Received: 28 July 2020 | Revised: 15 October 2020 | Accepted: 4 January 2021

DOI: 10.1002/ca.23719

ORIGINAL COMMUNICATION

CLINICAL ANATOMY WILEY

Temporomandibular joint anatomy: Ultrasonographic appearances and sexual dimorphism

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Abstract

Introduction: Temporomandibular joint (TMJ) dysfunction is common, with a greater prevalence in females. While magnetic resonance imaging (MRI) is commonly used for clinical investigation, ultrasonography represents a potential alternative in some clinical scenarios. We designed a protocol for ultrasonographic evaluation of the TMJ and assessed its reliability. Presentation was compared between the sexes to establish whether an anatomical dichotomy underlies the female preponderance of TMJ dysfunction.

Materials and methods: Ultrasound imaging of the TMJ was carried out in the longitudinal and oblique planes. Standard images were produced using model skulls and healthy volunteers. Measurements were made between the temporal bone, mandibular condyle, joint capsule and overlying skin, as well as of condylar translation during mouth opening. Both joints were scanned in 50 healthy volunteers. Measurements were repeated to evaluate reliability. A novel classification system was used to assess lateral condylar morphology.

Results: The protocol facilitated reliable visualization of key anatomical features of the TMJ (average intraclass correlation coefficient = 0.75, $\bar{p}$ = 5.4E-03). Distribution of condylar morphology differed between the sexes. The capsular-cutaneous distance ('joint depth') and condylar-temporal bone distance ('interarticular distance') were significantly greater in males than in females.

Conclusions: Ultrasonography provides reliable views of the TMJ in two planes: longitudinal and oblique. Observed sexual dimorphism in TMJ anatomy might be associated with the female preponderance of dysfunction. With a standardized scanning protocol, ultrasound could provide a rapid, cost-effective alternative to MRI as a point-of-care imaging tool in TMJ clinics.

KEYWORDS
condyle, sexual dimorphism, temporomandibular joint, TMJ dysfunction, ultrasound

1 | INTRODUCTION

The temporomandibular joint (TMJ) is one of the most frequently moved joints in the human body, with particular involvement in mastication and speech. It is formed on each side by the mandibular condyle projecting superiorly toward the concave glenoid fossa of the temporal bone, together comprising a bilateral craniomandibular articulation. The TMJ is encased by a fibrous joint capsule which is lined with synovial membrane. The interarticular space is divided into superior and inferior synovial fluid-filled compartments by a fibrocartilaginous articular disc (Bordoni & Varacallo, 2019). The morphology of the mandibular condyle is thought to affect TMJ dynamics (Villamil, Nedel, Freitas, & Macq, 2012), and has previously been categorized according to the profile of the superior surface of the condylar head viewed in the coronal plane (Yale, Allison, & Hauptfuehrer, 1966). However, as the sonographic view of the TMJ does not permit visualization of the whole superior surface, we developed a novel classification system to characterize variation in the lateral profile of the condylar head.

Imaging of the TMJ has progressively evolved in parallel with the development of new technologies. Conventional radiographs, computerized tomography (CT) scanning, magnetic resonance imaging (MRI) and ultrasonography have all been used, each with their own advantages and disadvantages (Talmaceanu et al., 2018). Because of its high resolution, clear contrast between tissues, and the ability to acquire functional information from dynamic imaging without the need for ionizing radiation or contrast media, MRI has become the imaging modality of choice for assessment of the TMJ (Bag et al., 2014). While ultrasound imaging has been used to evaluate TMJ effusions, examine the fibrocartilaginous disc, and guide intra-articular injections (Bag et al., 2014), it has yet to be adopted as a mainstream point-of-care assessment tool. As ultrasound cannot penetrate bony structures, the anatomical geometry of the TMJ is generally considered unconducive to comprehensive imaging (Katzberg, 2012). Nevertheless, the potential to obtain clinically useful real time images of the TMJ during movement, rapidly and cost-effectively (Talmaceanu et al., 2018), is appealing compared to more expensive, time consuming imaging modalities.

A certain amount of confusion exists over the interpretation of sonographic TMJ images (Meyers & Oberle, 2016). Therefore, to be useful in routine clinical practice, adoption of a standardized imaging protocol based on reference images could mitigate the reported operator-dependence of the use of ultrasound to diagnose TMJ dysfunction (Kundu, Basavaraj, Kote, Singla, & Singh, 2013), and improve its clinical applicability.

TMJ dysfunction is common, with symptoms reported in up to 35% of the population (Adèrn, Stenvinkel, Sahlqvist, & Tegelberg, 2014; Bertoli et al., 2018). Females are consistently found to be at a higher risk of developing dysfunction than males (Bueno, Pereira, Pattussi, Grossi, & Grossi, 2018; De Kanter et al., 1993). The pathophysiology of TMJ dysfunction is diverse, and may include disorder of associated bones, capsule, development, disc, masticatory muscles and trauma, as well as systemic conditions (Peck et al., 2014). The reasons for this observed discrepancy in prevalence between the sexes remain unclear, but variable prevalence reported in different ethnic groups, for example between age-matched Chinese and Swedish cohorts (Hongxing, Astrøm, List, Nilsson, & Johansson, 2016), may support an anatomical hypothesis. In this study, condylar morphology and ultrasonographic measurements were compared between the sexes to screen for an anatomical dichotomy.

2 | MATERIALS AND METHODS

2.1 | Ultrasound scanning

Ethical approval was obtained from the Human Biology Research Ethics Committee of the University of Cambridge Council of the School of Biological Sciences (Application No. HBREC 2019.29). A total of 50 healthy volunteers were recruited by means of an online link disseminated via email and social media. All participants were over 18 years of age. The following exclusion criteria were applied: a previous TMJ disorder diagnosis or jaw fracture, recent dental, facial or ear surgery, present frequent use of a bite guard or orthodontic appliance, pregnancy, or current skin infection in the TMJ area. Participants gave written informed consent prior to scanning of both the left and right TMJ (n = 100).

Images were acquired using a 5–13 MHz linear ultrasound probe (General Electric Logiq V2, General Electric Healthcare, Wauwatosa, Wisconsin). Ultrasound scanning was conducted in two planes, referred to as longitudinal and oblique (Figure 1), similar to those described in previous studies (Melis, Secci, & Ceneviz, 2007). The longitudinal plane is approximately coronal, running superior to inferior on sonographs, while the oblique plane is orientated according to the direction of condylar translation in mouth opening (with resultant variation between individuals), posterosuperior to anteroinferior. Ultrasound images were acquired with the participant in the supine position, with the operator and ultrasound machine positioned on the same side as the joint being scanned. The vertical height of each subject was also recorded.

First, anatomically accurate plastic model skulls (Adam Rouilly Limited, Kent, UK) were imaged, in order to characterize the longitudinal and oblique sonographic views of the TMJ without confounding soft tissue. Models were submerged in water to facilitate scanning, as depicted in Figure 2. Images in both planes were produced to characterize the presentation of bone, as a useful reference when evaluating sonographs of joints *in vivo*.

In the longitudinal plane, four measurements were made (Table 1): between the inferior-most and superior-most visible aspects of the temporal bone and condyle respectively, the lateral-most aspect of the condyle and overlying joint capsule, lateral-most joint capsule and overlying skin, and inferior-most aspect of the condylar head and overlying joint capsule. In the oblique plane, similar measurements between the lateral-most aspect of the condyle, capsule and skin were made with the mouth open and closed (Table 2). In addition, condylar translation during mouth opening was measured by placing digital calipers over video ultrasound images recorded in the oblique plane, during which the probe was held stationary.

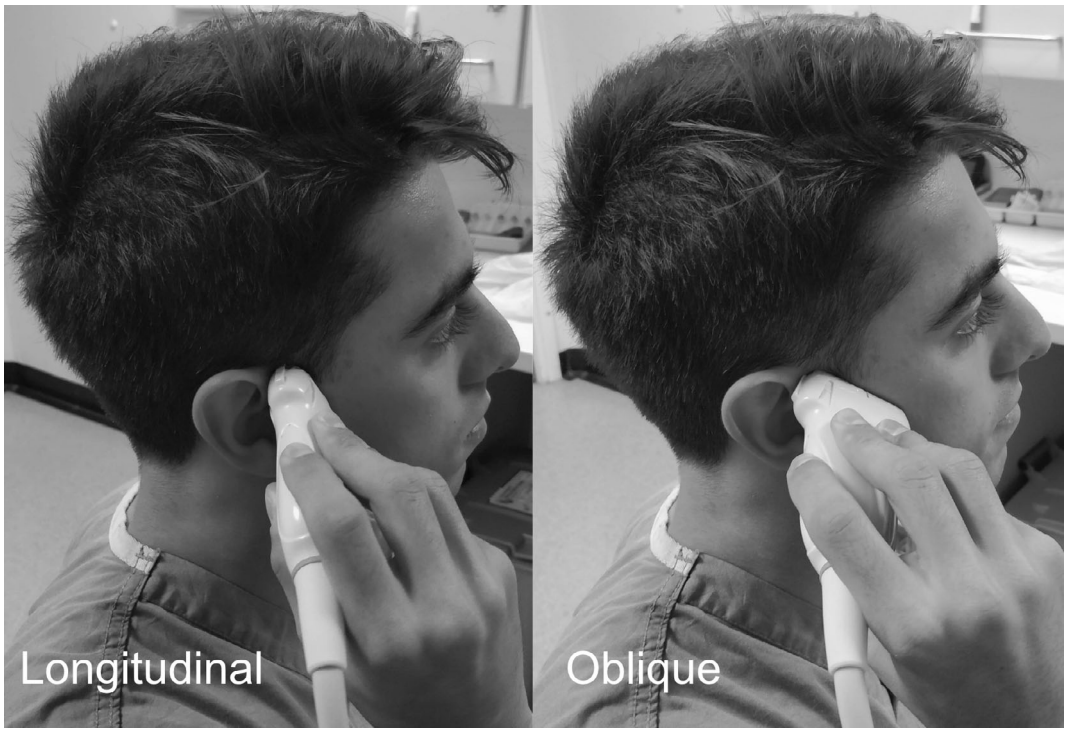

FIGURE 1 Ultrasound probe placement as defined in the protocol. Longitudinal (left) and oblique (right) planes are shown. The oblique plane varies according to the precise plane of translation of the mandibular condyle during mouth opening

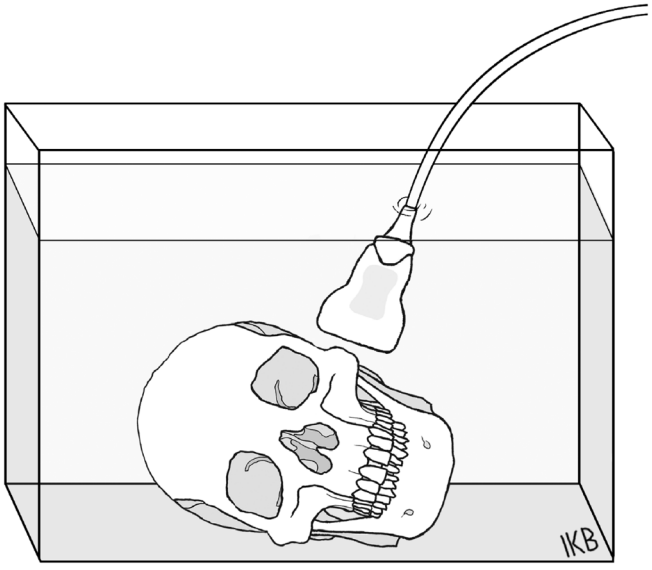

FIGURE 2 Schematic diagram depicting how sonographic images were obtained of the temporomandibular joints of an anatomically accurate plastic skull, submerged in water

An ordinal scale of four categories was produced, based on observations of sonographs and dry bone samples, to characterize variation in the lateral aspect of the condylar head: flat, round, blunt spike, and sharp spike. Exemplar profiles, traced along dry bones, for each category are depicted in Figure 3.

For a quantitative assessment of the reliability of the protocol, measurements were repeated 10 weeks after the last scanning session, using saved images of 14 TMJs from 7 participants, with the operator blinded to previous measurements.

TABLE 1 Measurements made in the longitudinal plane

Name	Abbreviation	Description
Capsular-cutaneous distance (joint depth)	CapCutL	Between lateral-most aspect of the joint capsule and overlying skin.
Lateral joint space	ConCapL	Between lateral-most aspect of the condyle and corresponding joint capsule.
Inferolateral joint space	IConCap	Between inferior-most point of the condylar head and overlying joint capsule.
Condylar-temporal bone distance	ConTem	Between superior-most and inferior-most visible aspects of the condyle and temporal bone respectively.

2.2 | Statistical analysis

Most parameters exhibited statistically significant ($p < .05$) deviation from $W = 1$ in Shapiro-Wilks tests, indicating non-normal distribution. Wilcoxon signed-rank tests were thus used to quantitatively analyze

sex differences, and Kendall rank correlation coefficients were calculated to characterize association between variables. $p < .05$ was accepted as statistically significant.

To evaluate reliability, repeated measurements were compared by calculation of two-way random effects intra-class correlation coefficients for absolute agreement (ICC 2,1), with qualitative classification according to conventional definitions (Koo & Li, 2016): poor ICC < 0.5; 0.5 < moderate ICC < 0.75; 0.75 < good ICC < 0.9; 0.9 < excellent ICC.

Statistical analysis was conducted in R (v3.5.1), with figures produced in Affinity Designer (v.1.7.3).

TABLE 2 Measurements made in the oblique plane

Name	Abbreviation	Description
Capsular-cutaneous distance; mouth closed	CapCutO	Between lateral-most aspect of the joint capsule and overlying skin (closed mouth).
Condylar-capsular distance; mouth closed	ConCapO	Between lateral-most aspect of the condyle and corresponding joint capsule (closed mouth).
Capsular-cutaneous distance; mouth open	OpenCapCutO	Between lateral-most aspect of the joint capsule and overlying skin (open mouth).
Condylar-capsular distance; mouth open	OpenConCapO	Between lateral-most aspect of the condyle and corresponding joint capsule (open mouth).
Condylar translation in maximal mouth opening	Trans	Distance travelled by the condyle during mouth opening.

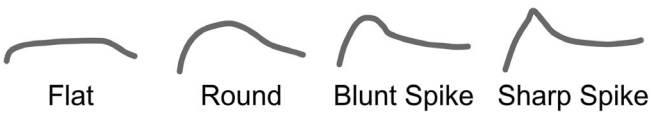

FIGURE 3 Exemplar profiles for each morphological category. Orientation is analogous to the longitudinal sonographic plane: left = superior, right = inferior. All four categories were frequent in both dry bone samples and ultrasound scans

3 | RESULTS

The typical sonographic appearance of the TMJs in a submerged plastic model skull is shown in Figure 4. In the longitudinal plane, the temporal bone is seen superior to the mandible, with an intervening space which contains the articular disc and two joint compartments. In the oblique plane, the condyle is imaged, often without more of the mandible or temporal bone visible, depending on the angle of the probe. These images provided a useful point of reference for interpretation of subsequent *in vivo* imaging.

Standard images of volunteers' TMJs are depicted in Figure 5 (longitudinal) and Figure 6 (oblique), with anatomical measurements illustrated. In contrast to the sonographic images obtained from submerged skulls, soft tissues such as the joint capsule can be seen. Notably, in the oblique plane, the condyle can be visualized throughout its full range of translation during mouth opening.

Intraclass correlation coefficients calculated for each measured parameter are displayed in Table 3. Moderate to good agreement was indicated throughout, suggesting that measurements were reliable.

Significant differences between the sexes were recorded in capsular-cutaneous distance in the longitudinal and oblique (with mouth open and closed) planes (Table 4), indicating that the TMJ is situated deeper to, that is, further from, external skin, in males. Condylar-temporal bone distance was also significantly greater in males than females, indicating a greater distance between the temporal bone and condyle.

Males were taller than females on average (Wilcoxon signed-rank test, $W = 520.5$, $p = 4.424E\text{-}05$). Significant correlations were

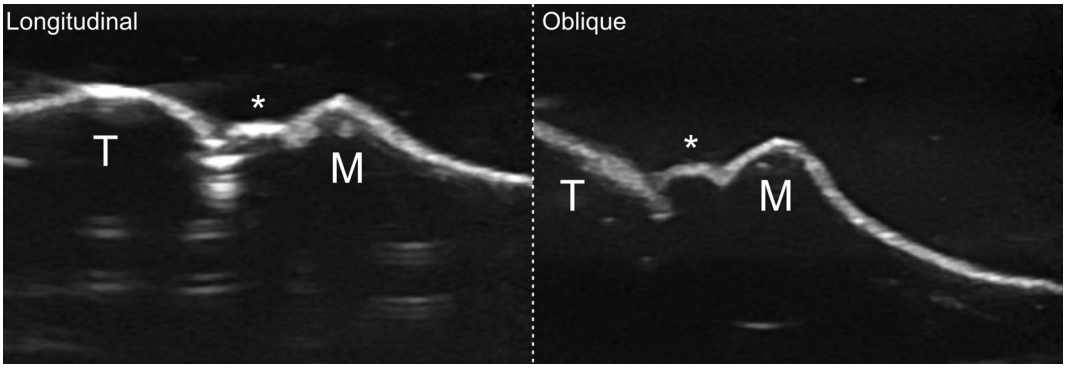

FIGURE 4 Sonographs of plastic model skulls (which lack confounding soft tissue such as the joint capsule) submerged in water. Views in the longitudinal and oblique plane are depicted, with annotations to indicate the mandible (M), temporal bone (T) and connecting plastic (asterisk), which does not feature in normal anatomy. In oblique scans, the temporal bone and body of the mandible are often not visible at all, depending on the exact angle of the probe

observed of height with condylar-temporal bone distance (Kendall rank correlation coefficient, τ = 0.202, p = .004), capsular-cutaneous distance in the longitudinal plane (τ = 0.141, p = .043), capsular-cutaneous distance in the oblique plane, mouth closed (τ = 0.166, p = .017), whereas correlation with capsular-cutaneous distance in the oblique plane, mouth open was not significant (τ = 0.134, p = .055).

The distribution of morphologies within each sex was presented in a bar chart for direct comparison (Figure 7). All morphologies occur in both sexes, but with differences in their distribution. Flat and round profiles are most common in males, with lower frequencies of blunt or sharp spikes. In contrast, most female condyles exhibited round or blunt spike profiles, with relatively few flat or sharp spikes.

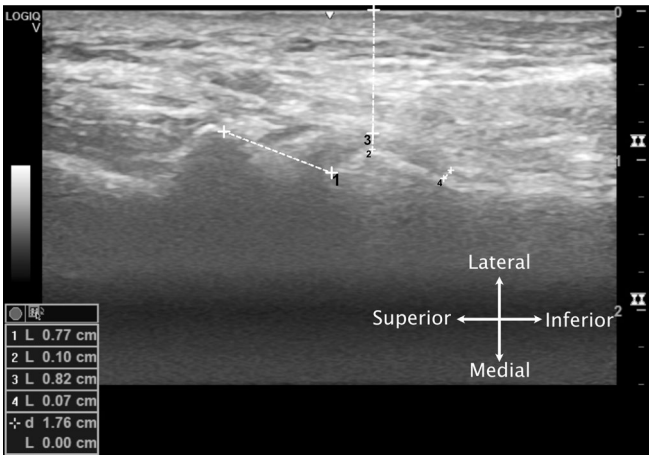

FIGURE 5 Measurements made in the longitudinal plane: (1) condylar-temporal bone distance; (2) condylar-capsular distance; (3) capsular-cutaneous distance; (4) inferolateral joint space

4 | DISCUSSION

This novel ultrasound protocol facilitated reliable visualization of the TMJ in the longitudinal and oblique planes, as indicated by high intraclass correlation coefficients for the measured distances between temporal bone, condyle, joint capsule and skin. Furthermore, it provides a simple method with associated standard images by which the lateral-most aspect of the TMJ can be visualized and assessed with ultrasonography.

Differences in the male and female distribution of condylar morphology were evident (Figure 7). Future studies could be conducted to demonstrate this quantitatively by calculating the minimum angle formed by the lateral profile of the condyle. Any functional

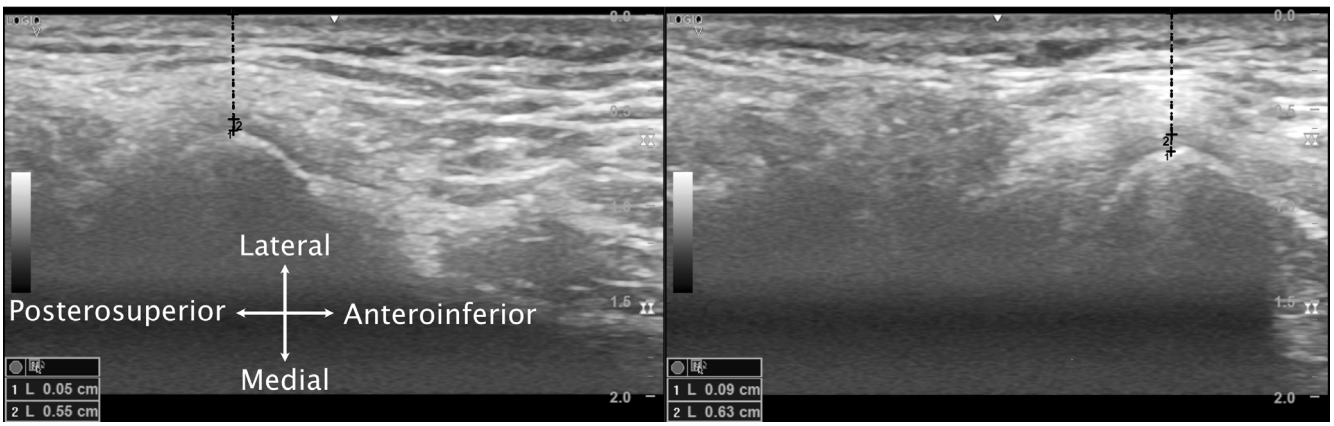

FIGURE 6 Measurements made in the oblique plane, with mouth closed (left) and open (right): (1) condylar-capsular distance; (2) capsular-cutaneous distance

TABLE 3 Intraclass correlation coefficients comparing repeated measurements

Parameter	icc	*F*	*p*	Agreement
Capsular-cutaneous distance (L)	0.874	15.1	4.90E-06	Good
Condylar-capsular (L)	0.884	15.9	3.90E-06	Good
Condylar-temporal bone distance	0.841	12.5	2.36E-05	Good
Inferolateral joint space (L)	0.799	12.8	0.0017	Good
Capsular-cutaneous distance (O)	0.558	3.6	0.0115	Moderate
Lateral joint space (O)	0.520	3.4	0.0166	Moderate
(Open mouth) Capsular-cutaneous distance (O)	0.877	15.0	5.30E-06	Good
(Open mouth) lateral joint space (O)	0.536	3.3	0.0185	Moderate
Condylar translation	0.839	11.5	2.59E-05	Good

TABLE 4 Wilcoxon signed-rank tests comparing parameters between the sexes

Parameter	*W*	*p*
Capsular-cutaneous distance (long.)	1715.0	.0011
Lateral joint space (long.)	1425.5	.2032
Condylar-temporal bone distance	1556.0	.0301
Inferolateral joint space	1369.5	.3783
Capsular-cutaneous distance (oblique; mouth closed)	1715.5	.0011
Lateral joint space (oblique; mouth closed)	1296.0	.7102
Capsular-cutaneous distance (oblique; mouth open)	1608.5	.0113
Lateral joint space (oblique; mouth open)	1168.5	.6119
Condylar translation	1323.0	.5777

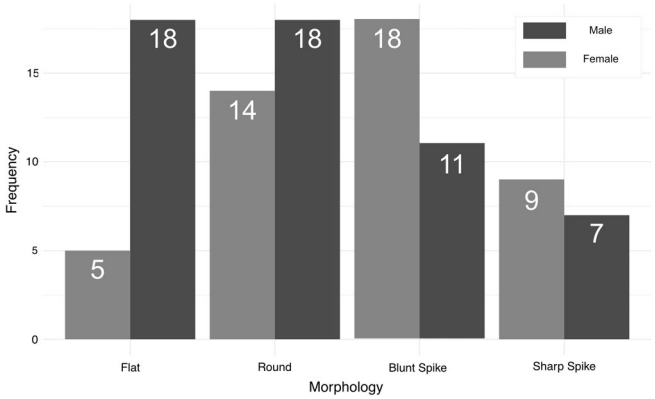

FIGURE 7 Bar chart comprising the distribution of condylar morphologies in males (dark) and females (light). Distributions tend toward flat/round or round/blunt spike profiles respectively, though all categories occur frequently in both sexes

significance is unclear, since the lateral aspect of the condyle does not interact directly with the articular disc or temporal bone.

Greater capsular-cutaneous and condylar-temporal bone distances were observed in male participants, in part due to greater general size, as indicated by the relationship with height. Condylar-temporal bone distance is an inter-articular measurement, whereas capsular-cutaneous distance represents joint depth, mostly determined by the masseter muscle as it overlies the mandible. Both exhibited correlation with height, suggesting that a component of the difference between the sexes is a consequence of greater general size. Variation in anatomy between the sexes may relate mechanistically to the large difference in the prevalence of dysfunction observed between the sexes.

Specific anatomical measurements outlined here could be useful in a diagnostic context. Some meta-analyses suggest that ultrasound is a potential alternative to MRI for diagnosing disc displacement (Li et al., 2012), but a very wide range of accuracy is reported: 13–100% (Melis et al., 2007), as a consequence of the technique being highly operator-dependent (Kundu et al., 2013). The use of a formal ultrasound protocol may offer an opportunity to limit variation between observers. In addition, prior to this study, ultrasonographic evaluation has been predominantly qualitative (Friedman et al., 2020). This study described parameters which could be used to detect the presence of pathology. With a standardized scanning protocol, ultrasound may represent a cost effective, rapid alternative to MRI as a point-of-care imaging tool in TMJ dysfunction clinics.

A limitation of this study is that evidence of TMJ dysfunction is frequently observed in MRI scans of asymptomatic individuals (Salé, Bryndahl, & Isberg, 2013). Therefore, without corresponding MRI reference images of the participants, it was not possible to preclude the presence of occult TMJ pathology in the study population.

Further investigation is required to determine if there is any relationship between anatomical parameters defined here and pathological features such as disc displacement or joint effusion, as well as symptoms, such as impeded mouth movement and clicking. Future ultrasound studies could also be used to determine how anatomical differences between the sexes may contribute to the differential prevalence of TMJ dysfunction.

ACKNOWLEDGMENTS

The authors extend our thanks to Miss Isla K. Bresland for creating Figure 2. We thank Mrs. Lisa Childs, Dr. Richard Lloyd and Mr. James Skeates for their help in the Human Dissection Room, University of Cambridge. We are grateful to the 50 volunteers who gave up their time to participate in this study. Finally, we would like to thank Mr. Anosh Bonshahi for his assistance in participant recruitment.

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How to cite this article: Thirunavukarasu AJ, Ferro A, Sardesai A, et al. Temporomandibular joint anatomy: Ultrasonographic appearances and sexual dimorphism. *Clinical Anatomy*. 2021;34:1043–1049. https://doi.org/10.1002/ca.23719