Bite force measurement system using pressure-sensitive sheet and silicone impression material

Katsuya ANDO, Yuji FUWA, Masahiro KUROSAWA, Takamasa KONDO and Shigemi GOTO

Department of Orthodontics, School of Dentistry, Aichi-Gakuin University, 2-11 Suemori-dori, Nagoya, Aichi 464-8651, Japan
Corresponding author, Katsuya ANDO; E-mail: ankatsu@dpc.aichi-gakuin.ac.jp

This study was conducted to reduce the bias in measured values caused by the thickness of materials used in occlusal examinations. To this end, a silicone impression material for bite force measurement and an experimental model of a simplified stomatognathic system were employed in this study. By means of this experimental model, results showed that the effect of bias toward the posterior arch could be reduced in the anterior-posterior distribution of bite forces and in the occlusal contact areas due to the thickness of the materials used in occlusal examinations.

Key words: Bite force, Occlusal contact area, Silicone impression material

INTRODUCTION

During an occlusal examination, the occlusal contact area and bite force of a patient provide valuable information for oral disease diagnosis, treatment, and prognosis. Presently, a variety of occlusal examination methods are available. They include occlusal registration by articulating paper, examination with dental cast models mounted on an articulator, and occlusal analysis by muscle activity or mandibular movements. However, these methods have been indicated to be frequently and heavily influenced by the subjectivity and clinical experience of practitioners. Against this background, an accurate measurement method and a set of objective measurement standards for bite force analysis are not only highly desired, but that they must be established promptly.

In 2004, a system was introduced which comprised a CCD camera (Occluser FPD 707, Fuji Film Corp., Tokyo, Japan) and a bite force measurement system using a pressure-sensitive sheet (Dental Prescale 50H, type R, Fuji Film Corp.). In terms of advantages, this new bite force measurement system is first of all not influenced by the subjectivity and experience of practitioners. Another advantage is that it requires only a simple chairside procedure to measure occlusal contact areas and bite forces easily, objectively, and quantitatively (Figs. 1 and 2). However, a disadvantage of this occlusal examination method has been indicated. The disadvantage lies in the use of an interocclusal material with a certain thickness, such as the pressure-sensitive sheet. As a result, over-detection of the occlusal contact area and bite force of the posterior teeth near the hinge axis occurs.

In light of the over-detection drawback, there arose a need to measure the occlusal contact area objectively and quantitatively using a silicone impression material that has high fluidity and almost non-existent thickness at the occlusal contact area. In conjunction, a light transmission device was developed to read the silicone impression material using a bite force measurement system (Fig. 3). With which, the occlusal contact area of the silicon impression material and its thickness limit of readable range were measured, thereby demonstrating its efficaciousness.

The objective of this study was to compare the occlusal contact areas obtained from the silicone impression material and pressure-sensitive sheet using the herein-mentioned experimental model of a simplified stomatognathic system. The occlusal contact area obtained from the silicone impression material and the average bite pressure obtained from the pressure-sensitive sheet were then multiplied to estimate the bite force when there was nothing between the occlusal surfaces. Thereafter, the estimated bite forces were compared with the bite forces obtained from the pressure sensors, which were incorporated into the experimental model and used in place of teeth.

MATERIALS AND METHODS

Experimental model
Apart from the thickness of materials used in an occlusal examination, another aspect of concern in occlusal contact area measurement is the anterior-posterior distribution of bite forces. Several factors integrally affect the anterior-posterior distribution of bite forces. They are namely: changes in the
positions of teeth and mandible, elastic deformation of the jaw bone, load on the periodontal soft tissue, lever effect, and masticatory muscle activities. To minimize the influence of these factors, an experimental model (Hanau H2-0) (Water Pik Technology Inc., Colorado, USA) of a simplified stomatognathic system, without premature contacts using a semi-adjustable articulator (Fig. 4), was constructed in this study.

The lower arch of the articulator had pressure sensors (LM-10KA, Kyowa Electronic Instruments Corp., Tokyo, Japan) substituted for teeth. Each sensor had a sensitive element which comprised a spherical surface of 4 mm radius to directly measure the bite force at each occlusal contact point. A total of four sensors were placed, with one sensor each in the left and right regions of anterior teeth and the left and right molar regions. In the maxillary arch of the articulator, an attached glass plate came into contact simultaneously with the four pressure sensors.

As for the condylar spheres of the articulator, they were designed to reduce the lever effect upon detecting a biting force in the region of the anterior teeth from the time a small load was applied. To achieve this reduction in lever effect, a path of condylar guidance with the molar region as the fulcrum was established so that the condyle could slide anterosuperiorly without resistance. To prevent loading the articulator in advance, a counterbalance was added to the maxillary posterior region so that weights were balanced in the anterior and posterior regions in the maxillary arch centering on the articulator hinge axis. In addition, anterosuperior
movements of the condylar spheres were allowed without hindrance from the weight of the counterbalance or the maxillary arch in articulator. To achieve these movements, the load was lifted immediately before the right and left condylar spheres floated from the superior direction. Then, a constant-load compression tester (AGS-A, Shimadzu Corp., Kyoto, Japan) was used to apply a load to the articulator in the center of each of the four sensors, whereby real-time value at each pressure sensor was measured using an instrumentation amplifier (WGI-300B-1, Kyowa Electronic Instruments Corp.) (Fig. 5).

The load applied ranged from 1 kgf to 7 kgf at 1-kgf intervals and at a speed of 1 mm/min. At each load value, 10 measurements were made with the instrumentation amplifier. To examine whether the experimental model had the adequate accuracy required for this investigation, the relationship between loads applied with a constant-load compression tester and the values measured by the pressure sensors was studied.

**Occlusal contact areas obtained from the silicone impression material and pressure-sensitive sheet**

The materials placed between the occlusal surfaces of the articulator were namely a dark gray silicone impression material, a single pressure-sensitive sheet, or a stack of two pressure-sensitive sheets. Loads ranging from 4 kgf to 7 kgf, increasing at 1-kgf intervals, were applied.

The mixed silicone impression material was molded using a 1-mm-thick frame as a guide, which was placed on the peripheral border of the glass plate of the maxillary arch in the articulator. For occlusal contact area measurement using the silicone impression material, it was performed 10 times each at the four points of the anterior, posterior, right, and left areas. Occlusal contact area measurement was then carried out using the bite force measurement system with a built-in light transmission device. Similarly, for occlusal contact area measurements using the single pressure-sensitive sheet and a stack of two pressure-sensitive sheets, they were performed 10 times each using the bite force measurement system.

Average values of the right and left measurements of these three types of materials were used as representative values for scattergrams' plotting. Regression equations, which expressed the anterior-posterior distributions in the regions of anterior and posterior teeth, were calculated and comparisons were made.

**Comparison of bite forces obtained from a single pressure-sensitive sheet, two pressure-sensitive sheets, and silicone impression material and estimation of bite force with nothing between the occlusal surfaces**

To measure the bite force when there was nothing between the occlusal surfaces, measurements were performed at the four pressure sensors located in the anterior, posterior, left, and right areas. Loads of 4 kgf to 7 kgf were applied at 1-kgf intervals, and
measurement at each sensor was performed 10 times using an instrumentation amplifier. Values obtained were converted from kgf to N.

With the single pressure-sensitive sheet and two pressure-sensitive sheets, their average bite forces were measured 10 times each using the bite force measurement system. To estimate the bite force with nothing between the occlusal surfaces, it was obtained by multiplying the occlusal contact area obtained from the silicone impression material and the average bite pressure from the single pressure-sensitive sheet. For the four different conditions (namely the three types of materials and with nothing between the occlusal surfaces), the average values of the calculated or measured left and right values were used as the representative values, and a scattergram was plotted for each. Thereafter, the regression equations, which expressed the anterior-posterior distributions in the regions of anterior and posterior teeth, were calculated and comparisons were made.

RESULTS

Accuracy of the experimental model

The relationship between the loads applied with a constant-load compression tester and the values measured by the pressure sensors was expressed by the regression line, \( y = 0.24x + 0.04 \), for the anterior teeth region, and \( y = 0.24x + 0.09 \) for the posterior teeth region. The y-intercepts of the regression lines converged at almost 0. A proportional relationship was found between the loads applied and the values measured by the pressure sensors for the two
regression lines. In addition, the slopes and y-intercepts of the two regression lines were similar (Fig. 6).

**Occlusal contact areas obtained from the silicone impression material and pressure-sensitive sheet**
The following regression equations expressed the anterior-posterior distributions of occlusal contact areas obtained from the silicone impression material, single pressure-sensitive sheet, and two pressure-sensitive sheets, respectively: 

\[ \begin{align*}
    y &= 0.57x + 0.04, \\
    y &= 0.32x + 0.03, \\
    y &= 0.23x + 0.01 \quad (\text{Fig. } 7).
\end{align*} \]

**Comparison of bite forces obtained from single pressure-sensitive sheet, two pressure-sensitive sheets, and silicone impression material and estimation of the bite force with nothing between the occlusal surfaces**
The regression equation, \( y = 0.96x + 0.05 \), expressed the anterior-posterior distribution of bite forces obtained from the pressure sensors. The regression equation, \( y = 0.47x + 0.01 \), expressed the anterior-posterior distribution of the bite forces obtained by multiplying the average bite pressure of the single pressure-sensitive sheet and the occlusal contact area of the silicone impression material. The regression equation, \( y = 0.33x - 0.43 \), expressed the anterior-posterior distribution of the bite forces obtained from the single pressure-sensitive sheet. The regression equation, \( y = 0.21x - 0.64 \), expressed the anterior-posterior distribution of the bite forces obtained from the stack of two pressure-sensitive sheets (Fig. 8).

**DISCUSSION**

**Accuracy of the experimental model**
The y-intercepts of the regression lines of the anterior teeth and posterior teeth regions almost converged at 0. The regression lines expressed the relationship between the values measured by the pressure sensors and the loads applied by the constant-load compression tester. From this result, it seemed that the weights in the anterior and posterior regions of the maxillary arch centering on the articulator hinge axis were balanced by adding the counterbalance. Therefore, loading the maxillary anterior arch in advance was thought to have a counterbalancing effect.

The regression lines of the anterior and posterior teeth regions were directly proportional and were almost the same. From this result, the anterior and posterior pressure sensors could be considered to have the necessary accuracy within the predetermined loading range (i.e., 1 kgf to 7 kgf) for this investigation. Therefore, by virtue of this result, the constructed experimental model enabled the understanding of the anterior-posterior distribution of bite forces when nothing was between the occlusal surfaces by using pressure sensors in place of teeth.

**Study of the occlusal contact areas obtained from the silicone impression material and pressure-sensitive sheet**

---

**Fig. 7** The regression equations expressed the anterior-posterior distribution of occlusal contact areas obtained from the silicone impression material, single pressure-sensitive sheet, and two pressure-sensitive sheets.

**Fig. 8** The regression equations expressed the anterior-posterior distribution of bite forces obtained from the silicone impression material, single pressure-sensitive sheet, two pressure-sensitive sheets, and the pressure sensors.
The slope of the regression equation expressing the anterior-posterior distribution of the occlusal contact areas for the single pressure-sensitive sheet was smaller than that for the silicone impression material. This result indicated a bias of the anterior-posterior distribution of the occlusal contact areas toward the molar region. Such a slope for the stack of two pressure-sensitive sheets was smaller than that of the single pressure-sensitive sheet. This result further confirmed the notion that the anterior-posterior distribution of occlusal contact areas was indeed biased toward the molar region.

When an impression material used in an occlusal examination has some thickness, it has the effect of biasing the anterior-posterior distribution of occlusal contact areas toward the posterior arch near the hinge axis. From the above results, it was shown that occlusal contact area measurement using silicone impression material with almost non-existent thickness at the occlusal contacts could reduce the effect of such bias.

Comparison of bite forces obtained from the single pressure-sensitive sheet, two pressure-sensitive sheets, and silicone impression material and the estimation of bite force with nothing between the occlusal surfaces

The slope of the regression equation expressing the anterior-posterior distribution of bite forces obtained from the single pressure-sensitive sheet was smaller than that obtained from the pressure sensors. This result indicated that the anterior-posterior distribution was biased toward the molar region. Further, the slope of the regression equation expressing the anterior-posterior distribution of bite forces obtained from the two pressure-sensitive sheets was small compared to that obtained from the single pressure-sensitive sheet. Similarly, this result indicated a bias of the anterior-posterior distribution of bite forces toward the molar region. Upon comparing the following regression equations which expressed the anterior-posterior distribution of bite forces, namely (1) multiplying the average bite pressure of the single pressure-sensitive sheet and the occlusal contact area of the silicone impression material; (2) values measured from the pressure sensors; and (3) values obtained from pressure-sensitive sheets, it was found that the regression equation from (1) was more similar to (2) than to (3).

When an impression material used in an occlusal examination has some thickness, it has the effect of biasing the anterior-posterior distribution of bite forces toward the posterior arch near the hinge axis. From the above results, the method which derived the bite force by multiplying the average bite pressure (obtained from the single pressure-sensitive sheet) and the occlusal contact area (obtained from the silicone impression material) was thought to reduce the effect of such bias. In addition, the method which derived the bite force using the pressure-sensitive sheet and silicone impression material could be used as a means to establish the criteria for estimating the bite force with nothing between the occlusal surfaces. In the future, the next step forward is to establish a reliable and accurate method of obtaining occlusal contact areas using pressure-sensitive sheet and silicone impression material.

CONCLUSIONS

This study was conducted to reduce the bias of measured values due to the thickness of materials used for occlusal examinations. Silicone impression material was applied to a bite force measurement system, and comparisons were made between the occlusal contact areas obtained from the pressure-sensitive sheet and the silicone impression material using the experimental model—a simplified stomatognathic system. Bite force was obtained by multiplying the occlusal contact area from the silicone impression material and the average bite pressure obtained from the pressure-sensitive sheet. This estimated bite force was then compared against the bite force obtained from the pressure sensors incorporated into the experimental model. By this comparison process involving different methods and the results thereof yielded in this study, it was thus determined whether it was possible to estimate the bite force with nothing between the occlusal surfaces.

1) A method was used to measure occlusal contact areas by means of a silicone impression material with the bite force measurement system and with a light transmission device. Results of this study showed that this method reduced the effect of bias toward the posterior arch in the anterior-posterior distribution of occlusal contact areas, which is typically caused by the thickness of materials used in occlusal examinations.

2) A method was used to derive the bite force by multiplying the average bite pressure obtained from the pressure-sensitive sheet and the occlusal contact area obtained from the silicone impression material. Results of this study showed this method reduced the effect of bias toward the posterior arch in the anterior-posterior distribution of bite forces due to the thickness of materials used in occlusal examinations. In light of the encouraging results of this study, it was thus suggested that such a method of deriving bite forces could be used as a means of establishing
criteria for estimating the bite force with nothing between the occlusal surfaces.

ACKNOWLEDGEMENTS
This study was supported in part by a Grant-in-aid for the High-Tech Research Project (2003–2007) from the Ministry of Education, Culture, Sports, Science and Technology, Japan.

REFERENCES