Research Paper

Sonographic Measurement of Condylar Translation, Joint space and Mouth Opening in Healthy and Subjects with Temporomandibular Joint Disorders

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ABSTRACT

Objectives: A sonographic approach can be used to quantify joint movement, muscle thickness, and available joint space. This study aimed to compare the amount of mouth opening, joint articular distance, and both anterior and inferior translation of the mandibular condyle between healthy participants and individuals with temporomandibular joint (TMJ) disorders.

Methods: A cross-sectional study design was used with 52 participants (control: 26 healthy and TMJ: 26 symptomatic individuals) recruited using convenience sampling. The joint space distance and the anterior and inferior condylar translation on both sides were evaluated using sonography during maximum mouth opening and closing. Mouth opening was measured with a graduated ruler. Reliability was performed on a subgroup (n=10) with an interval of 3-7 days.

Results: The reliability was good to excellent (ICC=0.57-0.94). The highest reliability was related to the joint space distance. The mean values for mouth opening were 43.1 and 35.3mm, respectively for healthy and TMJ patients. The anterior condylar translation was 7.14-7.57mm, inferior condylar translation was 2.35-2.66mm, and the joint space distance was 49.4-0.44mm. No significant differences were found between the left and right sides in either group. The mouth opening and joint space values were significantly higher in the healthy group while the rate of anterior transition movement was higher but not significant. Furthermore, there was a significant negative relationship between pain, mouth opening, and joint distance.

Discussion: Sonography can be considered an accurate tool for the assessment of joint space and condylar translation in individuals with symptomatic TMJ disorders.

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Highlights

• Temporomandibular joint disorders (TMJD) are among the most common oral-facial conditions and are considered a major concern in health and rehabilitation.

• Evaluation of joint play movements in patients with TMJD can provide practical and useful information for diagnosing and evaluating treatment outcomes.

• Ultrasonography is recognized as being a safe method for assessing joint motion and soft tissue thickness, both in the clinic and research settings.

• Healthy subjects have a significantly reduced range of motion (ROM) and translation movement relative to TMJD subjects.

• Both Joint sides should be considered in the evaluation and screening of patients.

Plain Language Summary

Involvement of the temporomandibular joint (TMJ) structures results in pain during activity or at rest, muscular stiffness, and potentially joint locking. Patients usually seek for other problems, such as dental pain or ear infection while the pathology is in the TMJ. Appropriate diagnosis of such disturbances and involvement can reduce the treatment costs and patient concerns. One of the valuable instruments in the diagnosis of joint dysfunction of TMJ is sonography. Using ultrasonography, joint passive motion, normal tracking of the joint surface, and joint spaces are determined and any abnormal movement pattern will be diagnosed immediately with high precision.

1. Introduction

The presence of temporomandibular joint disorders (TMJD), including pain within the region, are among the most common oral-facial conditions and include several diseases with different causes and pathologies [1]. Involvement of the masticatory muscles and the TMJ structures can cause individuals to seek treatment for pain during activity or at rest, muscular stiffness, movement limitation, and potentially joint locking [2, 3]. Chronic joint involvement may affect the individual's quality of life, which can lead to psychological stress, depression, and reduced social interaction [4]. The reported prevalence of symptoms and joint involvement has been approximately 31% for adults/elderly and 11% for children/adolescents, and the most prevalent TMJD was disk displacement [5].

Evaluating the outcome of TMJ-directed treatment requires accurate knowledge of the changes made in the joint and the measurement of appropriate and valid related variables. One such traditionally used variable is the amount of mouth opening and the joint range of motion (ROM) with several previous studies using these two measures to determine the effectiveness of their treatment protocol and subsequent individual improvement [6, 7]. The amount of mouth opening has been measured using tools, such as rulers, meters, and goniometers [8]. However, the accuracy of these measures as a reflection of the condition of the joint and the effectiveness of interventions is questioned as they cannot indicate the condition of the joint condyles when the mouth is open. Consequently, it is necessary to investigate more accurate techniques through the use of more appropriate tools [9]. When the mouth is opened, the condyles first roll forward on the discs, and then the condyle-disc assembly glides forward [10]. In patients with a TMJ disorder, the rhythm of movement and motor coordination about the joint is altered. In addition, motor sequence changes during mouth opening cause movement dysfunction and a reduced joint ROM [8].

The distance of joint surfaces at rest can be considered an indicator in the evaluation of disorders of this joint, and reducing the distance of joint surfaces can affect both function and movements bilaterally. Examination of joint movements, including rotation of the condyle, and anterior and lower displacement of the articular condyles, can effectively identify joint problems. Evaluation of arthrokinematic joint movements in patients and their comparison with healthy individuals can provide practi-

cal and useful information for diagnosing and evaluating treatment outcomes. This issue has received less attention in previous studies despite accurate and valid evaluation methods having a known capacity to improve measurement accuracy [8, 11]. Currently, accurate diagnostic methods provided by ultrasound imaging can determine the thickness of the muscles, the distance between joint surfaces, and the amount of joint displacement and movement. Ultrasonography is safe for use on joints and tissues, both in the clinic and research settings [9, 12, 13].

In this study, we investigated the reliability of using ultrasound to evaluate the joint position and joint space and the anterior and inferior condyles during the opening, and compare these measures between healthy participants and those with a diagnosed TMJD.

2. Materials and Methods

Participants

A total of 52 participants were recruited from a population of convenience with an age range of 18-45 years, a control group of 26 healthy individuals (age=33.38±8.03), and 26 patients with a symptomatic TMJD (34.38±6.81 years). All the patients were diagnosed and referred by the physician. For the healthy controls, inclusion criteria were the absence of joint pain and noise, complete opening of the mouth, and no pain [13, 14], and the exclusion criterion was a history of any orthodontic treatment. For the symptomatic TMJD group, inclusion criteria were the presence of a TMJD that had been diagnosed by a physician and a history of symptoms for at least six months [14], and the exclusion criteria were a history of radiotherapy to the head or neck [15], the presence of Pain on a Numerical Rating Scale (P-NRS)>4 when opening the mouth, inability to chew, and bone changes on radiography examination day [16]. The informed consent form was obtained from all participants in the study, and the ethics committee of the University of Social Welfare and Rehabilitation Sciences approved the study (Code: IR.USWR.REC.1399.205).

Ultrasonography evaluation

The ultrasonography used a sampling frequency of 25 frames per second to provide a sufficiently detailed sonographic evaluation. The device was an Ultrasonix ES500 machine (Ultrasonix Medical Corporation, Vancouver, BC, Canada) with a linear bandwidth of 6-12 MHz set with a frequency of 10Hz and a depth of 3cm. For this purpose, a linear probe was used, which is appropriate for surface imaging and has a lateral penetration depth [17]. To perform the tests, participants sat upright with their heads in neutral. An evaluation was performed from both sides by placing the transducer transversely on the joint and the zygomatic arch to make the outer edge of the condyle visible (Figure 1). Imaging was performed for 10 s at the maximum open and closed mouth positions. A total of 3x10-second images were collected from each side with the average values obtained and used for statistical analysis. After determining the condyle in both the open and closed mouth position, an ellipse was drawn around the mandible in both frames and two lines were drawn horizontally and vertically from the center of the mandible to evaluate the degree of anterior and vertical (inferior) translation of the mandibular condyle. The intersection of the two horizontal and vertical lines was measured and recorded as anterior and inferior displacement (Figure 2) [12]. All assessments were performed by the same ultrasound-trained person who was blinded to the subjects. In a pilot test, the test-retest measurement was repeated at 3-7 intervals to evaluate the test-retest reliability.

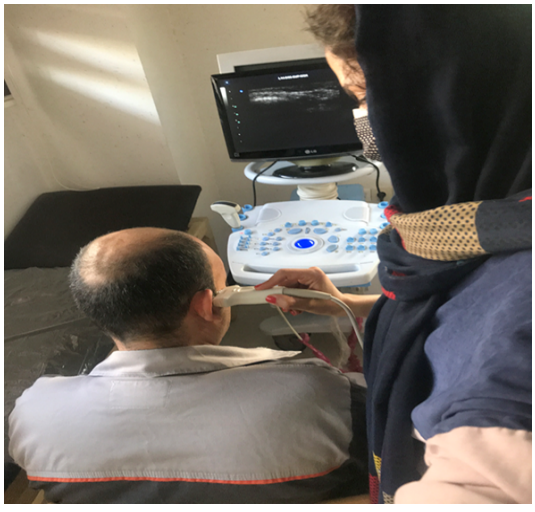

Figure 1. Test condition in sitting posture

Figure 2. Ultrasound image indicating mandible displacement

Red line = anterior translation of the condyle

Yellow line = inferior translation of the condyle

Mouth opening amount

To assess the amount of mouth opening, participants were asked to open their mouths to a maximum for three separate measures. The distance between the edges of the upper and lower teeth was measured in millimeters with a ruler. The average of the three measures was obtained and recorded and considered the maximum amount of mouth opening [12].

Pain assessment

The amount of pain was recorded with a pain numerical rating scale (P-NRS) with the participant in resting, maximal mouth opening, and maximal grip positions. The maximum score of 10 on the P-NRS was considered the criterion. The studied sonographic parameters were repeated by the same tester on ten healthy individuals on two different days with an interval of 3-7 days to evaluate the test-retest reliability of the data, where an average of three repetitions of measurements per day was used to compare the correlation.

Statistical analysis

Descriptive statistics of the variables analyzed included the mean, median, and standard deviation of data. The Kolmogorov-Smirnov test was used to evaluate the normal distribution of data, and according to the normality of the data, to determine the presence or no presence of a Gaussian distribution and whether parametric statistics can be used. An independent t-test was used to compare the differences between the two groups. The intra-class correlation ($ICC_{2.1}$) coefficient was used to evaluate the test-retest reliability of the data. A Pearson's correlation test was used to evaluate the correlation between pain and other variables. The significance level was defined at 0.05, and all data analyses were performed using SPSS software, version 16.

3. Results

The results of the test-retest reliability showed that the data had an acceptable level of reliability (ICC=0.70). The ICC value between the mean of the three repetitions in the two sessions for the variables of mouth opening, joint spacing, and anterior and lower joint translation was 0.57, 0.94, 0.91, and 0.70, respectively. These were determined as acceptable results. The demographic characters of participants and descriptive results of measured variables are presented in Table 1.

As can be seen in Table 1, the average age of the patient group was 34.38 years, which is older than the healthy group, but there was no significant difference. Also, the rate of joint opening and joint distance in the patient group was less than in the healthy group.

Table 1. Descriptive values of data for healthy and symptomatic groups

Group	Variables	Min	Max	Mean±SD
Healthy	Age (y)	18	45	33.11±8.03
	Height (cm)	154	191	172.88±9.82
	Weight (kg)	49	97	75.80±13.28
	Mouth opening amount	37	48	43.10±3.60
	Right articular space	0.37	0.58	0.49±0.04
	Right anterior translation	5.08	8.94	7.14±0.87
	Right inferior translation	1.31	3.19	2.35±0.50
	Left articular space	0.37	0.59	0.49±0.05
	Left anterior translation	5.44	9.48	7.05±0.83
	Left inferior translation	1.45	3.30	2.29±0.52
Symptomatic subject	Age (y)	20	45	34.38±6.81
	Height (cm)	148	196	172.38±12.48
	Weight (kg)	50	99	80.0±15.95
	Mouth opening rate	25	49	35.3±6.9
	Right articular space	0.32	0.57	0.44±0.07
	Right anterior translation	5.14	9.50	7.57±1.09
	Right inferior translation	1.64	3.81	2.66±0.53
	Left articular space	0.3	0.56	0.42±0.07
	Left anterior translation	5.71	9.16	7.56±0.96
	Left inferior translation	2.02	3.85	2.85±0.50

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The mean amount of pain in the patient group on the left side was 2.27±1.76 and pain on the right side was 2.23±1.79. Comparison of the results of the parameters of joint spacing, anterior displacement, and lower joint displacement on both right and left sides showed no significant difference between left and right in each group. A comparison of results between the healthy control and the participant groups was done with an independent t-test, which showed no significant difference between the two groups in terms of age, height, and weight; the two groups were matched. All variables except the anterior displacement variable on the right side showed a significant difference between the two groups (P=0.12) (Table 2).

The Pearson correlation coefficient was used to evaluate the correlation between pain and other variables in the symptomatic TMJ group. In this study, the results showed a significant inverse correlation between the amount of pain (right or left) and the amount of mouth opening (r=-0.57, P=0.002). Further, there was a negative inverse relationship between the amount of right-side joint distance and right-side pain (r=-0.68, P<0.001), and in the left (r=-0.80, P<0.001). There was no significant relationship between anterior and inferior displacement and pain.

Table 2. Comparative results between the two groups

Variables	Mean	95% Confidence Interval		Sig.
		Lower Limit	Upper Limit	
Age (y)	-1.26	-5.41	2.88	0.54
Height (cm)	0.50	-5.75	6.75	0.87
Weight (kg)	-4.19	-12.37	3.99	0.30
Mouth opening rate	0.77	0.46	1.08	0.000
Right articular space	0.04	0.08	0.01	0.004
Right anterior translation	-0.42	-0.97	0.12	0.12
Right inferior translation	-0.31	-0.60	-0.01	0.03
Left articular space	0.06	0.03	0.1	0.00
Left anterior translation	-0.55	-0.84	-0.26	0.00
Left inferior translation	-0.51	-0.01	-0.008	0.04

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4. Discussion

TMJD can be caused by a variety of factors, including inadequate mouth closure, masticatory muscle involvement, and involvement of the joint structures [18]. As a result of these changes, the balance of joint movements is disturbed during the opening and closing of the mouth and may cause headaches, joint clicking, and destructive changes in the joint and lateral displacement of the mandible.

The first aim of the present study was to determine the test-retest reliability of using an ultrasonography device to evaluate joint movements and the comparative evaluation of the joint movements between healthy and patients.

Data reliability is one of the important characteristics of evaluation where the measured values are expected to be relatively constant. In this study, intra-rater reliability was investigated. The value of the $ICC_{2.1}$ of the variables for the mouth opening amount (0.57), joint distance (0.94), anterior joint displacement (0.91), and lower joint displacement (0.70) were all obtained and found as acceptable results compared to previous research. In the study by Ho et al. , the reliability of ultrasonography data for the rate of anterior translation of the TMJ during mouth opening was examined in healthy individuals. They demonstrated that the reliability for both the intra-rater and inter-rater was excellent (ICC=0.93-0.92) [12]. This was consistent with the results of the present study on anterior joint displacement (ICC=0.91). Further, Ho et al. stated that one reason for the high reliability was the careful selection of the mandibular condyle and the correct evaluation that is based on the location of the landmarks, which were the criteria followed in this study. In addition to anterior translation, the reliability of lower joint translation was also considered, which was not investigated in the study by Ho et al. [12]. Chen et al. also reported the reliability of anterior translation during the movement of mouth opening and closing to be at an acceptable and excellent level (ICC=0.98-0.97) [8]. In the study by Landes et al., the recurrence of mandibular condyle transmission during full mouth opening, protrusion forward, and lateral movements were both evaluated. They demonstrated that there was an optimal absolute error of condyle displacement (0.4-0.8) and a relative error for condyle translation (5-9%) [9].

In the current study, the mean mouth opening, the amount of anterior translation, the amount of lower translation, and the amount of joint distance were respectively 43.1, 7.14, 2.35, and 0.49mm. Ho et al. reported the amount of mouth opening to be 40-62mm and the average amount of anterior translation as 12.55mm [12]. Travers et al. reported a mouth opening of 46.6 mm and an anterior transfer of 11.6 mm; however, the evaluation method was different and was done through a three-dimensional evaluation system [19]. Salaorni et al. reported a mean mouth opening of 55mm and an anterior condyle translation of 14mm in healthy individuals [20]. In some other studies, including Landes et al., Chen et

al., and Yao et al. [8, 9, 21], the amount of translation motion during mouth opening was reported respectively 10.9±3.6 to 12.9±3.3, 10.3±3.7, and 13.7±2.5mm in healthy subjects. The normal value of mouth opening is 40-54mm [15], which is similar to our findings. Further, the amount of anterior translation found in this study was in the reported range of previous studies [8, 21, 22]. However, the average value obtained in the present study was lower than in other studies [9, 23], which is most likely due to the evaluation method and the differences between the available samples.

In the TMJ group, the amount of mouth opening was 35.3 mm, the amount of anterior translation was 7.57mm, the amount of inferior translation was 2.66mm, and the amount of joint space was 0.44mm. Similar to this study, Chen et al. reported the amount of anterior condyle translation to be 9mm; however, this was one of the very few symptomatic TMJ studies providing this measure that can be used for comparison [8]. In the current study, no significant difference was observed between the measured parameters on the left and right sides of each group. Limited studies have examined both sides concurrently. Consistent with the present study, Sójka et al. did not observe a significant difference between the variables of right and left ROM or condyle ROM when opening the mouth, or ROM of the condyle during retrograde movement in healthy individuals [15].

In this study, a significant positive correlation was seen between the ROM of the right and left condyles during mouth opening (r=0.81), which indicates that both joints move in the same direction and in unison with each other [15]. In the study by Loi et al., no significant difference was found between the sides [16]. The condyle movement in the right and left sides of normal individuals indicates the same movement pattern during jaw movements. In healthy subjects, Piehslinger et al. used axiography to show smooth, uniform, and symmetrical movement of the jaw during mouth opening and closing. Consequently, there was no expectation of differences between the two-side movement patterns [24].

Another aim of this study was to compare the parameters in the two groups of healthy and symptomatic TMJ participants. Most parameters showed significant differences between the two groups. This supports findings by Landes et al. that showed that the rate of mouth opening was significantly higher in healthy individuals [9]. In contrast, the rate of anterior transition movement in symptomatic participants was significantly higher than in healthy controls. This was also found in other studies that have examined joint movements with ultrasonography. One reason is the creation of compensatory movement in the joint that occurs due to the amount of mouth opening being higher in healthy subjects as well as in patients with more forward translation. Compensatory movement at the TMJ occurs to compensate for the amount of mouth opening in patients. Symptomatic individuals are likely to compensate for less mouth opening by increasing forward movement translation. This may be used as a diagnostic factor in subsequent evaluations, which has been emphasized in other studies [9]. The present study results confirm that TMJ dysfunction can be assessed using the amount of anterior movement.

The inferior movement of the condyles and the amount of joint distance have not been studied elsewhere. These two variables showed a significant difference between the two groups so that the joint distance was greater in the healthy controls, which shows that their TMJ is at its normal distance, whereas with pathology, this distance is reduced. Increased spasms of the masticatory muscles around the jaw joint may occur in symptomatic individuals with a subsequent reduction in joint space, which may also explain the increase in compensatory translation movement in these individuals. In contrast, the rate of inferior translation is higher in the symptomatic TMJ group and maybe a reason to compensate for the reduction of joint space. Further, there was a significant negative relationship between the amount of pain and the amount of mouth opening and joint distance. This is most likely a protective mechanism to avoid pain through a temporary compensatory reduction in ROM. In contrast, destructive joint changes, such as displacement of the inter-articular disc, entrapment of intra-articular elements, and increased spasm and muscle stiffness secondary to joint involvement, can further reduce the joint ROM. This study showed no correlation between pain and translation movement as increased pain was usually accompanied by a decrease in the amount of movement. Even in asymptomatic healthy individuals, minor destructive changes in the joint can cause limitation of movement [22]. Most patients with changes in the articular discs are associated with decreased translation movement. However, because the transfer of the disc and condyle has not been investigated in this study, no comment can be made in this regard [25]. Nonetheless, due to the low intensity of pain in these individuals, the rate of translation movement with pain intensity did not show a significant correlation.

5. Conclusion

This study showed that sonography can be considered an accurate tool for the assessment of joint space and condylar translation in individuals with symptomatic TMJD. Also, the results of this study showed that the differences in the TMJ ROM clearly separated asymptomatic subjects and patients with TMJD.

Limitations and advantages

One of the main limitations of this study was the coincidence with the paired period of COVID-19, which limited the access to participant recruitment, and it was not possible to measure the strength of the masticatory muscles due to the lack of cooperation by the participants. Further, the ability to gain a review of the same patient to test reliability was particularly difficult for participants due to the pandemic conditions. It is suggested that in future studies, the strength of the masticatory muscles should be measured with the help of a dynamometer or the use of electromyography. In addition, classifying the evaluated samples into different groups of conflict and the subsequent use of comparative investigation may provide improved and more accurate results. This is the first study in Iranian subjects with TMJD, which evaluated the movement ROM with sonography. Such studies will improve the direction of research in the field of physiotherapy in the future in Iran.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Ethics Committee of the University of Social Welfare and Rehabilitation Sciences (USWR) (Code: IR.USWR.REC.1399.205). Written informed consent was obtained from each subject.

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Authors' contributions

Conceptualization and Supervision: Hamidreza Mokhtarinia and Zahra Mosallanezhad; Methodology: Zahra Mosallanezhad and Charles Philip Gabel; Investigation, Writing-original draft, and Writing-review & editing: All authors; Data collection: Sonia Yaghoubi; Data analysis: Hamidreza Mokhtarinia and Zahra Mosallanezhad;

Conflict of interest

The authors declared no conflict of interest.

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References

[1] Elias FM, Birman EG, Matsuda CK, Oliveira IR, Jorge WA. Ultrasonographic findings in normal temporomandibular joints. Brazilian Oral Research. 2006; 20(1):25-32. [DOI:10.1590/S1806-83242006000100006] [PMID]

[2] American Academy of Orofacial Pain. Orofacial pain guidelines for assessment, diagnosis and management. Management of temporomandibular disorders. Batavia: Quintessence Publishing; 1996. [Link]

[3] Tjakkes GH, Reinders JJ, Tenvergert EM, Stegenga B. TMD pain: The effect on health related quality of life and the influence of pain duration. Health and Quality of Life Outcomes. 2010; 8:46. [DOI:10.1186/1477-7525-8-46] [PMID] [PMCID]

[4] Kim TY, Shin JS, Lee J, Lee YJ, Kim MR, Ahn YJ, et al. Gender difference in associations between chronic temporomandibular disorders and general quality of life in Koreans: A cross-sectional study. Plos One. 2015; 10(12):e0145002. [DOI:10.1371/journal.pone.0145002] [PMID] [PMCID]

[5] Valesan LF, Da-Cas CD, Réus JC, Denardin ACS, Garanhani RR, Bonotto D, et al. Prevalence of temporomandibular joint disorders: A systematic review and meta-analysis. Clinical Oral Investigations. 2021; 25(2):441-53. [DOI:10.1007/s00784-020-03710-w] [PMID]

[6] Coombs MC, Bonthius DJ, Nie X, Lecholop MK, Steed MB, Yao H. Effect of measurement technique on TMJ mandibular condyle and articular disc morphometry: CBCT, MRI, and physical measurements. Journal of Oral and Maxillofacial Surgery. 2019; 77(1):42-53. [DOI:10.1016/j.joms.2018.06.175] [PMID] [PMCID]

[7] Pereira LJ, Gavião MB, Bonjardim LR, Castelo PM, van der Bilt A. Muscle thickness, bite force, and craniofacial dimensions in adolescents with signs and symptoms of temporomandibular dysfunction. The European Journal of Orthodontics. 2007; 29(1):72-8. [DOI:10.1093/ejo/cjl055] [PMID]

[8] Chen HY, Wu SK, Lu CC, You JY, Lai CL. Assessing the mobility of the mandibular condyle by sonography. Patient Preference and Adherence. 2014; 8:1419-25. [DOI:10.2147/PPA.S72532] [PMID] [PMCID]

[9] Landes CA, Sader R. Sonographic evaluation of the ranges of condylar translation and of temporomandibular joint space as well as first comparison with symptomatic joints. Journal of Cranio-Maxillofacial Surgery. 2007; 35(8):374-81. [DOI:10.1016/j.jcms.2007.06.005] [PMID]

[10] Levangie PK, Norkin CC. Joint structure and function: A comprehensive analysis. Philadelphia: FA Davis; 2001. [Link]

[11] Walker N, Bohannon RW, Cameron D. Discriminant validity of temporomandibular joint range of motion measurements obtained with a ruler. Journal of Orthopaedic & Sports Physical Therapy. 2000; 30(8):484-92. [DOI:10.2519/jospt.2000.30.8.484] [PMID]

[12] Ho KY, Laskowski B, Garcia D, Hardy CJ, Puentedura E. Measurement of anterior translation of the mandibular condyle using sonography. Journal of Physical Therapy Science. 2019; 31(1):116-21. [DOI:10.1589/jpts.31.116] [PMID] [PMCID]

[13] Laskowski B, Hahn D, HardyCJ. Measurement of anterior translation of the mandibular condyle using ultrasonography [PhD thesis]. Reno: University of Nevada; 2017. [Link]

[14] Díaz DZR, Müller CEE, Gavião MBD. Ultrasonographic study of the temporomandibular joint in individuals with and without temporomandibular disorder. Journal of Oral Science. 2019; 61(4):539-43. [DOI:10.2334/josnusd.18-0278] [PMID]

[15] Sójka A, Huber J, Kaczmarek E, Hędzelek W. Evaluation of mandibular movement functions using instrumental ultrasound system. Journal of Prosthodontics. 2017; 26(2):123-8. [DOI:10.1111/jopr.12389] [PMID]

[16] Ioi H, Counts AL, Nanda RS. Condylar movement analysis in subjects with clinically normal temporomandibular joints, utilizing an amorphous sensor. Journal of Oral Rehabilitation. 2003; 30(4):379-85. [DOI:10.1046/j.1365-2842.2003.01103.x] [PMID]

[17] Carmody KA, Moore CL, Feller-Kopman D. Handbook of critical care and emergency ultrasound. New York: McGraw Hill Professional; 2011. [Link]

[18] Sharma S, Gupta DS, Pal US, Jurel SK. Etiological factors of temporomandibular joint disorders. National Journal of Maxillofacial Surgery. 2011; 2(2):116-9. [DOI:10.4103/0975-5950.94463] [PMID] [PMCID]

[19] Travers KH, Buschang PH, Hayasaki H, Throckmorton GS. Associations between incisor and mandibular condylar movements during maximum mouth opening in humans. Archives of Oral Biology. 2000; 45(4):267-5. [DOI:10.1016/S0003-9969(99)00140-5] [PMID]

[20] Salaorni C, Palla S. Condylar rotation and anterior translation in healthy human temporomandibular joints. Schweizer Monatsschrift für Zahnmedizin. 1994; 104(4):415-22. [PMID]

[21] Yao W, Zhou Y, Wang B, Yu T, Shen Z, Wu H, et al. Can mandibular condylar mobility sonography measurements predict difficult laryngoscopy? Anesthesia & Analgesia. 2017; 124(3):800-6. [DOI:10.1213/ANE.0000000000001528] [PMID]

[22] Celic R, Jerolimov V, Knezovic Zlataric D. Relationship of slightly limited mandibular movements to temporomandibular disorders. Brazilian Dental Journal. 2004; 15(2):151-4. [DOI:10.1590/S0103-64402004000200012] [PMID]

[23] Landes CA, Sterz M. Evaluation of condylar translation by sonography versus axiography in orthognathic surgery patients. Journal of Oral and Maxillofacial Surgery. 2003; 61(12):1410-7. [DOI:10.1016/j.joms.2003.04.002] [PMID]

[24] Piehslinger E, Celar AG, Celar RM, Slavicek R. Computerized axiography: Principles and methods. Cranio. 1991; 9(4):344-55. [DOI:10.1080/08869634.1991.11678382] [PMID]

[25] Takatsuka S, Yoshida K, Ueki K, Marukawa K, Nakagawa K, Yamamoto E. Disc and condyle translation in patients with temporomandibular disorder. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology. 2005; 99(5):614-21. [DOI:10.1016/j.tripleo.2004.08.024] [PMID]

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