Can the Measurement of Jaw-Opening Forces Assist in the Diagnosis of Temporomandibular Disorders?

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Aims: To investigate the effectiveness of a novel jaw-opening–force measuring device as a screening tool to aid in the diagnosis of temporomandibular disorders (TMD). **Methods:** Symptomatic TMD patients (n = 58) and control TMD-free participants (n = 56) were screened by an oral medicine specialist according to the Diagnostic Criteria for TMD (DC/TMD). TMD patients were divided into three subcategories based on TMD symptoms (myofascial pain, disc displacement, and both combined). Jaw-opening forces were measured in both groups with an adjustable head device connected to a 1,000-N–load cell. Seven attempts were recorded at 10-second intervals by a data-capturing system. The geometric mean force values were obtained after discarding the first and last attempts. **Results:** TMD-free participants had greater jaw-opening forces than TMD patients both without and with adjustments for age, sex, height, and weight (both $P < .001$). The geometric mean ± standard deviation values for TMD patients were 18.5 ± 1.62 N and 47.7 ± 1.53 N for TMD-free participants. Differences in jaw-opening forces among the three TMD subcategories were not statistically significant; however, patients with disc displacement (23.7 ± 1.46 N) had greater jaw forces than patients with myofascial pain (17.0 ± 1.74 N) and both myofascial pain and disc displacement (17.0 ± 1.56 N). **Conclusion:** This study demonstrated that differences in jaw-opening forces could be used as a diagnostic tool for TMD. Future studies should explore the potential of this device to measure improvement in jaw-opening forces following TMD treatment. *J Oral Facial Pain Headache 2020;34:199–205. doi: 10.11607/ofph.2587*

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Temporomandibular disorders (TMDs) is an umbrella term for conditions causing pain and dysfunction of the temporomandibular joint (TMJ), masticatory muscles, and associated structures.[1] TMD is a multifactorial disease process potentially caused by traumatic events; laxity of the ligaments of the TMJ; improper activity of the muscle during TMJ motion (hypertrophy, atrophy, or contracture); changes in the composition of the synovial fluid; parafunction; hormonal influences; and/or articular changes.[2] The main signs and symptoms of TMD include pain and tenderness of the muscles and joints; decreased mandibular range of motion; joint clicking or crepitus; headache; and functional limitation or deviation of jaw opening.[1,2] Orofacial pain is the most common presenting feature of TMD and is the main prompt for patients to seek treatment.[1] Around 6% to 13% of the general population is affected by TMD, although up to 70% of the population will experience signs or symptoms of TMD at some point in their lives. Chronic painful TMD can be associated with depression, decreased coping ability with day-to-day tasks, lack of sleep, disability, and stress.[1,3] The causes of conditions affecting TMD are not completely understood. Current evidence suggests that TMD myofascial pain involves an interplay among a peripheral nociceptive source in the muscle, a faulty central nervous system component, and decreased coping ability.[4] The Orofacial Pain Prospective Evaluation and Risk Assessment (OPPERA) project has accomplished substantial advances in understanding the multifactorial nature of TMDs.[5] The OPPERA study has found several genetic associations with various biologic pathways that may contribute to TMD.[6] In addition, the OPPERA work has also continued to investigate sociodemographic, clinical, and genetic factors that predict and affect TMD. However, according to the OPPERA study, chronic TMD contribute to a central sensitization component.[7,8] At present, assessment of TMD is based on pain history and clinical examination with imaging such as plain films (transcranial and transpharyngeal), dental radiographs, computed tomography (CT) scans, magnetic resonance imaging (MRI), and, on rare occasions, arthroscopic examination, whereby a small thin tube (cannula) along with a camera (arthroscope) are inserted to view the area and help determine the diagnosis.[9,10] The main goal of TMD management is to improve pain, function, and quality of life. Simplistic conservative management of TMD has been shown to be efficacious for a high percentage of patients with chronic TMD.[11]

Mandibular movements (jaw opening and jaw closing) are controlled by the muscles of the masticatory system with the assistance of the ligaments, articular disc, and condyle.[12] The muscles of the masticatory system control jaw opening and closing forces with the assistance of passive structures, such as the ligaments and joint sources. Mandibular movements are the result of an interaction between muscle forces and movement constraints caused by the articular surfaces.[12] To date, most studies have investigated jaw-closing movements and bite-force estimates.[13–15] In comparison, the properties of the jaw depressor muscles (digastric, geniohyoid, and mylohyoid) are not fully investigated. These muscles act against the hyoid bone to pull the mandible downward[16] and are assisted in this process by the stylohyoid, infrahyoid, and lateral pterygoid muscles, which assist in stabilizing the hyoid bone and promoting the anterior sliding movement of the mandibular condyle.[16]

A small number of previous studies have provided estimates of average muscle forces required for jaw opening and their associations with sex, biologic parameters (eg, facial size), and anthropometric parameters (eg, height and weight).[12,16,17] However, these studies used measuring devices that were quite variable, ranging from rigid metal frame systems mounted on tables to flexible head devices composed of adjustable velcro belts.[16–18] In addition, these studies focused on biomechanical analysis, which included not only muscle and joint forces but also the torques generated by these forces.[12] Mandibular movements are the only parameters that can be objectively recorded and measured. A recent study conducted by Brunton et al, which used an adjustable rigid extraoral device, found that jaw-opening force values were greater in male than in female subjects; however, force values were poorly associated with biologic and anthropometric parameters.[19] Another study used jaw-opening forces in dysphagia patients to determine the usefulness of a jaw-opening force test to screen for dysphagia and pharyngeal residue. The study found that jaw-opening strength was useful for predicting pharyngeal residue.[18]

So far, the usefulness of jaw-opening forces as a screening tool for diagnosing TMD has been poorly explored. This study aimed to investigate whether jaw-opening forces can be used as a quantitative diagnostic tool to screen for TMD (including myofascial pain, disc displacement, and both myofascial pain and disc displacement).

Materials and Methods

This study recruited 58 TMD patients and 56 TMD-free participants aged 15 to 84 years from the Faculty of Dentistry, University of Otago, Dunedin, New Zealand. Ethical approval was obtained from the Health and Disability Ethics Committees (approval number 17/NTB/171). As no information was available about the variability of jaw-opening forces in this population, a sample size calculation could not be performed prior to recruitment. Instead, data were collected for 79 participants, at which point the study biostatistician, who had no involvement in data collection, was provided with the raw data using uninformative group codes. Prior to this, a 20% difference in force was determined likely to be of clinical importance. The data were mean centered before being viewed to preserve blinding and were ultimately log transformed to address skew. A pooled standard deviation (SD) of 0.42 on the log scale was used to determine that to detect 20% lower mean forces in one group (a difference of 0.22 on the natural log scale) with 80% power when using a two-sided test at the .05 level, 57 participants were needed in each group, 114 in total. Recruitment continued until this target was achieved.

The recruited participants were screened by an oral medicine specialist according to the Diagnostic Criteria for TMD (DC/TMD) protocol (examining the range of mandibular movements, pain, joint sounds, occlusion, oral behavior, and musculoskeletal state).[20] The TMD patients were divided into three subcategories based on their TMD symptoms: presence of myofascial pain; disc displacement with reduction; and myofascial pain and disc displacement combined.

Patients who were diagnosed with osteoarthritis and patients who were using muscle relaxants were excluded from the study. As a control group, TMD-free participants (exclusion criteria included myofascial pain, symptomatic TMJ disorders, current orthodontic treatment, patients using muscle relaxants, or the absence of natural dentition) were recruited from among the staff and students of the University of Otago Faculty of Dentistry. After obtaining informed consent, the participants provided demographic information, including name, contact information, date of birth, sex, and self-reported ethnicity. The investigator who conducted the measurement of jaw-opening forces (J.R.) was not blinded to each participant's TMD status, but the biostatistician (A.R.G.) was blinded through the use of noninformative group codes until the primary analyses were completed.

Jaw-opening forces in both groups were measured with a previously described[19] adjustable head device consisting of 3D-printed head gear and chin caps connected to a 1,000-N load cell (Fig 1). The device was placed on the participant's head and tightened to the point where there was a solid connection with the chin cap (Figs 2a and 2b).

Participants were instructed to sit comfortably in a chair, maintaining a straight back and keeping their head in a vertical position. Three test attempts were performed for each participant prior to data collection to ensure the participant's comfort and that the device was placed correctly. With their jaw held in centric position (centric occlusion) (Fig 2a), participants were instructed to attempt to open their jaw seven times as forcefully as possible for an average of 2 seconds, pausing for a 5-second interval between each attempt (Fig 2c). The jaw-opening forces were recorded in a data capture system (BioTronics) and analyzed using PicoLog software (Pico Technology).

Each jaw-opening attempt was recorded as a graph of millivolt variation during each movement, and the highest peak observed during each jaw-opening movement was recorded and measured. The output millivolt values were converted into force values in Newtons by loading the 1,000-N load cell with known force outputs using a 5-kN load cell in an Instron universal testing machine (Instron 3369).

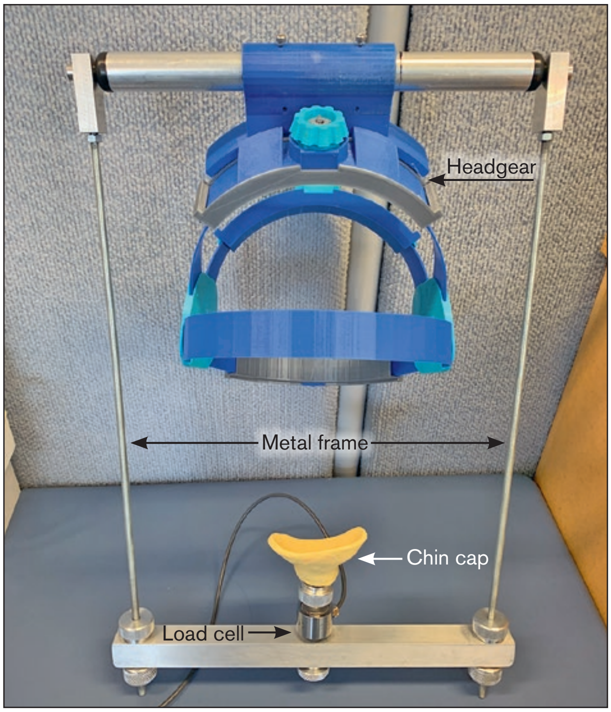

Fig 1 The 3D-printed head gear and chin caps connected to a 1,000-N load cell.

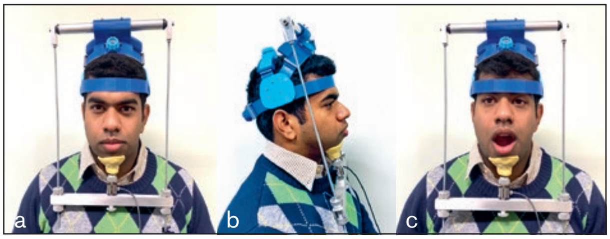

Fig 2 **(a)** Jaw-opening device in centric occlusion. **(b)** Side view. **(c)** During maximum opening.

Statistical Analysis

Appropriate summary statistics were presented (means and SDs for approximately normally distributed variables; geometric means and SDs for log-normally distributed variables; medians and interquartile ranges [IQRs] for other continuous variables; and counts and percentages for categorical variables). The two groups (TMD patients and TMD-free participants) were compared in terms of demographics with the appropriate statistical test (*t* test for normally distributed variables; Mann-Whitney *U* test for other continuous variables; chi-square test for categorical variables; and Fisher exact test for categorical variables when more than 20% of cells had expected cell counts below 5), with similar tests for TMD subgroups (one-way analysis of variance [ANOVA], Kruskal-Wallis test with post hoc Dunn test, chi-square test, and Fisher exact test). ICCs were estimated using a two-way mixed-effects model for absolute agreement. Linear regression models were used to compare the two groups using each individual's mean force, both without adjustment and adjusting for age, sex, height, and weight as linear terms. Similar models were used to compare the three subgroups of TMD. Standard model diagnostics were used, including inspecting histograms of residuals and scatter plots of residuals against fitted values and continuous predictors. When model residuals were improved by a log transformation, this was retained, and differences were

Table 1 Demographic Details of TMD Patients and TMD-Free Participants

	Overall (N = 114)		TMD patients (n = 58)		TMD free (n = 56)		P value
Median (IQR) age, y[a]	24.0	(19.0)	26.0	(30.0)	24.0	(12.5)	.388
Sex,[b] n (%)							**.011**
Male	36	(32)	12	(21)	24	(43)	
Female	78	(68)	46	(79)	32	(57)	
Ethnicity,[c] n (%)							**< .001**
Māori	4	(4)	0	(0)	4	(7)	
European	77	(68)	52	(90)	25	(45)	
Asian	30	(26)	6	(10)	24	(43)	
Other	3	(3)	0	(0)	3	(5)	
Mean (SD) height, cm[d]	168.8	(10.4)	167.2	(10.2)	170.5	(10.4)	**.085**
Geometric mean (SD) weight, kg[e]	69.4	(1.26)	67.4	(1.27)	71.4	(1.24)	.177

Statistically significant *P* values are shown in **bold**.
IQR = interquartile range.
[a]Mann-Whitney *U* test.
[b]Chi-square test.
[c]Fisher exact test.
[d]Two-tailed *t* test.
[e]Two-tailed *t* test after log transformation.

Table 2 Demographics of TMD Subgroups

	Muscle (n = 18)		Disc displacement (n = 15)		Both (n = 25)		P value
Median (IQR) age, y[a]	21.5	(40.0)	22.0	(26.0)	31.0	(27.0)	.630
Sex,[b] n (%)							.385
Male	5	(28)	4	(27)	3	(12)	
Female	13	(72)	11	(73)	22	(88)	
Ethnicity,[b] n (%)							.354
European	16	(89)	15	(100)	21	(84)	
Asian	2	(11)	0	(0)	4	(16)	
Mean (SD) height, cm[c]	167.7	(8.4)	170.5	(11.9)	164.8	(10.0)	.221
Geometric mean (SD) weight (kg)[d]	68.7	(1.31)	69.8	(1.21)	65.2	(1.28)	.635

[a]Kruskal-Wallis test.
[b]Fisher exact test.
[c]One-way ANOVA.
[d]One-way ANOVA after log transformation.

reported as the ratios of the geometric means rather than the differences of arithmetic means. Likelihood ratio tests were used to examine the addition of quadratic terms for continuous independent variables. Statistical analyses were performed using Stata 15.1 with two-tailed tests when available, with $P < .05$ considered statistically significant.

Results

Sample Characteristics

A total of 58 TMD patients and 56 TMD-free participants were included in this study. The median age was 24 years (ranging between 15 and 84 years), with the sample being mostly female (68%) and European (68%). While there was no evidence of a difference between the TMD and TMD-free groups in terms of age, there was a higher percentage of women (79% vs 57%, chi-square $P = .011$) and a higher percentage of Europeans in the TMD patient group (90% vs 45%), with a greater percentage of TMD-free participants identifying as Asian (43% vs 10%) (Fisher exact test for ethnicity $P < .001$). The mean (± SD) height (168.8 + 10.4 cm) and geometric mean (± geometric SD) weight (69.4 + 1.26 kg) was similar in both groups despite the sex and ethnicity differences (Table 1).

As shown in Table 2, there were no statistically significant differences in these variables among the TMD subtypes.

Maximum Jaw-Opening Forces

The jaw-opening forces for the second to sixth trials were reliable, with little variation between repeated measurements in the same participants. The intraclass correlation coefficient (ICC) using a single measurement was 0.979 (95% CI: 0.972 to 0.984). With all five measurements used, this ICC was 0.996 (95% CI: 0.994 to 0.997), indicating extremely high reliability.

Figure 3 shows the median (along with the maximum, 75th percentile, 25th percentile, and minimum) and individual mean forces by TMD status. In unadjusted analyses, there was evidence that geometric mean ± SD forces in TMD patients (18.5 ± 1.62 N, 95% CI: 16.3 to 21.0) were 61% lower than in TMD-free participants (47.7 ± 1.53 N, 95% CI: 42.5 to 53.5) (ratio of geometric means = 0.39, 95% CI: 0.33 to 0.46, $P < .001$). These differences were slightly attenuated after adjusting for age, sex, height, and weight (TMD patients having 58% lower forces in this model), with the difference remaining statistically significant (ratio = 0.42, 95% CI: 0.35 to 0.49, $P < .001$). However, none of the covariates were statistically significant except for height, where forces increased by 6.1% per 5-cm increase in height (95% CI: 0.4% to 12.0%, $P = .035$). The association with height did not vary by sex (interaction $P = .678$) or TMD status (interaction $P = .463$).

For the TMD subtypes (Fig 4), there was no evidence of a statistically

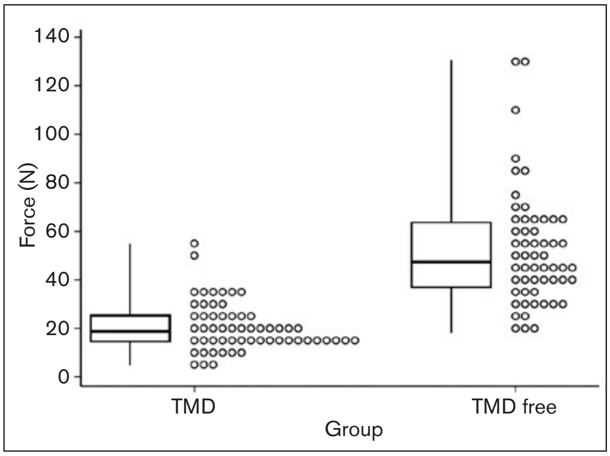

Fig 3 Box-and-whisker and strip plots showing unadjusted mean forces for TMD patients and TMD-free participants.

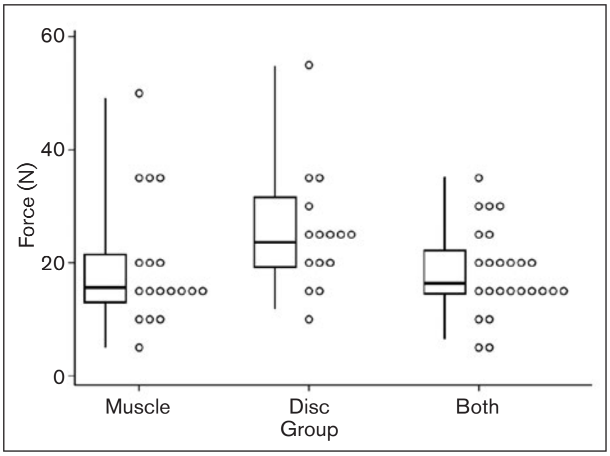

Fig 4 Box-and-whisker and strip plots showing mean forces for TMD subtypes.

significant difference in the unadjusted model (Wald *P* = .071) or in the adjusted model (Wald *P* = .165). However, patients with disc displacement (geometric mean ± SD = 23.7 ± 1.46 N) had numerically greater jaw forces than patients with myofascial pain (17.0 ± 1.74 N) and both myofascial pain and disc displacement (17.0 ± 1.56 N). The association with height was no longer statistically significant (*P* = .051), but was comparable to the overall analysis (8.2% higher/5 cm, 95% CI: −0.8% to 18.0%).

Discussion

This study investigated the maximum jaw-opening forces in participants diagnosed with TMD. Both before and after adjusting for the biologic and anthropometric parameters, the mean jaw-opening forces in TMD participants were significantly lower than in TMD-free participants (geometric means of 18.5 N for TMD and 47.7 N for TMD free). This substantial difference suggests that jaw opening was limited in TMD participants. TMD pain is typically felt in the masticatory muscles (including the masseter and temporalis), ear, and face and is often altered by mandibular movement. Patients with masticatory myofascial pain have limited mouth opening, and the muscles are usually tender to palpation.[21–23] Masticatory muscle pain can be found in all age groups, peaking in adults between 20 and 40 years and occurring predominantly in women. This was reflected in this study, as the majority of the participants with TMD were female (79%), and 45% were aged between 20 and 40 years, with a median age of 26 years. The OPPERA study showed a similar incidence of TMD in men and women, but development of chronicity was higher in women.[24] Furthermore, studies have reported a higher incidence of TMD in women, with a female to male ratio ranging from 2:1 in the general population to 8:1 in clinical settings.[25,26]

The three TMD subtypes (facial pain, disc displacement, and facial pain and disc displacement combined) investigated in this study did not show statistically significant differences in the measured jaw-opening forces. However, patients with disc displacement (geometric mean 23.7 N) had numerically greater jaw forces than patients with myofascial pain (17.0 N) and both myofascial pain and disc displacement (17.0 N). Of the various TMD conditions investigated, disc displacement with reduction has the least effect on oral health–related quality of life.[27,28] Although this condition is frequently pain free, joint sounds may be heard. It is widely accepted that TMD have a multifactorial etiology, with an interplay between patient health and psychologic, genetic, and biomechanical (parafunction) factors.[29] Most studies on biomechanical parafunctions rely on questionnaires. Questionnaires are invariably susceptible to recall bias, which limits the validity of such data. Jaw opening is important not only as a record of the severity of the TMD symptoms, but also as an indication of rate and degree of improvement. Until now, the screening of TMD has been based on indirect and subjective measures.[26] The jaw-opening–force measuring device used in this study provides an adjunct to the currently available clinical approaches for diagnosing and monitoring treatment for chronic painful TMD.

As in all studies, this study has its limitations. Evaluation of TMD includes assessment of mandibular range of motion, including maximum opening, maximum lateral and protrusive excursions, and mandibular opening pattern (ie, symmetric vs asymmetric). The main bias could potentially be produced by the fact that maximum lateral and protrusive excursion forces were not measured in this study. In addition, this device only measured the maximum jaw-opening force, which does not differentiate the contributions of different masticatory muscles. In fact, the differences in contribution to opening force might relate to the different symptoms experienced by patients. Further work must be done to assess the individual contribution of each muscle in jaw-opening force and the forces generated during lateral excursive movements.

However, this device did allow for objective measurement of muscle forces, and the results showed that there was a significant difference in the mean forces for TMD vs non-TMD patients. In the present study, parafunctional habits (bruxism and clenching) were not considered; however, nocturnal bruxism is suggested to be a sleep disorder.[11] Furthermore, the device used in the present study measured the force along the main axis; therefore, the contributions of the other degrees of freedom of the mandible might have been underrepresented. Other factors, such as mandibular angle, might also have accounted for the variation in jaw opening, but were not investigated in the present study. Previous studies have demonstrated that head position modulates the dynamics of jaw opening.[30,31] Every attempt was made to standardize the head position for each participant; however, the head position might have influenced these measurements to a certain degree. The investigator involved in measuring jaw-opening forces was not blinded to the participant's TMD status, but the measurement process is objective, and this seems unlikely to introduce bias. Investigating the electromyographic activity of muscles during jaw opening and their correlation with jaw-opening forces would be of interest. This should be a future area of research, which would eventually provide a unique, minimally invasive, simple, and cost-effective approach to the diagnosis of TMD.

Conclusions

Within the limitations of this study, the results provide valuable insight into the clinical parameters of TMD and point to muscular pain as a major cause of limited mouth opening, even in patients who present with joint discomfort. This evidence confirms the need for conservative measures in the management of chronic pain, especially if this pain is centrally mediated. Further work examining muscle force in conjunction with muscle activity measurements must be performed for a more complete picture.

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References

1. 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 Qual Life Outcomes 2010;8:46.
2. Bitiniene D, Zamaliauskiene R, Kubilius R, Leketas M, Gailius T, Smirnovaite K. Quality of life in patients with temporomandibular disorders. A systematic review. Stomatologija 2018;20:3–9.
3. Fan WY, Tiang N, Broadbent JM, Thomson WM. Occurrence, associations, and impacts of nocturnal parafunction, daytime parafunction, and temporomandibular symptoms in 38-year-old individuals. J Oral Facial Pain Headache 2019;33:254–259.
4. Mense S. The pathogenesis of muscle pain. Curr Pain Headache Rep 2003;7:419–425.
5. Maixner W, Diatchenko L, Dubner R, et al. Orofacial pain prospective evaluation and risk assessment study—The OPPERA study. J Pain 2011;12(11 suppl):T4–T11.e1–e2.
6. Smith SB, Maixner DW, Greenspan JD, et al. Potential genetic risk factors for chronic TMD: Genetic associations from the OPPERA case control study. J Pain 2011;12(11 suppl):T92–T101.
7. Slade GD, Ohrbach R, Greenspan JD, et al. Painful temporomandibular disorder: Decade of discovery from OPPERA studies. J Dent Res 2016;95:1084–1092.
8. Harper DE, Schrepf A, Clauw DJ. Pain mechanisms and centralized pain in temporomandibular disorders. J Dent Res 2016;95:1102–1108.
9. McNeill C. Management of temporomandibular disorders: Concepts and controversies. J Prosthet Dent 1997;77: 510–522.
10. Okeson JP. Management of Temporomandibular Disorders and Occlusion, ed 7. St Louis: Mosby, 2014.
11. Polonowita AD, Thomson WM, Thorburn DN. Clinical efficacy of a simplified approach to managing chronic temporomandibular disorders: Evidence from a 1-year case series. Oral Surg Oral Med Oral Pathol Oral Radiol 2019;128:227–234.
12. Koolstra JH, van Eijden TM. Biomechanical analysis of jaw-closing movements. J Dent Res 1995;74:1564–1570.
13. Pruim GJ, de Jongh HJ, Ten Bosch JJ. Forces acting on the mandible during bilateral static bite at different bite force levels. J Biomech 1980;13:755–763.
14. Waltimo A, Könönen M. A novel bite force recorder and maximal isometric bite force values for healthy young adults. Scand J Dent Res 1993;101:171–175.
15. de Abreu RA, Pereira MD, Furtado F, Prado GP, Mestriner W, Jr, Ferreira LM. Masticatory efficiency and bite force in individuals with normal occlusion. Arch Oral Biol. 2014;59:1065–1074.
16. Sharkey P, Boyle DK, Orchardson R, McGowan DA. Jaw opening forces in human subjects. Br Dent J 1984;156:89–92.
17. Bolt KJ, Orchardson R. Relationship between mouth-opening force and facial skeletal dimensions in human females. Arch Oral Biol 1986;31:789–793.
18. Hara K, Tohara H, Wada S, Iida T, Ueda K, Ansai T. Jaw-opening force test to screen for dysphagia: preliminary results. Arch Phys Med Rehabil 2014;95:867–874.

19. Brunton PA, Loch C, Waddell JN, Bodansky HJ, Hall R, Gray A. Estimation of jaw-opening forces in adults. Orthod Craniofac Res 2018;21:57–62.
20. Schiffman E, Ohrbach R, Truelove E, et al. Diagnostic Criteria 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 2014;28:6–27.
21. Gray RJ, Davies SJ, Quayle AA. A clinical approach to temporomandibular disorders. 1. Classification and functional anatomy. Br Dent J 1994;176:429–435.
22. Gray R, Al-Ani Z. Temporomandibular Disorders: A Problem-Based Approach. Chichester: John Wiley & Sons, 2011.
23. Greene CS. The etiology of temporomandibular disorders: Implications for treatment. J Orofac Pain 2001;15:93–105.
24. Slade GD, Fillingim RB, Sanders AE, et al. Summary of findings from the OPPERA prospective cohort study of incidence of first-onset temporomandibular disorder: Implications and future directions. J Pain 2013;14(12 suppl):T116–T124.
25. Bagis B, Ayaz EA, Turgut S, Durkan R, Özcan M. Gender difference in prevalence of signs and symptoms of temporomandibular joint disorders: A retrospective study on 243 consecutive patients. Int J Med Sci 2012;9:539–544.
26. Manfredini D, Chiappe G, Bosco M. Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD) Axis I diagnoses in an Italian patient population. J Oral Rehabil 2006;33:551–558.
27. Bayat M, Abbasi AJ, Noorbala AA, Mohebbi SZ, Moharrami M, Yekaninejad MS. Oral health–related quality of life in patients with temporomandibular disorders: A case-control study considering psychological aspects. Int J Dent Hyg 2018;16:165–170.
28. John MT, Reissmann DR, Schierz O, Wassell RW. Oral health-related quality of life in patients with temporomandibular disorders. J Orofac Pain 2007;21:46–54.
29. Magnusson T, Egermarki I, Carlsson GE. A prospective investigation over two decades on signs and symptoms of temporomandibular disorders and associated variables. A final summary. Acta Odontol Scand 2005;63:99–109.
30. Kohno S, Matsuyama T, Medina RU, Arai Y. Functional-rhythmical coupling of head and mandibular movements. J Oral Rehabil 2001;28:161–167.
31. Muto T, Kanazawa M. Positional change of the hyoid bone at maximal mouth opening. Oral Surg Oral Med Oral Pathol 1994;77:451–455.