STANDARDIZED PROTOCOL OF ULTRASONOGRAPHIC EXAMINATION OF TEMPOROMANDIBULAR JOINTS AND MASTICATORY MUSCLES

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Abstract

The aim of the study eas to standardize the ultrasonography (USG) protocol for TMJ and masticatory muscles (MM) examination by unifying the clinically relevant USG parameters, determining their norms, and considering gender differences. The study involved 63 volunteers. The selected individuals with normal dental occlusion were divided into two groups: 26 females and 27 males. A 12L3 linear transducer with a frequency of 2.9 to 11.5 MHz (SIEMENS Acuson Juniper) was used. The following USG parameters with clear interpretation were studied: capsular width, condylar translation amplitude, thickness of MM at rest and contraction, percentage of MM thickening at contraction, the condyle and disc position at open and closed mouth, movement of the condyle and disc during mouth opening, subchondral cartilage complex. No significant differences were found between the right and left TMJ and MM parameters in both groups. A significant difference in USG parameters was observed between males and females, except for the amplitude of TMJ condyle translation and the percentage of MM thickening. On the basis of the obtained results, a standardized USG protocol for TMJ and MM was proposed, allowing a high-quality comprehensive USG examination of TMJ and MM structures in patients suspected of temporomandibular disorders.

Keywords: *temporomandibular joint, masticatory muscles, temporomandibular disorders, ultrasonography, dental occlusion.*

1. INTRODUCTION

Currently, ultrasonography (USG) is one of the most prevalent diagnostic techniques for temporomandibular joints (TMJ) and surrounding tissues, offering a range of advantages, including safety, low cost, absence of absolute contraindications, short examination duration, wide equipment availability, psychological patient acceptance, easy monitoring of disease progression or long-term treatment results, ultrasound-guided manipulations, rapid dynamic examination, and suitability for patients with labile psyche, children, and adolescents. The quality of the obtained images is independent of the presence of fixed metal structures in the oral cavity, cranial bones, or adjacent areas, and ultrasound findings are available immediately after examination. It can be performed for patients with a pacemaker or claustrophobia [1-5]. However, this technique has certain limitations, such as the inability to fully examine TMJ bone elements, the dependence of USG images on topographical and anatomical features, operator-dependent quality of examination description, and long learning curve of operator [4,6]. According to meta-analysis data, some authors suggest using USG rather for excluding temporomandibular disorders (TMD) than for confirming them [2]. Therefore, USG can be considered a useful technique for the rapid screening of patients with suspected TMD.

Considering the characteristics of the technique, USG allows the evaluation of soft tissues, subchondral structures, and articular cartilage [1,7].

An important parameter for establishing a clinical diagnosis of "TMJ disc displacement" is the disc position relative to the articular condyle during habitual occlusion and maximal mouth opening [8-10]. According to DC/TMD [11], anterior, posterior, medial, lateral, and combined disc displacements are distinguished. Authors note the difficulty of visualizing medial disc displacement due to the limited ultrasound penetration through bones and other anatomical structures [6]. Additionally, visualization of the lateral and posterior disc displacement is challenging [1,6,9]. Some

researchers describe an increase in the lateral condyle-capsule distance as an indirect sign of disc displacement [12]. However, this approach is criticized by other authors, as anatomical changes such as capsule thickening or effusion are necessary for increasing this distance [13]. There is also evidence that, even in the presence of TMD, no significant increase in lateral condyle-capsule distance was detected [14]. The authors interpret the increase in capsular width as the presence of an effusion [1-3,15-17]. Authors [17] also found a significant correlation between the capsular width and pain intensity in the TMJ area.

USG is used to assess parameters such as the amplitude and nature of the condylar movement [5,6,18]. Amplitude of condylar translation is the extent of displacement from the articular fossa (with closed teeth) to the top of articular eminence during maximal mouth opening. Sonographic characterization of joint movement involves evaluating the smoothness and synchronicity of condylar and disc movement. USG can detect noises during mouth opening or closing, but the nature of these sounds is better determined by auscultation [5,19].

Ultrasound can also evaluate subchondral structures of the condyle to exclude degenerative changes [1]. However, evaluating this parameter is debated, due to the lower sensitivity of USG to degenerative changes compared to magnetic resonance imaging (MRI) or cone-beam computed tomography (CBCT). Nevertheless, considering its high specificity, USG can exclude the presence of degenerative changes in the joint, particularly juvenile idiopathic arthritis in children [20-22].

In addition to TMJ assessment, USG can examine the condition of masticatory muscles, including the masseter muscle (MM) [15,23]. Muscle disorders may arise from TMDs and vice versa [16]. Among TMD patients, 45% of them complain of pain associated with excessive strain in the MM [24]. To alleviate such patients' conditions, authors suggest using botulinum toxin A, assessing the percentage thickening of the masseter muscle during isometric contraction, to evaluate its effect [25,26]. Additionally, by evaluating the percentage thickening of the masseter muscle during teeth clenching in normal occlusion, authors [27] obtained an objective, rapid technique for diagnosing post-traumatic MM contractures, allowing the determination of the degree of muscle damage. Other researchers [28] found a negative correlation between the volume of the masseter muscle and pain sensations in cases of arthralgia.

For a practising dentist dealing with TMD issues, the USG operator must provide a comprehensive assessment of TMJ elements and para-articular structures.

Another challenge in USG diagnostics is the standardization of examination protocols, as no unified USG protocol for a comprehensive examination of TMJ structures and masticatory muscles was found in literature. Standardization requires establishing norms of USG parameters for TMJ and masticatory muscles [13]. Authors emphasize the need for studies involving a significant number of healthy individuals to improve evaluation accuracy [1]. Additionally, it is essential to identify USG parameters with clear interpretation and reproducibility, independent of operator skills or experience. According to a systematic review [29], it is necessary to standardize the measurement sites of masticatory muscle parameters, such as thickness, length, and volume. The authors [30] highlight the importance of USG assessment of TMJ morphometric values and their correlation with internal TMJ disorders, age, ethnicity, and gender.

The most common TMJ disorder is disc displacement (DD), constituting 41% to 55.5% among arthrogenic TMD cases [31-33]. The sensitivity of USG for DD, according to different authors, ranges from 76% to 88% [1,2,16]. Age groups at risk for DD development fall within 15-34 years, with a significant predominance among females [34,35]. Therefore, defining USG parameter norms for this age group is particularly relevant.

Considering the above observations, the objective of our study was to standardize the USG protocol for examining TMJ and masticatory muscles by unifying the clinically useful USG parameters, determining their norms, and identifying their gender-specific features.

2. MATERIALS AND METHODS

63 volunteers participated, undergoing a general dental examination. Fifty-three individuals were selected in the study on inclusion and exclusion criteria.

Inclusion criteria:

1. Age 18-34 years.
2. No history of TMJ disorders.
3. Absence of TMJ complaints.

Exclusion criteria:

1. Malocclusion.
2. Detection of TMJ disorders during USG examination.
3. Presence of noises in TMJ.
4. Deviation in mouth opening trajectory.
5. Presence of systemic musculoskeletal disorders.

The selected individuals were divided into two groups based on gender: 26 females (Group 1) and 27 males (Group 2). In total, 106 TMJs were examined.

A 12L3 linear transducer with a frequency of 2.9 to 11.5 MHz (SIEMENS Acuson Juniper) was used to study the TMJ, adjacent areas, and masticatory muscles. TMJ examinations were conducted with individuals in supine position, with the mouth closed and open, as well as in dynamic motion (during mouth opening and closing). To assess the studied parameter, the transducer was positioned in horizontal and/or frontal planes, with the final measurement done with the transducer in a horizontal plane. At the beginning of examination, the operator made several fan-like movements with the transducer, to determine the position of the TMJ anatomical structures. The position of the transducer and its angle of inclination were adjusted according to the anatomical features of each volunteer. The masticatory muscles (m. masseter) were assessed in the buccal area.

In describing the USG images of TMJ and masticatory muscles, the following terms were used [15]: hyperechoic for areas providing a brighter echo signal, anechoic (no echo) for areas without signal reflection, hypoechoic for areas characterized by a reflection of echo signals darker than the surrounding structures, while the areas with the same or similar echogenicity are called isoechoic.

Based on a literature review and practical experience, the following USG parameters, considered clinically useful with clear interpretation and reproducibility, were selected for analysis.

USG parameters with the mouth closed (in habitual occlusion):

- Disc position relative to the condyle (Fig. 1): Evaluation was performed in two planes. The contour of the condyle is visualized as a hyperechoic strip above the echo shadow of the condyle. The disc is characterized as a hypo- or isoechoic area above the condyle.

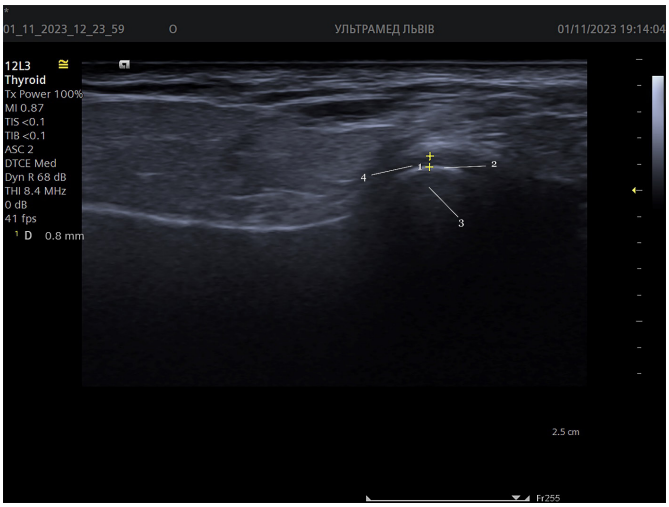

Fig. 1. USG image of TMJ with the mouth closed.
1 – capsular width (distance between yellow crosses);
2 – subchondral cartilage complex;
3 – echo-shadow of the condyle;
4 – disc

- Capsular width above the condyle (Fig. 1): Measurement was carried out in a horizontal plane between the condyle (at 12 o'clock) and the upper limit of the hypo- or anechoic area corresponding to the TMJ disc or joint gap.

USG parameters in dynamic motion:

- Ultrasonographic characterization of condylar movement: Evaluation of the synchrony of the condylar and disc movement in the horizontal plane, as well as the smoothness of this movement.

- Condylar translation amplitude (Fig. 2): Measurement was performed in a horizontal plane between the point on the condylar apex

with the mouth closed and the condylar apex with the mouth maximally open.

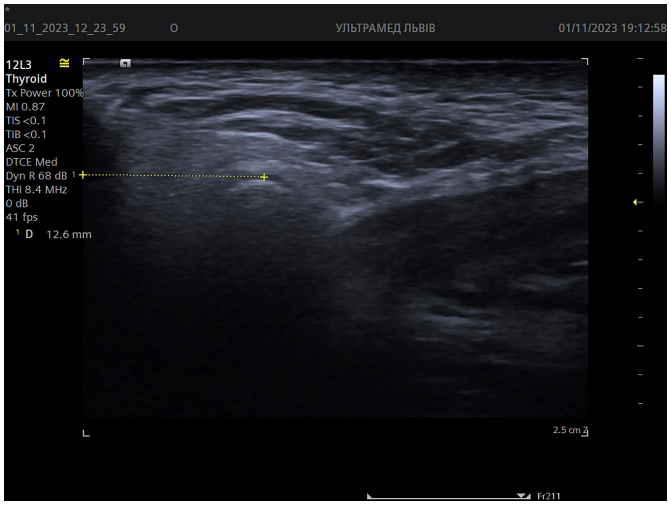

Fig. 2. Condyle location with the mouth open. Condylar translation amplitude

USG parameters with the mouth maximally open:

- condyle position relative to the articular eminence (Fig. 2), evaluation performed in two planes.

- disc position relative to the condyle (Fig. 2), evaluation performed in two planes.

The subchondral cartilage complex (SCC) of the mandibular condyle was assessed in two planes with the mouth closed and maximally open. The SCC is characterized by a hyperechoic signal on the surface of the TMJ condyle (Fig. 1). The clarity of SCC and the uniformity of its thickness were evaluated.

In the buccal area, the following USG parameters of the masticatory muscles were assessed:

- thickness of the masseter muscle at rest (Fig. 3a). Evaluation performed in the horizontal plane. The masseter muscle is visualized as a wide horizontal hypoechoic band. The muscle structure is heterogeneous due to the presence of echogenic linear inclusions. Measurement was performed in the region of the highest muscle thickness along its internal borders;

- thickening of the masseter muscle at contraction in habitual occlusion (Fig. 3b). Measurement was carried out in the horizontal plane in the same area of the masseter muscle where the thickness measurement at rest was performed.

- percentage of masseter muscle thickening, calculated using the formula ((B-A)/B)x100%, where A is the muscle thickness at rest, and B is the muscle thickness at contraction [27].

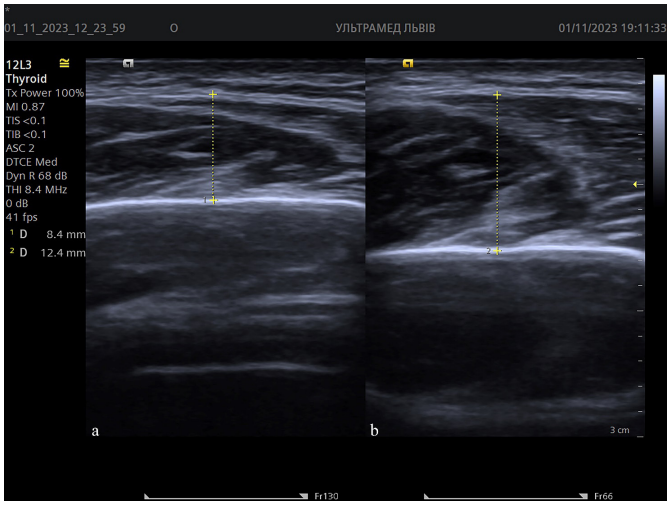

Fig. 3. Thickening of the masseter muscle at contraction (a – masseter muscle at rest, b - masseter muscle at contraction)

Statistical analysis

The mean values and standard deviations (M±σ) of USG parameters were calculated separately for the right and left TMJs and masticatory muscles within each study group. If no significant difference between the left and right sides was observed, the USG parameter data for the left and right sides was combined, and M±σ was calculated for each of the study groups. Next, a comparison of USG parameters for TMJs and masticatory muscles was made between the study groups. The significance of the difference between the left and right sides, as well as between the study groups, was determined using the Student's t-test. If no significant difference was found between Group 1 and Group 2, the USG parameter data for Group 1 and Group 2 was combined, and the overall M±σ was calculated for both groups.

3. RESULTS AND DISCUSSION

No significant difference in USG parameters between the right and left TMJs and masticatory muscles was found in both Group 1 (females) and Group 2 (males) (Tables 1-2). This allowed

the combination of right and left sides within each group. A significant difference in USG parameter values for TMJs and masticatory muscles was found between males and females, except for condylar translation amplitude and the percentage of masseter muscle thickening (Table 3). Therefore, the USG parameters data for Group 1 and Group 2 were combined, and the overall M±σ values were calculated for both condylar translation amplitude and the percentage of masseter muscle thickening (Table 3, column "Total").

Table 1. Mean values (M±σ) of USG parameters for the left and right TMJs in Groups 1 and 2

	Group 1 (Females)			Group 2 (Males)		
	Left TMJ	**Right TMJ**	**p-value**	**Left TMJ**	**Right TMJ**	**p-value**
Capsular widths, mm	0.92±0.23	0.98±0.23	p>0.05	1.09±0.23	1.13±0.20	p>0.05
Condylar translation amplitude, mm	14.16±1.68	13.75±1.35	p>0.05	13.95±1.92	14.53±2.54	p>0.05

Table 2. Mean values (M±σ) of USG parameters for the left and right masticatory muscles in Groups 1 and 2

	Group 1 (Females)			Group 2 (Males)		
	Left masseter	**Right masseter**	**p-value**	**Left masseter**	**Right masseter**	**p-value**
Thickness of masseter muscle at rest, mm	9.65±1.30	9.53±1.42	p>0.05	11.33±1.44	11.43±1.39	p>0.05
Thickness of masseter muscle at contraction, mm	12.98±1.78	12.54±1.80	p>0.05	15.56±2.01	15.60±1.88	p>0.05
Masseter muscle thickening at contraction, %	26.26±5.49	24.40±5.28	p>0.05	27.04±5.17	26.63±3.88	p>0.05

Table 3. Gender differences in USG parameters of TMJs and masticatory muscles (M±σ)

	Group 1 (Females)	**Group 2 (Males)**	**p-value**	**Total**
Capsular widths, mm	0.95±0.23	1.11±0.22	p<0.05	
Condylar translation amplitude, mm	13.95±1.52	14.24±2.25	p>0.05	14.10±1.92
Thickness of masseter muscle at rest, mm	9.59±1.35	11.38±1.40	p<0.05	
Thickness of masseter muscle at contraction, mm	12.76±1.79	15.58±1.93	p<0.05	
Masseter muscle thickening at contraction, %	25.33±5.41	26.83±4.53	p>0.05	26.11±5.01

In all volunteers, during habitual occlusion, the posterior band of the disc was positioned above the condyle. During maximal mouth opening, the mandibular condyle was consistently located under the top of the articular eminence, coinciding with the disc in all cases. The movement of the mandibular condyle in all observed cases was smooth and synchronous with the disc.

The subchondral cartilage complex in USG images in all participants was clear and of uniform thickness.

Based on the literature review and our results, a USG examination protocol for TMJs and MMs is proposed (Table 4).

Table 4. Ultrasound Examination Protocol for TMJs and MMs

Ultrasound Examination Protocol for Temporomandibular Joints and Masticatory Muscles	
Examination No: Patient's Name: DOB: Examination Date:	
Left TMJ	
In habitual occlusion:	**Reference range:**
Disc position relative to the condyle	above the condyle
Capsular width above the condyle, mm	0.9-1.3 mm for males, 0.7-1.2 mm for females
In dynamic motion:	
USG nature of the condylar movement	smooth synchronous movement of the mandibular condyle and disc without TMJ noises
Condylar translation amplitude, mm	12.2-16.0 mm
At maximum mouth opening:	
Position of the condyle and disc relative to the condyle	mandibular condyle positioned under the top of the articular eminence, coinciding with the disc
Subchondral cartilage complex of the mandibular condyle	clear and uniform thickness
Thickness of the masseter muscle at rest, mm	10.0-12.8 mm for males, 8.2-10.9 mm for females
Thickness of the masseter muscle at contraction, mm	13.7-17.5 mm for males, 11.0-14.6 mm for females
Percentage of masseter muscle thickening during maximum contraction, %	21-31%
Right TMJ	
In habitual occlusion:	**reference range:**
Disc position relative to the condyle	above the condyle
Capsular width above the condyle, mm	0.9-1.3 mm for males, 0.7-1.2 mm for females
In dynamic motion:	
USG nature of the condylar movement	smooth synchronous movement of the mandibular condyle and disc without TMJ noises
Condylar translation amplitude, mm	12.2-16.0 mm
At maximum mouth opening:	
Position of the condyle and disc relative to the condyle	mandibular condyle positioned under the top of the articular eminence, coinciding with the disc
Subchondral cartilage complex of the mandibular condyle	clear and uniform thickness
Thickness of the masseter muscle at rest, mm	10.0-12.8 mm for males, 8.2-10.9 mm for females
Thickness of the masseter muscle at contraction, mm	13.7-17.5 mm for males, 11.0-14.6 mm for females
Percentage of masseter muscle thickening during maximum contraction, %	21-31%
USG specialist opinion	

In the daily practice of prosthetic dentistry, patients with TMJ and MM disorders are increasingly encountered [36]. Timely diagnosis of TMDs is particularly crucial for patients undergoing total prosthetic rehabilitation based on natural teeth and/or implants. Untimely detection of TMD often leads to exacerbation of its course during or immediately after prosthetic treatment, resulting in complications in the patient-dentist relationship. Therefore, it is extremely important to involve modern, prompt, available, and sufficiently informative radio-diagnostic techniques in TMD. Despite MRI and CBCT being considered the gold standard for TMD diagnosis, USG plays a significant role due to its numerous advantages [4].

During USG examination of TMJ and MM, various parameters are assessed, which, for the sake of discussion, can be categorized into those with unambiguous interpretation and those causing controversies. Based on the analysis of scientific literature, as well as our own experience, USG parameters with unambiguous interpretation were selected, and their normative evaluation was provided based on the examination of 53 volunteers aged 18-34 years.

According to our study, the capsular width on USG images ranges from 0.9 to 1.3 mm for males and 0.7 to 1.2 mm for females. Literature reports a normative range for capsular width varying from 0.2 mm to 2.0 mm [14,15]. This wide range is attributed to the use of different examination techniques, devices, and reference points for measurement by different authors [3,6,15,16,23]. Moreover, gender differences are often not taken into account in these studies, which impacts measurement outcomes. Our calculations indicate a significant difference between males and females ($p<0.05$).

In the clinic, the course of chronic osteoarthritis can be suspected when a decreased capsular width is detected, while an increased width suggests the presence of intra-articular effusion. In particular, the study [3] has assessed the sensitivity and specificity of USG compared to MRI for detecting joint effusion by determining capsular width. The authors identified two critical values, namely 2.0 mm (sensitivity 55.9%, specificity 94.7%) and 1.75 mm (sensitivity 67.6%, specificity 82.4%). If the capsular width was higher than the critical value, then the diagnosis of joint effusion was established. The critical value of 1.75 mm is approximately 50% higher than our calculated mean norm. Therefore, a difference in US capsular width between right and left joints exceeding 50% could reasonably indicate effusion, especially when aligned with clinical signs. When effusion is suspected in both TMJs, USG results should be compared with the upper limit of the norm.

Regarding the calculation of condylar translation amplitude, our data showed no significant difference between males and females (13.95±1.52 for females, 14.24±2.25 for males, $p>0.05$). Also, other researchers did not indicate gender differences in this parameter and calculated it for both sexes combined. Authors [37] found that the condylar translation amplitude on USG images in the same group of individuals, assessed by the 1 of the 2 USG operators, was 14.0±2.9 mm and 13.8±2.6 mm by the other USG operator, aligning with our results (14.10±1.92 mm). Other authors provide a broader range of normal condylar translation, which is 12.7±3.2 mm for Engel Class I [38].

According to our study, the thickness of the masseter muscle at rest ranges from 8.2 to 10.9 mm and 10.0 to 12.8 mm for females and males, respectively, and during contraction, the thickness is 11.0-14.6 mm for females and 13.7-17.5 mm for males ($p<0.05$). There was no significant difference between males and females ($p>0.05$) when calculating the percentage of MM thickening (total value 21-31%). These results align with the existing literature [15], particularly a study where the masseter muscle thickness at rest in USG examinations of volunteers aged 18-55 was 8.67±1.74 mm and 12.22±2.1 mm during contraction, with a corresponding percentage increase of 29%. However, gender was not taken into account in that study. Other researchers [23] also reported similar significant gender-dependent differences in muscle thickness at rest and during contraction. For females, the thickness at rest ranged from 8.1 mm to 8.5 mm and from 10.5 mm to 10.9 mm during contraction. For males, the thickness at rest ranged from 9.0 mm to 10.0 mm and from 12.4 mm to 13.3 mm during contraction. At the same time, the percentage of MM thickening was

33±25% and did not significantly differ between males and females. Another study [24] found MM thickness at rest to be 17.16±2.33 mm in males and 11.21±2.47 mm in females. Discrepancies among these findings can be attributed to variations in measurement reference points, age groups, and ethnic differences. Moreover, the thickness of the masseter muscle was found to correlate with bite types [39-41]. In particular, some authors [39] indicate that an increase in the severity of mandibular prognathism was associated with a decrease in muscle thickness. An indirect confirmation of this dependency is the increase in the thickness of the masseter muscle after orthognathic surgery in patients with Class 3 malocclusion [41]. A direct relationship between the thickness of the masseter muscle and different vertical facial patterns was found, with thicker muscles in individuals with short faces and vice versa [40].

As for the relationship between the disc and condyle, both closed and open-mouth positions showed consistent data across authors, corroborating our findings. During closed mouth position, ultrasound imaging revealed the disc positioned above the condyle while, during mouth opening, it was located between the condyle and the articular eminence. At the same time, the movement of the disc and condyle was synchronous and smooth [6,8,42]. The condylar surface, or in other words, the SCC, observed in ultrasound images, normally displayed a clear contour with uniform thickness without erosions or other signs of destruction [4,21].

Various ultrasound protocols for TMJ and masseter muscle examination are described in the literature. In the Friedman et al. [6] protocol, joint structures were examined, namely the position of the disc, the condyle, and the presence of condylar changes, but the masticatory muscles were not taken into account. In the protocol of Ertürk et al. [15], capsular width, disc and condyle position and movement, and MM thickness were assessed, but the SCC changes and condylar translation were not studied. Other protocols are related only to separate USG parameters [3,14,24,25].

The urgent need for a unified clinical protocol for the ultrasonographic examination of the TMJ and MM prompted us to standardize the aforementioned USG parameters and develop a comprehensive protocol for daily clinical practice. All parameters specified in the protocol have a clear interpretation and defined norms. The protocol presented in the paper standardizes the USG examination of TMJ and MM, consequently minimizing operator's experience's impact on the examination results.

As of today, this protocol is actively utilized in our daily practice and proves to be particularly valuable in the comprehensive diagnosis of various TMDs, including disc displacements and inflammatory-degenerative TMJ conditions.

4. CONCLUSIONS

The calculated average values of USG parameters' norms for both males and females, along with the presented standardized protocol, allow for a high-quality comprehensive USG examination of TMJ and MM structures in patients suspected of TMDs.

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