Original Article

Development of a Measurement System for the Mechanical Load of Functional Appliances

Aya Shimazaki[1], Hitoshi Kimura[2], Norio Inou[2], Koutaro Maki[1]

[1]Department of Orthodontics, Showa University Dental Hospital, Tokyo, Japan

[2]Department of Mechanical Engineering, School of Engineering, Tokyo Institute of Technology, Tokyo, Japan

Corresponding author: Department of Orthodontics, School of Dentistry, Showa University. 2-1-1 Kitasenzoku, Ohta-ku, Tokyo 145-8515, Japan. Tel.: +81-3-3787-1151 Fax: +81-3-5734-2642

E-mail: shimazaki@dent.showa-u.ac.jp (A. Shimazaki), maki@dent.showa-u.ac.jp (K. Maki)

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Abstract

The morphology of the temporomandibular joint affects the force exerted by the masticatory muscles and, hence, the traction force needed to advance the mandible. The objective of this study was to develop a new device and to examine the mechanical load delivered to the mandible by the functional appliance as well as its relationship to the morphology of the mandibular condyle and articular eminence. Cone-beam computed tomography images of eight patients with skeletal Class II malocclusions due to mandibular undergrowth were acquired, and the angles indicating the shape of the mandibular condyle and articular eminence were measured. A new device was developed to calculate the traction force needed to advance the mandible in patients having a different morphology of the mandibular condyle and articular eminence. The results showed that the force of traction varied according to the morphology of the mandibular condyle and articular eminence. We concluded that the morphology of the mandibular condyle and articular eminence affect the amount of traction force needed to advance the mandible. The new measuring technique using the developed device might be effective for measuring the amount of traction force needed to advance the mandible.

1. Introduction

Functional appliances are removable devices that are used for the treatment of skeletal malocclusion caused by mandibular undergrowth (Andresen et al., 1953; Noro et al., 1994). Functional appliances have been widely used in clinical orthodontics for nearly a century. This type of therapy is mainly used in young patients. Nowadays, various types of functional appliances are used, for example, the Bionator and Activator (Balters, 1964; Harbold, 1974). Although the effects of functional appliances have been disputed, their mechanism of action underlying the improvement of skeletal malocclusion remains unclear (Ahlgren and Laurin, 1976; Bondevik, 1991, 1995; Weiland et al., 1997). These appliances are designed to advance the mandible forward and induce mandibular growth by changing the muscle tension and configuration of the temporomandibular joint (TMJ) assembly (Woodside et al., 1987). The shape of the mandibular condyle and articular eminence greatly affect the masticatory muscles and, hence, the occlusal load. Accordingly, the aim of this study was to develop a new device and to examine the mechanical load delivered to the mandible by the functional appliance as well as its relationship to the morphology of the mandibular condyle and articular eminence.

2. Materials and Method

2-1 Prototype mechanical slider

The force required to displace the mandible from the rest position to the advanced position was defined as the mandibular traction force (f). In order to measure the mandibular traction force (f), we developed a new device. First, we designed a prototype as a preliminary experiment. The upper and lower plates resembled the functional appliance. Bite registration was performed by bringing the incisors edge to edge, with a vertical opening of 4.0 mm, regardless of the initial overjet and overbite. A heat-curing acrylic resin (Orthocryl; Dentaurum Corporation) was used for fabrication. Before polymerizing the plates, the metal plate was interposed between the maxillary and mandibular dentitions. This metal plate had a thickness of 0.3-3.3 mm and had projections on each surface that would make a groove in the upper and lower acrylic portions.

A photo interrupter was attached to the mechanical slider, which was the main part of the new device. The photo interrupter is a sensor that can recognize whether the patient's dentition has reached the relatively advanced setting position. The upper and lower plates described above were fixed to the mechanical slider and developed into a prototype. The mandibular traction force (f) was measured using a digital weighing scale, which contained a strain gauge (Figure 1).

However, this prototype had some limitations. The first was that the plates easily slipped from the dentition, thus stopping the measurement process. The second was that the prototype required measuring the weight visually while checking the electrical signal from the photointerrupter. Therefore, accurate measurement was difficult.

2-2 Development of an automatic measurement device for mandibular traction force

The prototype was improved by utilizing data from the preliminary experiment. The plates must have an adequate retention to the forward position of the mandible. Accordingly, a cap clasp was added to the design of the plates, to utilize the undercut at the buccal side. A linear sensor was added to the mechanical slider to measure the displacement distance accurately. To ensure correct detection of the relatively advanced setting position, the photo interrupter and weighing scale were electrically connected to the central processing unit board (AP-SH2F-BA, PC-USB-04; Alpha Project company), which was connected to a computer (Figure 2). The positional information, judgement whether the relatively advanced setting position had been achieved or not, and elapsed time were recorded using a software (Tera-Term; Tera Term Project) every 0.5 s. The automatic measurement device was used to measure the mandibular traction force (f) for all the examined patients. The measurements were repeated multiple times (three to seven times) for the same patient. The sitting and supine positions were chosen as the measurement postures.

2-3 Subjects

As this was a pilot study, we included eight patients (four boys and four girls) diagnosed as having a skeletal Class II malocclusion due to mandibular undergrowth and treated using functional appliances. Patients with congenital and systemic diseases were not included in this study. The patients were over 6 years old and were required to have completed the eruption of all four upper and lower incisors. Their ages ranged from 7 years 10 months to 14 years 0 months. Before starting the functional appliance treatment, the possibility of free mandibular protrusion was checked, and in cases in which this was not achieved, necessary corrections were made before using the functional appliance. These corrections included maxillary or mandibular incisor leveling, and normalizing the maxillary or mandibular incisor axial inclination. All the patients provided written informed consent, and the study was approved by the Ethics Committee of the Showa University Dental Hospital.

2-4 Cone-beam computed tomography (CBCT)

To understand the morphological features of the TMJ, the following measurement points were used in this study from the initial examination using CBCT data (Figure 3) (Ilguy et al., 2014; Katsavrias, 2002; Katsavrias, 2003; Tadej et al., 1987).

1. Fr: Fossa roof (the highest point of the fossa)
2. Ae: Articular eminence height (the lowest point of articular eminence)
3. Po: porion (the highest point of the auditory meatus)
4. Or: orbitale (the lowest point on the lower edge of the orbit)
5. U6: upper first molar mesial cusp
6. U5: upper second premolar or primary molar buccal cusp
7. L6: lower first molar mesial cusp
8. L5: lower second premolar or primary molar buccal cusp
9. Ce: the point at which the F1 line cuts the eminence posterior surface

The following planes were established using the above measurement points.

1. FH plane: the plane passing through the Or and Po
2. F1: the line parallel to the FH plane passing through point Ce
3. Occlusal plane: the plane passing through U6, U5, L6, and L5 as the best-fit line
4. Fr-Ae plane: the plane passing through Fr and Ae
5. Ebf plane: the best-fit plane of the articular eminence inclination connecting the Ce
6. Ca-Cp: the broadest distance of the condyle
7. a-b: the most narrow distance of the condylar neck
8. Cc line: a line perpendicular to the Ca-Cp line, drawn from the middle of the Ca-Cp line (Cm)

In order to understand the morphology of the mandibular condyle, we measured the angles formed between the occlusal plane and the Fr-Ae plane, Ebf line, Ca line, and Cc line. Moreover, the angles between the FH plane and the Fr-Ae plane, Ebf line, Ca line, and Cc line were measured.

3. Results

For investigating the relationship between condylar morphology and mandibular traction force (f), the eight patients underwent measurements by using the automatic measurement device. The mandibular traction force, displacement distance of the mandible, and elastic modulus of the mandible were measured (Table 1). The angle measurements indicating the morphology of the mandibular condyle are summarized in Tables 2 and 3.

Discussion

The results of measuring the mandibular traction force (f) showed that the traction force while the patients were in the supine position was on average 200 g more that it was in the sitting position. This might be attributed to the effect of gravity. In other words, the change is assumed to be due to the influence of the mass of the mandibular bone and its surrounding soft tissue. The morphology of the mandible differs among the patients. For example, patient A had small values for the angles θFr-Ae, θEbf, θCa, and θCc (Figure 4a); in contrast, patient B had higher values (Figure 4b). Several relationships were observed between the morphological characteristics of the mandibular condyle and the articular eminence on one side and the mandibular traction force on the other side. We found that patients who had small values for the angles θFr-Ae, θEbf, θCa, and θCc required less mandibular traction force, and patients who had higher values for the same angles required more mandibular traction force. The correlation coefficient between the angle θCc・FH plane and mandibular traction force was statistically significant (P=0.007). Previous studies have proposed that individuals with a lower bite force or thinner masseter muscles seem to show a greater dentoalveolar sagittal change in response to functional appliance treatment (Antonarakis et al., 2012; Kiliaridis et al., 2010). In this study, we found that the mandibular morphology, especially the angle of the center of the condyle, was relevant to the mandibular traction force. This could be because when the mandible is advanced, the condyle slides forward along the eminence. Therefore, the angle of the center of the condyle is big, and hence, more mandibular traction force is needed to advance the mandible. However, in the clinical setting, patients unconsciously demonstrate muscle strength and individual differences in the joint capsule; therefore, not all patients always show this tendency.

4. Conclusion

We concluded that the morphology of the mandibular condyle and articular eminence affect the amount of traction force needed to advance the mandible. The new measuring technique using the developed device might be effective for measuring the amount of traction force needed to advance the mandible. This might help identify the required traction force for each individual according to the morphology of his/her condyle and articular eminence.

Conflict of interest statement

The authors declare no conflict of interest and declare no financial or personal relationship with any organization or people that would influence the outcomes of this research.

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Figure 1 Patient's plaster models (a), metal plate (b), prototype device (c), and measurement scenario with the prototype.

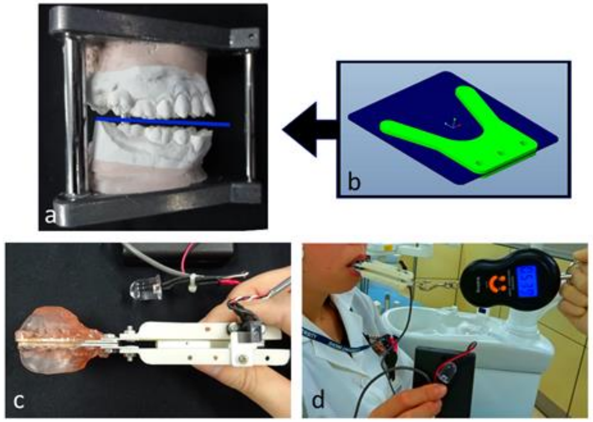


Figure 2 Linear sensor (a), photo interrupter (b,c), digital weighing scale containing a strain gauge (d), and overall view of the automatic measuring device for mandibular traction force (e).

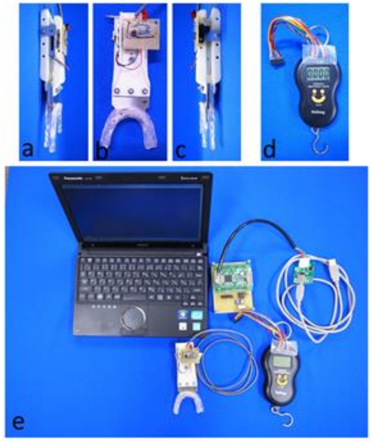


Figure 3 The points used in this study (a,b) and the planes used in this study (c,d).

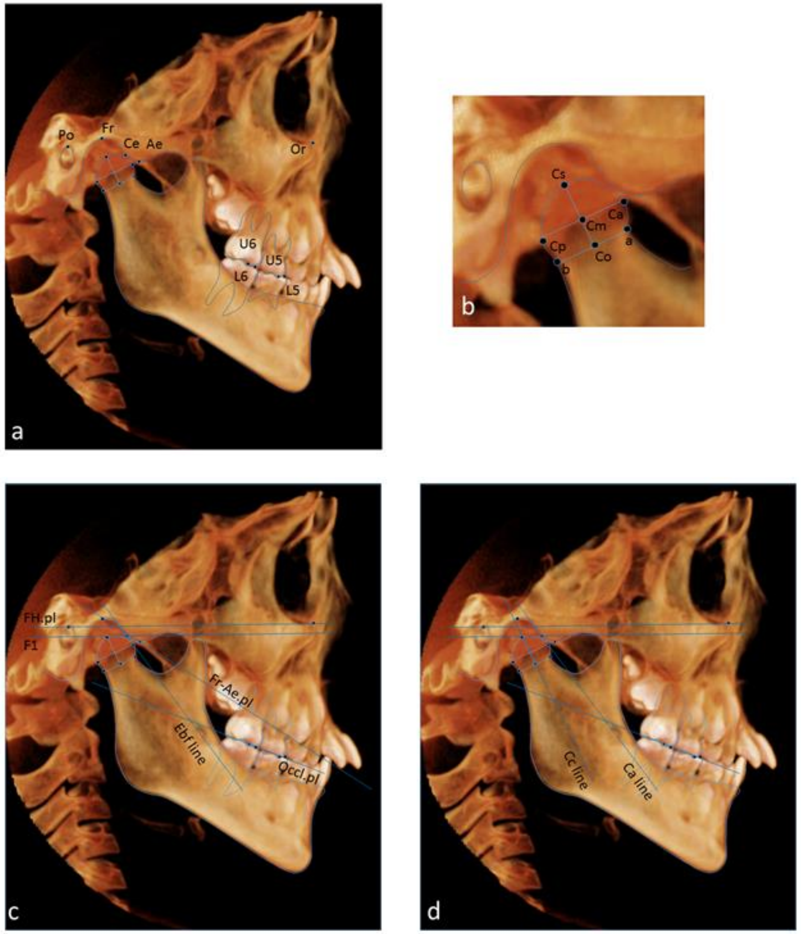
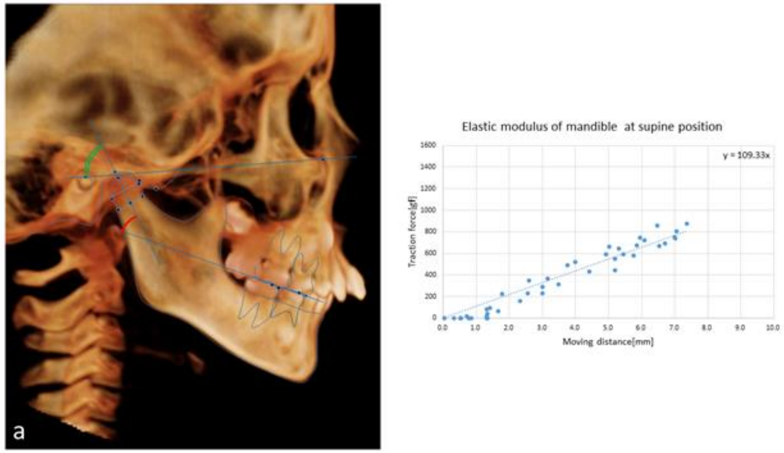


Figure 4 Comparison of patient A and B



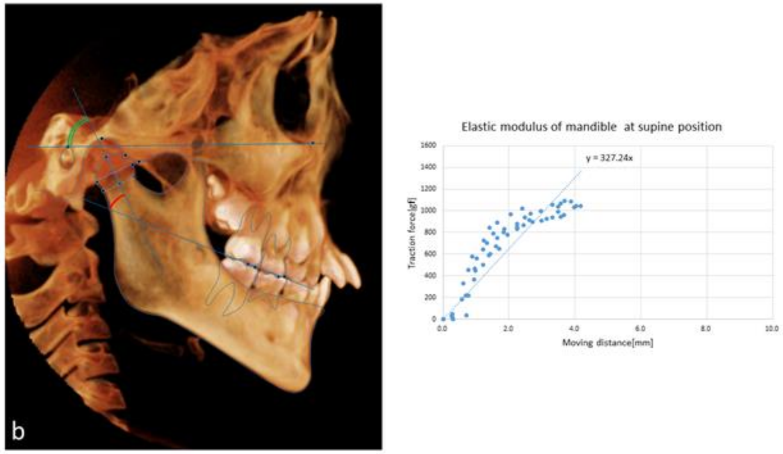


Table 1 Mandibular traction force (f), displacement distance, and elastic modulus of the mandible.

Measurement	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
Mandibular traction force [gf] Sitting	197	390	426	222	1363	477	1321	994
Supine	626	951	517	339	1372	499	1477	1411
Displacement distance of the mandible [mm] Sitting	4.9	2.2	4.3	2.4	3.4	3.0	7.3	8.9
Supine	5.5	2.6	4.7	3.2	4.8	2.8	8.7	9.0
Elastic modulus of the mandible [gf/mm] Sitting	48	161	96	101	377	169	188	139
Supine	109	327	103	124	324	184	186	215

Table 2 The angle measurements indicating the morphology of the mandibular condyle with the occlusal plane (Occ.pl)

Measurement	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
θ Fr-Ae・Occ.pl	19.5	21.2	16.2	20.4	18.2	30.1	25.2	32.1
θ Ebf・Occ.pl	28.2	31.7	24.1	23.5	23.8	43.6	34.2	35.8
θ Ca・Occ.pl	31.8	35.9	20.2	27.2	26.9	35.6	33.2	41.5
θ Cc・Occ.pl	53.6	61.7	55.6	62.8	66.7	63.0	55.2	75.7

Table 3 The angle measurements indicating the morphology of the mandibular condyle with the Frankfort plane (FH.pl)

Measurement	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
θ Fr-Ae・FH.pl	25.0	35.1	30.5	31.0	33.6	35.9	42.6	32.6
θ Ebf・FH.pl	43.8	48.3	40.1	42.2	45.4	48.7	62.0	42.9
θ Ca・FH.pl	34.9	31.0	33.5	38.4	40.8	41.6	52.6	45.2
θ Cc・FH.pl	68.8	73.1	74.7	75.6	83.6	76.1	76.0	78.4