Abstract: The present study’s aim was to compare temporomandibular joint (TMJ) images for individuals with and without temporomandibular disorder (TMD) using high-resolution ultrasonography (HRUS). The distance between the lateral-most point of the articular capsule and the lateral-most point of the mandibular condyle (lateral capsule-mandibular condyle distance) was determined to confirm the clinical diagnosis according to the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD). The sample group comprised 17 women and 15 men, aged 19-39 years, distributed into TMD (n = 20) and Asymptomatic (n = 12) groups. The evaluations were in closed- and open-mouth positions. The lateral capsule-mandibular condyle distance was measured in both positions. The articular surface of the condyle and the articular capsule were visualized as hyperechoic structures, and the articular disk was visualized as a central, hyperechogenic area surrounded by a hypoechogenic linear image. Morphological changes were observed in some TMD group participants, including joint effusion (hypoechogenic area), condylar erosions (increased hyperechoic area), and condylar surface irregularities. The lateral capsule-mandibular condyle distance did not differ between sides or groups among participants with intra-articular disorders with or without pain (P > 0.05).

In conclusion, HRUS allowed visualization of the TMJ structures, but did not allow confirmation of clinical diagnosis by DC/TMD.

Keywords: ultrasonography, temporomandibular joint, anatomy, temporomandibular disorders

Introduction

The temporomandibular joint (TMJ), one of the most important synovial joints in the human body, moves with the muscles, and teeth during mandibular movements. The anatomical elements forming the TMJ include the mandibular fossa, located in the petrous portion of the temporal bone, and the mandibular condyle. The articular disk is located between these two bones, consisting of fibrocartilage that improves the bones’ adaptation, and is attached to the medial and lateral pole of the mandibular condyle, accompanying it during mandibular movements. The articular disk divides the joint space into two compartments: the supradiscal and infradiscal spaces. The articular capsule surrounds the TMJ, and the extracapsular ligaments restrict mandibular movements, avoiding possible damage to the structures [1]. The normal articular disk position is when its posterior portion is located between the 12 and 13 o’clock positions on the articular surface, and its central portion is on the upper anterior face of the mandibular condyle’s articular surface [2].

Adverse conditions affecting the masticatory musculature and the TMJ can compromise the associations among the TMJ structures, with a consequent negative effect on function, causing pain, noise, and movement limitation. This condition is termed temporomandibular disorder (TMD).

Treatment for an individual suffering from TMD starts with a complete diagnosis, followed by a detailed clinical examination. The Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) is an evaluation method with defined criteria, which is simple to apply and perform to obtain the dysfunction diagnosis [3]. TMJ images may also be necessary to confirm suspicion of the disorder [4], assessing the associations between anatomical structures and observing progress of change [5].

The most common imaging methods are panoramic radiography, arthroscopy, computed tomography, ultrasonography, and magnetic resonance imaging (MRI). MRI is considered the gold standard for evaluating the TMJ’s anatomical structures; however, its availability is relatively low due to high cost and restriction in some cases, including those with a pacemaker or who suffer from claustrophobia. Recently, ultrasonography (US) has become a promising and viable tool to evaluate the TMJ’s anatomical structures and their associations with mandibular movements [5-8]. US is a non-invasive clinical technique that is inexpensive and allows the evaluation of structures in “real time.”

Given the above context, the study compared images of the TMJ’s anatomical structures in individuals with and without TMD using high-resolution ultrasonography (HRUS). Furthermore, measuring the distance from the lateral-most point of the articular capsule to the lateral-most point of the mandibular condyle verified possible differences between participants with articular disorders and asymptomatic individuals, confirming the clinical diagnosis using DC/TMD.

Materials and Methods

Sample

The Ethics Committee in Research of Piracicaba Dental School, University of Campinas (FOP-UNICAMP) approved this cross-sectional and observational study (protocol 051/2015). All experiments were performed in accordance with the Declaration of Helsinki, and all procedures were performed with written, informed consent from the participants.

Young adults aged between 18 and 40 years, with or without clinical signs and symptoms of TMD, were invited to participate. Between August 2016 and February 2017, 37 individuals were assessed for eligibility. The final sample was comprised of 17 women and 15 men, aged between 19 and 39 years (26.24 ± 4.63 years), who voluntarily attended the Ultrasound Laboratory of the FOP-UNICAMP. The participants were divided into two groups according to the following criteria:

TMD group (n = 20): presence of clinical signs and symptoms of TMD for at least the last 6 months, with no treatment.

Asymptomatic group (n = 12): absence of signs and symptoms of TMD.

The exclusion criteria for both groups were as follows: individuals incapable of providing informed consent, those with developmental disorders that may directly or indirectly affect structures of the head and neck, those who had undergone head and neck radiotherapy or chemotherapy, TMJ surgery, or used medication for pain, including analgesics.

The examiner was trained by experts on the DC/TMD instrument. The participants were previously informed of the study objectives and methodology in a clear, easily understandable way. To participate in the research, written authorization was required from the participants through an informed consent form. After they signed the consent form, the volunteers provided personal information by filling in a form.

DC/TMD

Axis I of the DC/TMD (International Network for Orofacial Pain and
which corresponds to clinical evaluation, was applied. The participant remained in a sitting position with their back resting on the backrest of a chair, their head in a natural position, and their feet on the floor. The participants were asked about TMD symptoms through a questionnaire. A single examiner (D.Z.R.D) conducted the tests.

The DC/TMD evaluates the following parameters:

- location of pain and headache;
- incisal relationships:
- horizontal and vertical incisors (mm);
- opening patterns: straight, corrected, or uncorrected deviation (mm);
- opening movements: pain-free unassisted opening, maximum unassisted, and assisted opening (mm);
- lateral and protrusive movements (mm);
- TMJ noises during opening, closing, lateral, and protrusive movements; and
- muscle (temporalis and masseter muscles) and TMJ pain by palpation.

DC/TMD was diagnosed from the diagnostic decision tree, which consists of three large branches. The first is related to the diagnosis of pain (pain-related TMD and headache) and the other two branches are used to obtain the diagnosis of jaw joint disorders (intra-articular joint disorders and degenerative joint disorders).

The participants were allocated to the TMD group or to the asymptomatic group, according to their respective diagnoses.

US Examination

Imaging Acquisition

The US examination was performed with a high-resolution linear array transducer of 38 mm and 7-18 MHz (SSA-780A-APLIO MX [Toshiba Medical Systems Corporation, Otawara, Japan]), which belongs to the Department of Pediatric Dentistry at FOP-UNICAMP. A single, properly trained examiner (D.Z.R.D.) obtained the images. The optimal resolution used was 14 MHz. After imaging, a pilot study was developed with a sample of 10 healthy volunteers and the DC/TMD was applied twice with an interval of at least seven days. Intra-examiner reliability was determined using Cohen’s kappa coefficient, obtaining a value of 0.7.

Sixty-four joints from 32 participants were evaluated according to the following parameters: visualizing the articular disk during mouth closing and opening, examining the articular surface of the mandibular condyle and upper edge of the joint capsule, and measuring the lateral capsule-mandibular condyle distance.

The US examination was performed in a room with low lighting. The participants sat with their back resting on the backrest of the chair, their head in a natural position, and their feet on the floor. The transducer was placed over the TMJ in a perpendicular and inferior position to the zygomatic arch and parallel to the mandibular ramus for a sagittal view, as shown in Fig. 1.

A static image of the right and left TMJ was obtained with the mandible in the rest position (without dental occlusion and slightly closed lips). The transducer was moved until an optimal view of the joint was obtained according to the participant’s face for the axial plan. Each image was captured three times for closed- and open-mouth positions.

The articular disk was assessed during static and dynamic examinations. The distance between the lateral-most point of the articular capsule and the lateral-most point of the mandibular condyle (lateral capsule-mandibular condyle distance) was measured in millimeters, using US equipment tools, in closed- and open-mouth positions. Three consecutive measurements were recorded and averaged.
The participants diagnosed with TMD were referred to a specialized center for treatment. One participant in each group presented MRI images of their TMJ, which had been obtained from independent clinical centers before the present study. These images were compared with the intra-articular findings from the two participants’ HRUS images to improve examiner training. The MRI images were taken in the sagittal plane, gradient-echo sequence (FFE-MOVIE), T1-weighted images; and coronal plane, gradient-echo sequence (FFE-vol), without venous contrast, at rest and following several degrees of opening of the mouth. Figures 2-4 show these images.

Statistical analysis

Descriptive statistics were applied consisting of mean and standard deviation values. Normality was assessed using the Shapiro-Wilk test. Since the data were normally distributed, the values of the lateral capsule-mandibular condyle distance were submitted to paired and unpaired Student’s t-test for inter-group comparisons and for intra-group comparisons of the right and left sides. One-way analysis of variance (ANOVA) was applied for inter-subgroup comparisons. The Bioestat 5.4 software package was used (Belém, Brazil), and a significance level of 0.05 was used.

Results

Thirty-two young adults (mean age of 26.24 ± 4.63 years) were examined clinically using the DC/TMD instrument and ultrasonography, and were distributed in the TMD group (n = 20, comprising 12 females and eight males) and the asymptomatic group (n = 12, comprising five females and seven males), as shown in the flow chart in Fig. 5.

Table 1 shows the sample distribution regarding TMD according to the DC/TMD instrument. The TMD group was distributed in three subgroups according to articular/pain and muscular disorders, as follows: only pain-related TMD (n = 3); only intra-articular joint disorders (n = 9); pain-related TMD + intra-articular joint disorders (n = 8) (Table 2).

On the HRUS images of the TMJ, the superior convexity of the mandibular condyle and the articular disk were visualized as a hyperechoic image. Furthermore, the articular disk was visualized with a superior and inferior hypoechoic halo, corresponding to the supradiscal and infradiscal spaces, respectively. The joint capsule consisted of a linear hyperechoic image, as shown in Figs. 2 and 3; the respective details were observed for all participants.

Figure 3 shows the landmarks in sagittal scans for measuring lateral capsule-mandibular condyle distance; Table 2 shows the respective values. There was no statistically significant difference between the right and left sides in either the TMD group or asymptomatic group, or between the two groups (Student’s t-test, P > 0.05). In addition, no statistically significant differences were found for inter-subgroup comparisons (ANOVA, P > 0.05), or for each subgroup within the asymptomatic group (Student’s t-test, P > 0.05).

Table 3 shows the types of intra-articular disorders according to DC/TMD. Fourteen participants presented with disk displacement with reduction (eight females and six males), whereas one female presented with disk displacement without reduction. Two males were diagnosed with degenerative joint disease; DDOR, disk displacement with reduction.

### Table 1 Sample distribution according to sex and DC/TMD

| Characteristic | Female (%) | Male (%) |
|---------------|------------|----------|
| Group         |            |          |
| TMD group     | 12 (37.5%) | 8 (25%)  |
| Asymptomatic group | 5 (15.63%) | 7 (21.87%) |
| TMD group     |            |          |
| Only pain-related TMD | 3 (25%) | 0 |
| Myalgia       | 2 (16.66%) | 0 |
| Local myalgia | 1 (8.34%)  | 0 |
| Only intra-articular joint disorders | 2 (16.66%) | 7 (37.5%) |
| Disk displacement with reduction | 1 (8.33%) | 6 (75%) |
| Degenerative joint disease | 0 | 0 |
| Pain-related TMD + intra-articular joint disorders | 7 (58.33%) | 1 (12.5%) |
| Myalgia + arthralgia + DJD | 0 | 1 (12.5%) |
| Headache attributed to TMD + DDR | 4 (33.33%) | 0 |
| Myalgia + arthralgia + DDR | 2 (16.66%) | 0 |
| Myalgia + arthralgia + headache attributed to TMD + DDR | 1 (8.34%) | 0 |
| Total         | 12 (100%)  | 8 (100%) |

DJD, degenerative joint disease; DDOR, disk displacement with reduction

### Table 2 Measurement of the distance between the lateral point of the articular capsule and the lateral point of the mandibular condyle (lateral capsule-condyle distance) in the TMD and asymptomatic groups (mm)

| Groups | Right US - CM | Right US - OM | Left US - CM | Left US - OM |
|--------|---------------|---------------|--------------|--------------|
| TMD group (total n = 20) | 0.70 ± 0.19 | 0.70 ± 0.19 | 0.68 ± 0.15 | 0.65 ± 0.15 |
| Only pain-related TMD (n = 3) | 0.63 ± 0.21 | 0.56 ± 0.16 | 0.73 ± 0.20 | 0.66 ± 0.13 |
| Only intra-articular joint disorders (n = 9) | 0.70 ± 0.16 | 0.56 ± 0.12 | 0.67 ± 0.15 | 0.63 ± 0.14 |
| Pain-related TMD + intra-articular joint disorders (n = 8) | 0.71 ± 0.22 | 0.67 ± 0.12 | 0.66 ± 0.12 | 0.65 ± 0.19 |
| Asymptomatic group (n = 12) | 0.71 ± 0.16 | 0.63 ± 0.16 | 0.7 ± 0.14 | 0.66 ± 0.15 |

Right US-CM, Right ultrasound in a closed-mouth position; Right US-OM, Right ultrasound in the open-mouth position; Left US-CM, Left ultrasound in the closed-mouth position; Left US-OM, Left ultrasound in the open-mouth position.

Student’s t-test P > 0.05 for intra and inter-group comparisons. ANOVA P > 0.05 inter-subgroup comparisons.
Table 3  Characteristics of TMDs in the TMD group

| TMD                                         | Female | Male |
|---------------------------------------------|--------|------|
| Disk displacement with reduction right and left | 4      | 1    |
| Disk displacement with reduction right      | 1      | 3    |
| Disk displacement with reduction left       | 3      | 2    |
| Disk displacement without reduction, without limited opening | 1 | - |
| Degenerative joint disease right and left   | -1     | -    |
| Degenerative joint disease right             | -1     | -    |
| Without articular disorders, with pain       | 3      | 3    |
| Total                                       | 12     | 8    |

TMD, temporomandibular disorder

Discussion

TMD represents 5%-12% of chronic pain conditions and is becoming more frequent in young adults (International Network for Orofacial Pain and Related Disorders Methodology, 2018; http://www.iadr.org/INFORM). In the present study, 32 young adults were evaluated, 12 women (37.5%) and eight men (25%) presented with signs and symptoms of TMD, as shown in Tables 1 and 3. These rates and sample size are similar to those reported by Mello-Júnior et al. [2], who evaluated nine men and 29 women with intra-capsular TMD through HRUS, and Müller et al. [9], who evaluated 16 women and 14 men with TMJ arthritis using US and MRI. Both studies showed higher rates in women than in men.

The TMJ anatomical structures were visible on HRUS at different echogenicity scales. In addition to the closed- and open-mouth positions, the articular disk was visualized as a hyperechoic image with a superior and inferior hypoechogenic halo, as shown in Fig. 3. Tálmaco et al. [10], Manfredini et al. [11], and Emshoff et al. [12] described similar images. However, Byahatti et al. [5] and Jank et al. [13] observed the articular disk as a hypo-to-isoechogenic band, whereas the mandibular condyle’s articular surface was hyperechoic. Assaf et al. [8] visualized the joint capsule’s upper border as a hyperechoic image. The differences found among these studies may be associated with the transducer’s resolution, which varied between 7.5 and 12 MHz [1,2,5,8,11,13,14]. The transducer used in the present study was 14 MHz, facilitating images with well-defined anatomical structures. US sensitivity is directly proportional to the transducer’s resolution; thus, increasing the resolution increases the sensitivity of the US [4].

Among the TMD group, 15 participants presented with disk displacement on one or both sides, comprising 14 with reduction and one without reduction, according to the DC/TMD (Table 3). However, the anterior position of the articular disk relative to the mandibular condyle on the dynamic HRUS images were less easy to observe. Therefore, the positions of other anatomical structures can provide signs of disk position [14-16]. For this reason, the distance from the lateral point of the articular capsule to the lateral point of the mandibular condyle (lateral capsule-mandibular condyle distance) was selected in the present study since this distance represents the lateral surface of the mandibular condyle in an axial view. According to Hayashi et al. [16], and Mello-Júnior et al. [2], these landmarks can be indirect US signs of the disk position, and may be enlarged in cases of lateral disk displacement. In the present study, the values of lateral capsule-mandibular condyle distance, in closed- and open-mouth positions, ranged between 0.56 and 0.70 mm for participants with disk displacement with reduction. These values are lower than the cut-off stated by Hayashi et al. [16] to separate joints with and without anterolateral disk displacement. Mello-Júnior et al. [2] described distances varying between 1.2 and 1.6 mm in individuals with TMD without disk displacement. Therefore, the HRUS images obtained in the present study may not confirm the disk displacement diagnosed clinically. A larger sample of patients with severe TMD would confirm these findings. In this context, in certain participants with an intra-articular disorder, morphological alterations in the mandibular condyle and articular disk were visualized on HRUS, such as hypoechogenicity of the anterior superior compartment of the TMJ, suggesting possible joint effusion, hypoechogenicity of the articular disk, suggesting degeneration, and increased hyperechoic reflection, suggesting erosion of the condylar surface. These findings are consistent with those of previous studies [2,6,8]. Consequently, the visualized irregularities may indicate advanced destruction of cartilaginous and ossuous structures, as shown in Fig. 3a.

Furthermore, measurements of the lateral capsule-mandibular condyle distance did not differ significantly between the TMD group and respective subgroups and the asymptomatic group in the two mouth positions. These results were unexpected, as 15 participants in the TMD group were clinically diagnosed with disk displacement and two with degenerative joint disease. The greater distance between the articular capsule and mandibular condyle may indicate disk displacement [14,16], as mentioned above. However, the number of participants may have been a limiting factor for possible significant differences. Furthermore, Motoyoshi et al. [17] suggested that soft tissue irregularities surrounding the TMJ might also help identify disc displacement.

The technique may be one reason for the different findings between the present study and the others cited. Despite considering the methodological details previously, HRUS images depend on the structures and the mouth/head posture. The transducer position may vary from horizontal (parallel to the zygomatic arch) to vertical (parallel to the mandibular ramus), thus producing a different image of the TMJ in a transverse, coronal, or sagittal plane. The planes of the images are not truly transverse, coronal, or sagittal; they are almost inclined as the transducer is tilted during examination to better visualize the different TMJ components [4].

One limitation of US exams is the correct visualization of the anterior position of the articular disc, as observed during the rotation and translation of the mandibular condyle in dynamic images from the closed-mouth to the open-mouth position. However, the central portion of the disc was observed in all participants when adjusting the transducer position constantly. According to Kundu et al. [4], only the lateral part of the TMJ can be reached in sonograms, while the medial part is hidden by the structures, so medial displacements of the disc might be overlooked. Another limitation of the present study is the lack of MRI images as a gold standard for all participants; they were not requested for ethical reasons.

In conclusion, HRUS allowed visualization of the TMJ’s anatomical structures as follows: the articular surface of the mandibular condyle was observed as a hyperechoic image; the articular disc as a hyperechoic image with a superior and inferior hypoechogenic halo, dividing the joint space into superior and inferior compartments, corresponding to supra and infradiscal spaces, respectively; the upper border of the joint capsule as a hyperechoic image.

It was also possible to observe morphological changes in certain TMD group participants with intra-articular disorders, including joint effusion (hypoechogenic area), condylar erosions (increased hyperechoic), and irregularities of the condylar surface.

The distance from the lateral-most point of the articular capsule to the lateral-most point of the mandibular condyle (lateral capsule-mandibular condyle distance) measured on the ultrasonographic scans did not differ between the TMD and asymptomatic groups; thus, the articular disorders diagnosed clinically by the DC/TMD could not be confirmed using the US images.

Acknowledgments

The authors are grateful to CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, Brazil) for the scholarship for the first author and Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP, Brazil) for financial support for the present study (Process 2011/12659-1). The authors also thank the participants.

Conflict of interest

The authors declare no potential conflict of interest with respect to the authorship and/or publication of this article.

References

1. Alomar X, Medrano J, Cabotova J, Clavero JA, Lorente M, Sierra I (2007) Anatomy of the temporomandibular joint. Semin ultrasound CT MR 28, 170-183.
2. Mello-Júnior CF, Sato Oumar C, Guimarães Filho HA (2011) Sonographic evaluation of temporomandibular joint internal disorders. Radiol Bras 44, 355-359.
3. Schiffman E (2014) Diagnostic for temporomandibular disorders (DC/TMD) for clinical and research applications: recommendations of the International RDC/TMD Consortium Network and Orofacial Pain Special Interest Group. J Oral Facial Pain Headache 28, 6-27.
4. Kundu H, Basavaraj P, Kote S, Singla A, Singh S (2013) Assessment of TMD disorders using ultrasonography as a diagnostic tool: a review. J Clin Diagn Res 7, 3116-3120.
5. Byahatti SM, Ramanamurthy BR, Mubeen M, Agnihotri PG (2010) Assessment of diagnos-
tic accuracy of high-resolution ultrasonography in determination of temporomandibular joint internal derangement. Indian J Dent Res 21, 189-194.

6. Emshoff R, Jank S, Bertram S, Rudisch A, Bodner G (2002) Disk displacement of the temporomandibular joint: sonography versus MR imaging. AJR Am J Roentgenol 178, 1557-1562.

7. Pereira LJ, Gavião MB, Bonjardim LR, Castelo PM (2007) Ultrasound and tomographic evaluation of temporomandibular joints in adolescents with and without signs and symptoms of temporomandibular disorders: a pilot study. Dentomaxillofac Radiol 36, 402-408.

8. Assaf AT, Kahl-Nieke B, Feddersen J, Habermann CR (2013) Is high-resolution ultrasonography suitable for the detection of temporomandibular joint involvement in children with juvenile idiopathic arthritis? Dentomaxillofac Radiol 42, 2-9.

9. Müller L (2009) Early diagnosis of temporomandibular joint involvement in juvenile idiopathic arthritis: a pilot study comparing clinical examination and ultrasound to magnetic resonance imaging. Rheumatology 48, 680-685.

10. Tălmăceanu D (2018) High-resolution ultrasonography in assessing temporomandibular joint disc position. Med Ultrason 20, 64-70.

11. Manfredini D, Tagini F, Melchiorre D, Zampa V, Bosco M (2003) Ultrasound assessment of increased capsular width as a predictor of temporomandibular joint effusion. Dentomaxillofac Radiol 32, 359-364.

12. Emshoff R, Bertram S, Rudisch A, Gassner R (1997) The diagnostic value of ultrasonography to determine the temporomandibular joint disk position. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 84, 688-696.

13. Jank S (2001) High-resolution ultrasonography of the TMJ: helpful diagnostic approach for patients with TMJ disorders? J Craniomaxillofac Surg 29, 366-371.

14. Elias FM, Birman EG, Matsuda CK, Oliveira Ilka RS, Jorge WA (2006) Ultrasonographic findings in normal temporomandibular joints. Braz Oral Res 20, 25-32.

15. Landes C, Waldendt H, Klein C (2000) Sonography of the temporomandibular joint from 60 examinations and comparison with MRI and axiography. J Craniomaxillofac Surg 28, 352-361.

16. Hayashi T, Ito J, Koyama J, Yamada K (2001) The accuracy of sonography for evaluation of internal derangement of the temporomandibular joint in asymptomatic elementary school children: Comparison with MR and CT. Am J Neuroradiol 22, 728-734.

17. Motoyoshi M, Kamijo K, Numata K, Namura S (1998) Ultrasonic imaging of the temporomandibular joint: a clinical trial for diagnosis of internal derangement. J Oral Sci 40, 89-94.