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Reliability of Quantifying Maximal Mouth Opening and Lateral Mandibular Shift in Individuals With and Without Temporomandibular Disorder Using Three-dimensional Ultrasound-based Motion Analysis

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Abstract

Background: Although magnetic resonance imaging is accurate, it is expensive to measure the movement of temporomandibular joint. The three-dimensional (3D) motion analysis system is an inexpensive measurement tool.

Objects: This study examined the reliability of quantifying the mouth opening and lateral mandibular shift and differences between individuals with and without temporomandibular disorder (TMD) using the hygienic method of surface markers on the skin with 3D ultrasound-based motion analysis.

Methods: This study included 24 subjects (12 with and 12 without TMD). Temporomandibular joint motion during mouth opening was recorded using two surface markers with 3D ultrasound-based motion analysis. An intraclass correlation coefficient [ICC (3,k)] was used to confirm the intrarater reliability of quantifying kinematic temporomandibular joint motion, and an independent t-test was used to evaluate differences in maximal mouth opening and lateral mandibular shift between the two groups.

Results: Assessment of mouth opening and lateral mandibular shift showed excellent test‐retest reliability with low standard error of measurement. The lateral mandibular shift and opening-lateral mandibular shift ratio were significantly increased in the TMD group during maximum mouth opening ($p<.05$). However, no significant difference in maximal mouth opening was observed between the groups with and without TMD ($p>.05$).

Conclusion: This hygienic and simple surface marker method can be used to quantify the mouth opening and lateral mandibular shift at the end-range of mouth opening. The TMD group showed an increased lateral mandibular shift movement at the end-range of mouth opening. The lateral mandibular shift movement can be regarded as a symptom in the diagnosis and treatment of TMD.

Key Words: Lateral mandibular shift; Mouth opening; Motion analysis; Temporomandibular disorders.

Introduction

Temporalmandibular joint disorder (TMD) is a common condition, with a prevalence of 6−93% (Poveda Roda et al, 2007). TMD stems from various causes. Dislocation of the TMJ disc and joint degeneration can result in limited mouth opening, crepitus, lateral mandibular shift during mouth opening and an asymmetrical face (Sureka et al, 2012). Bad habits and malocclusion can induce the overactivation of the masticatory muscle, resulting in difficulty of protrusion and mouth opening (Okeson and de Kanter,

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1996). A previous study demonstrated that range of lateral mandibular shift during mouth opening was associated with audible clicking TMJ sounds and patients with disc displacement with reduction showed larger lateral mandibular shift than in healthy subjects (Widmalm et al, 2016). Based on previous literatures, range of mouth opening and lateral mandibular shift were associated with TMD symptoms (Okeson and de Kanter, 1996; Sureka et al, 2012; Widmalm et al, 2016).

Symmetrical movement patterns—such as straight mouth opening—are important for pain reduction in the temporalmandibular joint (TMJ) region (Feteih, 2006). Straight mouth opening requires a range of lateral mandibular shift at least 2 ㎜ during mouth opening (Feteih, 2006). Inflammation in the posterior region of the TMJ leads to lateral mandibular shift during the end-phase of mouth opening (Friedman and Weisberg, 1982). Muscle imbalance in the TMJ region can induce lateral mandibular shift during the mid-phase of mouth opening (Friedman and Weisberg, 1982). In addition, a C-shaped lateral mandibular shift can be observed during mouth opening in individuals with TMJ impairments. A S-shaped lateral mandibular shift can be observed during mouth opening in individuals with TMJ subluxation (Wood and Branco, 1979). Therefore, assessment of the lateral mandibular shift is required to evaluate and manage TMD in patients (Grosfeld et al, 1985).

Lateral mandibular shift can be assessed using a variety of evaluation tools or devices, such as the U-shaped clutch placed on the lower teeth during magnetic resonance imaging (MRI) (Leader et al, 2003). Although MRI is accurate, it is expensive and the frame is difficult to wear in the mouth. The three-dimensional (3D) motion analysis system is an inexpensive measurement tool; however, the inner splint placed in the mouth has hygienic disadvantages (Naeije et al, 1995; Seedorf et al, 2004).

This study described an inexpensive and hygienic method using 3D ultrasound-based motion analysis with surface markers on the skin to assess the mouth opening and lateral mandibular shift during mouth opening. The purposes of this study were to 1) investigate the reliability of mouth opening and lateral mandibular shift measurements at the end-range of mouth opening, and 2) compare the differences in mouth opening and lateral mandibular shift measurements at the end-range of mouth opening between the TMD and non-TMD groups.

Methods

Subjects

For this study, subjects were recruited via posters, word of mouth and telephone on campus of Inje university. The TMD group included subjects with TMD according to the applied Research Diagnostic Criteria for TMD (RDC/TMD-Axis I) as assessed by examiner 1 (Table 1) (Look et al, 2010). RDC/TMD-Axis Ia was classified as the report of muscle palpation pain of temporalis or masseter with no limitation of unassisted jaw opening. RDC/TMD-Axis Ib was classified based on muscle palpation with limitation of unassisted jaw opening, which a cutoff distance between upper and lower teeth was <40 ㎜ (Look et al, 2010). The exclusion criteria were (1) symptoms related to the stomatog-

Table 1. Comparison of subject characteristics (N=24)

Variables	TMD[a] group (n_1=12)	Control group (n_2=12)	P value
Age (years)	20.08±1.62b	21.00±1.71	.19
Body mass (㎏)	62.83±10.94	62.82±12.40	.99
Height (㎝)	171.61±7.55	168.97±7.79	.40
Sex (male/female)	7/5	8/4	-

[a]temporomandibular disorder, [b]mean±standard deviation.

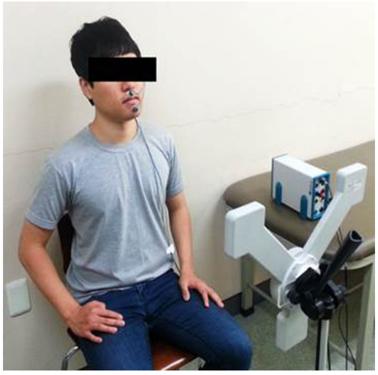


Figure 1. Measurement of the temporo-mandibular joint motion using a 3D ultrasound-based motion analysis system. Two single-active markers were attached on the upper jaw (philtrum) and midpoint of under jaw.

nathic system (migraine, intracranial neoplasm, toothache, neuralgia), (2) systemic diseases such as rheumatoid arthritis or fibromyalgia, (3) surgical history for TMJ disorder, (4) history of psychological disorders and the inability to answer a questionnaire and (5) other musculoskeletal pain in the neck, shoulder and back (Galhardo et al, 2013).

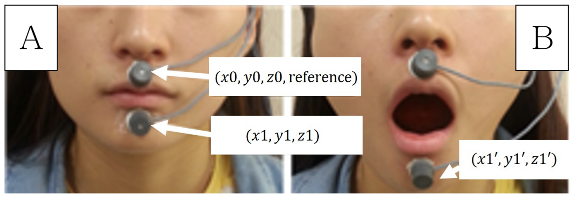
Individuals in the control group had no symptoms and pain related to TMD (Table 1). All subjects signed an informed consent form approved by the Inje University Faculty of Health Sciences Human Ethics Committee.

Recording the TMJ motions during mouth opening

To measure real-time TMJ motion, this study employed a 3D ultrasonic motion analysis system (CMS-HS) (Zebris Medizintechnik GmbH, Isny, Germany). Two single-active markers were attached on the upper jaw (philtrum) and the midpoint of the lower jaw (Figure 1). TMJ motion was defined as lower jaw motion relative to that of the upper jaw. The transducer sensor was placed in front of the subject's face. Before recording TMJ motion, two single marker were calibrated to zero while the subject maintained a resting closed mouth and neutral head position. The neutral head position (determined subjectively by each participant) was maintained in a vertical upright position without rotation or lateral flexion (Cagnie et al, 2007). The sampling rate was 60 Hz. The TMJ motion was calculated by the Windata 2.22.25 software using the ASCII file. TMJ motion data were recorded while subjects held an end-range mouth opening for 3 s. The maximum values of three trials were used to determine the TMJ motion (extent of mouth opening and lateral mandibular shift during the end-range mouth opening).

Kinematic model for mouth opening

Based on the kinematic data (ASCII file), we calculated the amount of mouth opening and lateral mandibular shift at the end-range of mouth opening using Microsoft Excel. Figure 2 shows the formula for calculating the amount of mouth opening and lateral mandibular shift. The amount of mouth opening was defined by the difference between the upper and lower jaw coordinates in the sagittal plane. The amount of lateral mandibular shift at the end-range of mouth opening was calculated by the difference between the upper and lower jaw coordinates in the frontal plane. To calculate the ratio of lateral mandibular shift relative to the mouth opening, the amount of lateral mandibular shift was divided by the amount of mouth opening.



$$Mouth\,opening\,(\text{mm}) = |y1' - y0| - |y1 - y0|$$

$$Lateral\,mandibular\,shift\,(\text{mm}) = |x1' - x0| - |x1 - x0|$$

Figure 2. Two single-active markers before (A) and after mouth opening (B) and equation for calculation of amount of mouth opening and lateral mandibular shift. Red line indicates the amount of mouth opening and green line indicates the amount of lateral mandibular shift at end-range of mouth opening. Upper jaw coordinates before mouth opening (x0, y0, z0, reference); Lower jaw coordinates before mouth opening (x1, y1, z1); Low jaw coordinates at end-range of mouth opening (x1′, y1′, z1′).

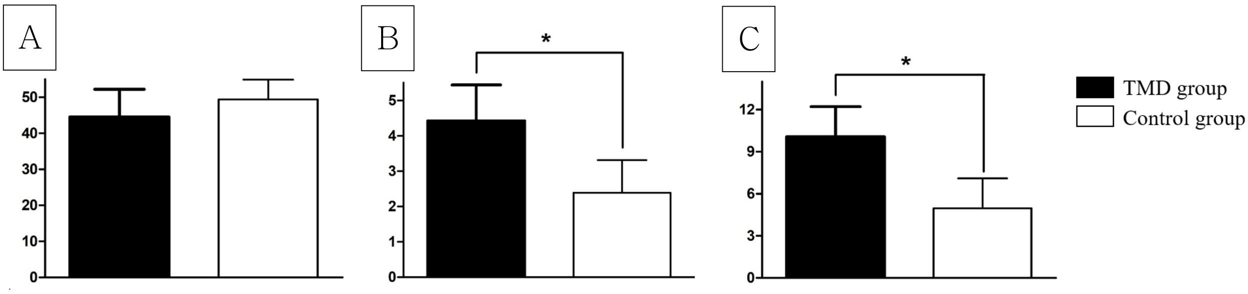


Figure 3. Comparison of (A) the amount of mouth opening (㎜), (B) lateral mandibular shift at end-range of mouth opening (㎜) and (C) lateral mandibular shift versus mouth opening ratio (%) between with and without temporomandibular disorder (TMD) group.

Procedures

Subjects were seated looking straight ahead with the thoracic region resting against the backrest of the chair and with hands over anterior thighs. The examiner cleaned the subject's skin around the lips using alcohol and attached single-active markers to the philtrum and midpoint of the lower jaw. Adhesive tape was attached over the skin to prevent movement of the fixed marker during mouth opening. Subjects were asked to minimize neck and head motion and to resist frowning during mouth opening. For each assessment, the subjects began with a relaxed closed mouth, opened the mouth maximally for 2 s, and then held an end-range mouth opening for 3 s (Baltali et al, 2008). To control the speed of mouth opening, subjects practiced mouth opening using a metronome. For familiarization before recording, subjects repeated five trials of opening-closing movements. Especially, in familiarization period, subjects opened the mouth using depression of lower jaw to prevent head and neck extension guiding by examiner's hands. After completing the familiarization, kinematic data were recorded three times during mouth opening. To minimize fatigue, subjects rested for 30 s between trials.

Statistical analysis

To confirm the intrarater reliability of the method of assessing the kinematic TMJ motion, we used an intraclass correlation coefficient [ICC (3,k)]. The standard error of measurement (SEM) was used to quantify the intersession consistency.

Independent t-tests were performed to compare the TMD and non-TMD groups regarding the amount of mouth opening, lateral mandibular shift, and lateral mandibular shift-mouth opening ratio. The significance level was set at .05. Data are expressed as means±standard deviation (SD). Statistical analyses were performed using the SPSS ver. 20.0 software (IBM Corp., Armonk, NY, USA).

Results

The subjects in this study were classified as RDC/TMD-Axis Ia based on the diagnostic criteria of the RDC/TMD-Axis (Look et al, 2010). The proposed assessment method for mouth opening and lateral mandibular shift showed excellent test−retest reliability (ICC=.94; 95% confidence interval, CI: .89 ‐.97 and ICC=.88; 95% CI: .77‐.94, respectively). The SEM in mouth opening and lateral mandibular shift were 1.61 and .34, respectively.

Maximum mouth opening in the TMD group (mean±SD, 44.55±7.64 ㎜) was less than that in control group (mean±SD, 49.40±5.49 ㎜), however, this difference was not significant (p=.09) (Figure 3A). The TMD group showed significantly greater lateral mandibular shift (mean±SD, 4.42±1.02 ㎜) at the end-range of mouth opening than the control group (mean±SD, 2.39±.92 ㎜) (p<.05) (Figure 3B). The lateral mandibular shift versus the mouth-opening ratio was significantly greater in the TMD group (mean±SD, 10.06±2.15%) than the control group (mean±SD, 4.97±2.13%) ($p<.05$) (Figure 3C).

Discussion

Using motion analysis, this study demonstrated greater lateral mandibular shift in individuals with compared to those without TMD. Compared to previous studies (Leader et al, 2003; Naeije et al, 1995; Seedorf et al, 2004), the surface marker of the 3D ultrasound-based motion analysis system in this study was more hygienic than using an inner marker in the mouth. Additionally, this study showed excellent test—retest reliability. To our knowledge, this is the first report of this hygienic and reliable method for comparison of TMJ motion using surface markers.

The proposed method for assessing the mouth opening and lateral mandibular shift demonstrated excellent test-retest reliability with a low SEM, suggesting that the proposed method showed consistency. The excellent reliability for the surface marker method in this study (ICC=.77-.94) was comparable to that established for a conservative method using an inner mouth device (ICC=.83-.93) (Seedorf et al, 2004). However, the U-shaped clutch and face bow used in the OKA-3D conservative method was difficult to wear, expensive, and non-hygienic (Naeije et al, 1995). Although skin movement may be included as measurement error in using surface markers in this study, the surface marker method is reliable, inexpensive, simple and hygienic. Therefore, the proposed method can be used as an alternative method of testing the amount of mouth opening and lateral mandibular shift.

The amount of lateral mandibular shift at the end-range of mouth opening was significantly greater in the TMD group than the control group ($p<.05$). Link and Nickerson (1992) suggested that the anterior disc displacement in individuals with TMD induces lateral mandibular shift during mouth opening. Muscle imbalance and muscle spasm in the TMJ can induce lateral mandibular shift toward the contralateral side during mouth opening (Farrar, 1968; Link and Nickerson, 1992). Okeson and de Kanter (1996) suggested that habitual use and malocclusion induce muscle overload, resulting in abnormal movement patterns, such as lateral mandibular shift. Although this cross-sectional study did not address the cause of increased lateral mandibular shift in the TMD group, our results suggest that a significantly increased lateral mandibular shift may be a potential source of TMD, or vice versa. Further longitudinal studies are needed to assess the cause and effect relationship between TMD and lateral mandibular shift.

TMJ locking can prevent full range of mouth opening due to condylar dislocation or disk displacement (Poveda Roda et al, 2007; Stegenga, 2010). However, the amount of maximum mouth opening showed no significant difference between the TMD and control groups in this study ($p>.05$), because the subjects in this study were non-severe patients categorized as RDC/TMD-Axis Ia, with localized tenderness to palpation in the temporal muscles or masseters muscle area, resulting in no significant difference.

This study had several limitations. First, our subjects with TMD had mild discomfort and pain. Patients with severe pain in the TMJ should be assessed in further reliability studies. Second, we did not control the activation of facial muscles during the assessment of mouth opening and lateral mandibular shift. Hypercontraction of facial muscles during mouth movement can result in overassessment of the amount of mouth opening and lateral mandibular shift. Although the subjects were asked not to frown during maximal mouth opening, a more controlled methodology is needed to minimize the measurement error. Future study would be needed to compare the reliability and validity between using measurement method in this study and using other methods such as measurement of distance between upper and lower teeth or U-shaped clutch placed on the lower teeth or MRI. Lastly, because the sample size was small, larger studies will be required to confirm the reliability and validity in future study.

Conclusion

This proposed hygienic method of 3D ultrasound-based motion analysis using surface markers demonstrated excellent test-retest intrarater reliability in quantifying the mouth opening and lateral mandibular shift at the end-range of mouth opening. This proposed motion analysis method could be used as an alternative method to quantify the amount of mouth opening and lateral mandibular shift as a simple, inexpensive and hygienic method in patients with mild TMD. Lateral mandibular shift at the end-range of mouth opening was significantly greater in the TMD group than the control group. Therefore, assessing the amount of lateral mandibular shift at the end-range of mouth opening might be useful for evaluation and management of individuals with TMD.

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