with age only on the left side (r=-0.16, p=0.04). The diameter of the left condylar process increased with age (r=0.22, p=0.004). Statistically significant correlations between the other measurements were shown in **Table 2**.

Discussion

Several reported studies have evaluated gender differences in the TMJ; women have a greater tendency to suffer from TMJ disorders.[12,13] Morphometric properties of the TMJ also show differences among various populations.

Table 2

Correlation summary for the parameters.

Parameter	Correlation coefficient (r)	Significance (p)
Right superior and posterior articular spaces	0.32	p<0.001
Right and left anterior articular space	0.467	p<0.001
Right superior articular space and condyle height	-0.164	p=0.03
Right superior articular space and condyle angle	0.193	p=0.01
Right and left posterior articular spaces	0.569	p<0.001
Right and left superior articular spaces	0.711	p<0.001
Right and left condyle angle	0.68	p<0.001
Right and left condyle heights	0.9	p<0.001
Left superior articular space and condyle height	-0.189	p=0.01
Left condyle height and condyle angle	-0.237	p<0.001

The effects of radiologic tools for an accurate diagnose were reported.[14] Appropriate surgical techniques are of crucial importance for both patients' post-operative period and their life quality through the rest of their lives. Therefore, choosing the best surgical protocol is greatly important besides gaining knowledge of the gross anatomy of this joint. Furthermore, investigating the effects of the surgical methods on the TMJ after surgery may increase patients' life quality. Various published surgical reports have demonstrated the effects of surgery on the joint.[5,8,15] Iguchi et al.[9] reported gross changes in the TMJ after a ramus osteotomy of 39 patients using CT and magnetic resonance imaging (MRI). They compared the joint anatomy between the pre- and post-operative periods. According to their results, all articular spaces were narrower after surgery. Likewise, the heights of the condyle and ramus of the mandible also decreased after surgery in all patients. Nevertheless, the morphometric values were not statistically different between genders in either the pre-operative or post-operative periods. In contrast to mandibular measurements, the lengths of the joint elements on the temporal bone such as the articular fossa and articular height increased two years after orthodontic surgery, while the anteroposterior width decreased.[16]

The elements composing the TMJ have been assumed to play a significant role in joint functions. In contrast, a micro-tomography study using 16 fresh cadaver mandibles pointed out that the cartilage had no effect on either the joint's morphological functions or the trabecular microstructure of the mandible's condyle.[2] Furthermore, Ma et al.[17] reported that the articular disc was not affected by activator therapy.

This study's main purpose was to evaluate the bony structures of the TMJ. However, the TMJ has a complex structure that consists of bone and soft tissue. Studies have reported the soft tissue properties of the TMJ using MRI;[18,19] these studies support our results to understand the anatomy of the TMJ in detail. Also, Safi et al.[20] retrospectively evaluated the bilateral condylar volume of 350 patients using cone-beam CT. According to their results, women had a smaller mandibular condyle than men, and age had no effect on the condylar volume. In contrast, our results demonstrate that aging correlates with posterior and superior articular spaces and condyle diameter.

Another morphological study of the TMJ that included CT images of 60 patients reported that the anterior articular distance was not statistically different between the right and left sides, while our results demonstrated significant differences for the anterior articular space.[21] The selection criteria were not well explained in that study, so their results may not be recognized as the morphometric values of the TMJ, because several studies have reported differences between healthy and pathological joints.

Detailed anatomical knowledge of the TMJ including bone and soft tissues has crucial significance to the development of new surgical techniques for the treatment of joint disorders. Recent studies using flap implantation to mandibular reconstruction had successful results.[22–24] Furthermore, facial asymmetry had a direct effect on TMJ morphometry.[25] Therefore, it is very important for neurosurgeons to have knowledge about the normal morphometry of TMJ.

Technology provides great opportunities in medical science. Researchers can complete pre-operative simulations using virtual-reality options. Detailed remodeling of the TMJ has also been studied using three-dimensional reconstructed radiological images.[26]

Morphometric studies focused on the comparing the pathological conditions with healthy joints for detecting morphometric changes.[27,28] Our study had a larger patient cohort than previous studies, as we included healthy people to evaluate the anatomical properties of the TMJ, while other studies compared pre- and post-operative changes in patients suffering from specific pathologies. Bony structures can be easily detected and reconstructed three-dimensionally on CT images, so our study provided detailed bony measurements of the TMJs. Furthermore, technology improvements have greatly contributed to medical education.[29] Since this is an incontrovertible contribution of technology, we used virtual reality images that were directly obtained from real patients' CT images. We completed our study using such images with a 1:1 ratio with real patients.

Patients do not always remain at the same angle during the CT scans. Therefore, the orientation function of radiological imaging software may not provide the same positions among all patients, and morphometric measurements may not be possible according to standard points. However, the Frankfurt horizontal plane is drawn according to bony landmarks, the inferior border of the orbit, and the superior border of the external acoustic meatus, which can be easily identified on the CT images. Hence, this plane helps researchers complete their morphometric studies without considering the patients' resting angles during radiologic scans. We performed our study using the Frankfurt horizontal plane, thus avoided subjectivity and made objective measurements using three-dimensional images. The angle between the Frankfurt horizontal plane and the posterior border of the mandibular condyle was evaluated for the first time in the present study. We suggest that the results of this study can make an important clinical contribution to the management of TMJ disorders.

Recent studies have mostly focused on monitoring the effects of surgeries on the TMJ. These studies compared the morphometric properties and alterations to this joint before and after surgeries on patients suffering from TMJ disorders. However, the present study was completed on patients who did not suffer from any TMJ disorder. Since we evaluated healthy joints, our results may be beneficial to create a more accurate differential diagnosis list.

The exact etiology of TMJ disorders remains unclear. Our results have shown that women had smaller articular spaces than men; this result may be an important reason for the high prevalence of TMJ disorders in women. Evaluating morphometric properties of TMJ of healthy individuals has some advantages. Knowing the morphometric properties of a healthy TMJ could be beneficial during diagnosis and for selecting an appropriate surgical method for treatment of TMJ disorders. Our results also provide the anatomical properties of the TMJ which will be useful for designing the appropriate prosthesis for condylectomy patients. Thus, life quality of these patients can be increased in the post-surgical period.

Conclusion

Knowing the range of the anatomical values that belong to the TMJ is crucial for patients' post-surgery life quality. Although the morphometry of the TMJ was widely studied, the present study was the first report that evaluated the morphometry of the healthy TMJ using three-dimensional hologramic images obtained from CT images of real patients. Our results will be beneficial for diagnosis and comparison between different races and contribute the literature for TMJ morphometry. Development of the technology provides us to investigate the morphometric values in more detail; thus, we completed our morphometric evaluations on three-dimensional models and between precise selected points. The main limitation of the present study was the lack of cadaveric measurements due to the insufficient number of specimens in our department. The other limitation was the lack of participant's information such as height, body weight, and body mass index, because the study was retrospective.

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