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Short communication

# Development of a measurement system for the mechanical load of functional appliances

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ABSTRACT

Devices called functional appliances are commonly used in orthodontics for treating maxillary protrusion. These devices mechanically force the mandible forward to apply traction force to the mandibular condyle. This promotes cartilaginous growth in the small mandible. However, no studies have clarified how much traction force is applied to the mandibular condyle. Moreover, it remains unknown as to how anatomical characteristics affect this traction force. Therefore, in this study, we developed a device for measuring the amount of force generated while individual patients wore functional appliances, and we investigated the relationship between forces with structures surrounding the mandibular condyle. We compared traction force values with cone-beam computed tomography image data in eight subjects. The functional appliance resulted in a traction force of 339–1477 gf/mm, with a mean value of 196.5 gf/mm for the elastic modulus of the mandible. A comparison with cone-beam computed tomography image data suggested that the mandibular traction force was affected by the mandibular condyle and shape of the articular eminence. This method can contribute to discovering efficient treatment techniques more suited to individual patients.



## 1. Introduction

Various muscles, including the digastric muscle, lateral pterygoid muscle, masseter muscle, temporal muscle, and medial pterygoid muscle, are attached to the mandible, which is the masticatory organ of humans. 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). This functional appliance differs from general removable appliances that are fitted to the upper or lower dentition, as it is characterized by a monoblock shape, whereby the top and bottom devices have been combined into one device. Functional appliances are designed to maintain the mandible forward position. When such a functional appliance is fitted, the muscles attached to the mandible try to pull the mandible backward to its original resting position. This force acts on and is said to promote cartilaginous growth of the mandibular condyle (Woodside et al., 1987). Additionally, it forces the teeth in the upper dentition diagonally to the lingual side. Nowadays, various designs of functional appliances have been developed so far, and these have been widely used in clinical orthodontics (Balters, 1964; Harbold, 1974).

However, a method of measuring how much force was being applied to the mandibular condyle in individual patients with the functional appliance attached did not previously exist. Furthermore, as it was unclear as to how anatomical characteristics affect such force, it had been impossible to evaluate how much growth was promoted. 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). Hence, 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. Development of an automatic measurement device for mandibular traction force

The force required to displace the mandible from the rest position to the advanced position was defined as the mandibular

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traction force (f). To measure f, we developed a new device. Fig. 1 shows process of the mandibular traction measuring device fabrication. The main part of device (Fig.1a-ii) engages in forward and backward rectilinear motion through a linear guide (Fig.1a-i). A photo interrupter and linear sensor were fitted to the each sides (Fig.1a-iii). The photo interrupter is a sensor that can recognize whether the patient's dentition has reached the relatively advanced setting position. This made it possible for the linear sensor to accurately measure the linear guide displacement distance. There is a male part of the metal plate (Fig.1a-iv) for affixing the intraoral plate to the end of the device.

The upper and lower intraoral plates resembled the functional appliance. Functional appliances are fabricated with the mandible in a characteristic position called the construction bite. Thus, 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. The upper and lower dentition plaster models were attached to an articulator in this construction bite position (Fig. 1b). A heat-curing acrylic resin (Orthocryl; Dentaurum GmbH & Co.) was used for fabrication. Usually, the resin is applied in this position to complete a normal monoblock functional appliance (Fig. 1c). Since the intraoral plates of the mandibular traction force measurement device needs to be divided between the maxillary and mandibular sites, before polymerizing the plates, a metal plate for division (Fig. 1d) 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 (female part) in the upper and lower acrylic portions (Fig. 1e). The intraoral plates must have adequate retention to prevent the plates from easily coming off the dentition. Accordingly, intraoral plates use the undercut of the buccal side.

The aforementioned female part of the upper and lower intraoral plates were fixated to the male part of the metal plate with mechanical sliding to create the mandibular traction force measurement device (Fig. 2a–c). The f was measured using a digital weighing scale, which contained a strain gauge (Fig. 2d). All data from the photo interrupter, linear sensor, and digital weighing scale were collected electrically. To ensure correct measurement, the photo interrupter, linear sensor, 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 (Fig. 2e). The positional information of the mandible, whether the relatively advanced setting position had been achieved, f, and elapsed time were recorded using a software program (Tera Term; Tera Term Project) every 0.5 s. The automatic measurement device was used to measure f for all the examined patients. The measurements were repeated five times for the same patient. The sitting and supine positions were chosen as the measurement postures.

### 2.2. Subjects

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 more than 6 years and were required to have completed eruption of all four upper and lower incisors. The average age of the subjects was 10 years 11 months. Before starting the functional appliance treatment, the possibility of free mandibular advancement was checked, and in subjects in whom 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 (2014–013).

### 2.3. Cone-beam computed tomography (CBCT)

To understand the morphological features of the temporomandibular joint, the following measurement points were used in this study from the initial examination using CBCT image data (Fig. 3) (Ilguy et al., 2014; Katsavrias, 2002; Katsavrias, 2003; Tadej et al., 1989).

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

The following planes were established using the aforementioned measurement points.

- FH plane: the plane passing through the Or and Po
- F1: the line parallel to the FH plane passing through point Ce
- Occlusal plane: the plane passing through U6, U5, L6, and L5 as the best-fit line
- Fr-Ae plane: the plane passing through Fr and Ae
- Ebf plane: the best-fit plane of the articular eminence inclination connecting the Ce
- Ca-Cp: the broadest distance of the condyle

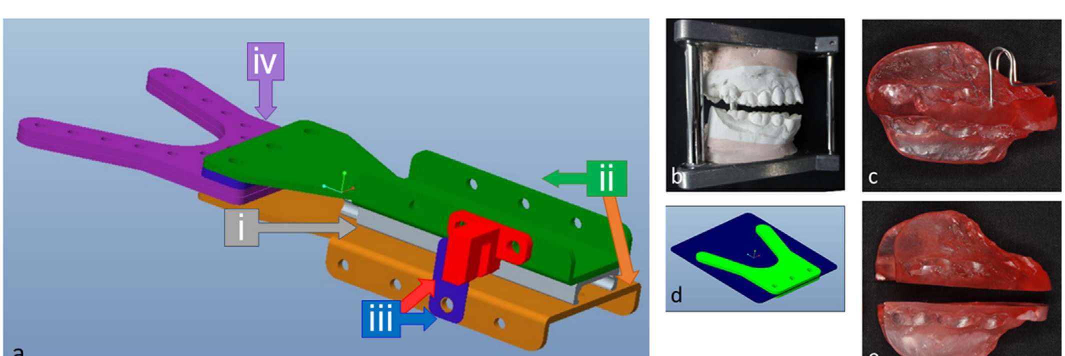


**Fig. 1.** Process of device fabrication. Schematic diagram of the main part of device (a), patient's plaster models (b), normal monoblock functional appliance (c), metal plate for division (d), upper and lower intraoral plates (e).

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