A Study on Measuring Occlusal Contact Area Using Silicone Impression Materials: an Application of this Method to the Bite Force Measurement System Using the Pressure-sensitive Sheet

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The aim of this study was to establish an objective and quantitative method of measuring occlusal contact areas. To this end, bite records were taken with a silicone impression material and a light transmission device was used to read the silicone impression material. To examine the effectiveness of this novel method, the occlusal contact area of the silicone impression material and its thickness limit of readable range were measured. Results of this study suggested that easy and highly accurate measurements of occlusal contact area could be obtained by selecting an optimal applied voltage of the light transmission device and an appropriate color of the silicone impression material.

Keywords: Occlusal contact area, Silicone impression material, Pressure-sensitive sheet

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.). This system reads data faster than a previous system using a scanner (Occluser FPD 703, Fuji Film Corp.). More importantly, measurement accuracy is increased with this system (Figs. 1 and 2). As for the pressure-sensitive sheet, it becomes red when microcapsules with varied sizes in the sheet break — depending on the load that is placed on the sheet. In terms of measurement standard, a constant correlation exists between the intensity of red color and the load pressure in the range of 5—120 MPa.

With the abovementioned bite force measurement system, the average bite pressure and occlusal contact area are measured by reading the red areas on the pressure-sensitive sheet. In addition, the bite force can be determined by taking the integral of the average bite pressure times the occlusal contact area.

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 chairs-side procedure to measure occlusal contact areas and bite forces easily, objectively, and quantitatively. 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.

Among the materials used for examining occlusion, the silicone impression material is thought to be more effective because it has high fluidity and almost no thickness at occlusal contact point. However, occlusal contact area measurement performed using conventional silicone impression material requires complicated procedures. Therefore, such a material is not considered suitable for measuring numerous occlusal contact points on dentition. In addition, the present bite force measurement system cannot handle the reading of silicone impression materials.

The aim of this study, therefore, was to establish an objective and quantitative method of measuring occlusal contact areas using a silicone impression material. To this end, a light transmission device was used in conjunction with a bite force measurement system to read the silicone impression material. To examine the effectiveness of this novel method, the occlusal contact area of the silicone impression material and its thickness limit of readable range were measured.
MATERIALS AND METHODS

Experimental setup and equipment
An indenter was attached to the load cell which was in the upper part of a constant-load compression tester (EZ Test, SHIMADZU, Kyoto, Japan), while a glass plate was attached to the lower table (Fig. 3).

Presently, the bite force measurement system (Occluzer FPD 707, Fuji Film Corp.) calculates the occlusal contact area and the average bite pressure of the red-colored areas. Therefore, it is not able to read a silicone impression material. With a view to displaying in red the occlusal contact points registered on the silicone material, a red electroluminescence sheet (EL sheet) of 0.25 mm thickness was built into an Occluzer cassette (Fig. 4). This sheet uniformly luminesced when an alternating voltage is applied to the fluorescent substances dispersed in a binder with a high dielectric constant.
was applied to fluorescent substances dispersed in a binder with a high dielectric constant. To make the light transmission device, a power source which could be continuously varied to a maximum applied voltage of 12 V was used (Fig. 5).

Experimental approach
To examine if light transmission at the occlusal contact points changed with the color of the silicone impression material, the following materials were used: white silicone impression material (Fit Checker II, GC Corp., Tokyo, Japan), black silicone impression material (Bite Checker, GC Corp.), light and dark gray silicone impression materials made from mixing the white and black silicone impression materials, and pressure-sensitive sheet.

Two types of occlusal contacts were used in this study: a flat indenter with a 0.8 mm radius was attached to the load cell in the upper part versus a spherical indenter with a 4.0 mm radius. Then, either a silicone impression material or a pressure-sensitive sheet was placed in between the indenter and the glass plate. The silicone impression material was mixed using a conventional method. It was molded using a frame of 1 mm thickness that was placed on the peripheral border of the glass plate of the lower table. A load of 30 kgf was applied at a speed of 1 mm/min (Fig. 6).

**Occlusal contact area using a flat indenter**
With a flat indenter, the area which contacted the material was the so-called "true" occlusal contact area. This was obtained by finding the cross-sectional area. In this study, the flat indenter used was made by cutting a cylindrical metal rod. To ensure the absence of deformation in the indenter due to the cutting, the occlusal contact area of the flat indenter was calculated — and compared — by measuring the diameters of the cross-section of the entire circumference using a digital caliper.

For the built-in light transmission device with the bite force measurement system, the applied voltage was varied at 0 V, 6 V, and 12 V. Measurements were made on four types of loaded silicone impression materials. As for the loaded pressure-sensitive sheet, it was placed in a cool, dark place for 30 minutes or more to stabilize its color formers, and then the bite force measurement system used for its measurements. The measurement for each impression material was performed 10 times, and the measured values including those of the cross-sectional area of the flat indenter were examined and compared.

**Occlusal contact area and thickness limit of readable range using a spherical indenter**
When a flat indenter was used against a flat surface, it was easy to establish the cross-sectional area of the indenter. However, when a spherical indenter was used against a flat surface, it was very difficult to establish the area of the indenter in contact with the material — the so-called "true occlusal contact area". Therefore, it was necessary to use an index to express the occlusal contact of a material when loaded with a spherical indenter in an occlusal examination. For such an index, we decided to use a numerical value to indicate how much material was between the indenter and the glass plate at the point of contact. The formula that we used was devised by Nakao, which calculated the silicone material thickness at the point of contact. The measured occlusal contact area of each material and the established
radius of the spherical indenter were used to calculate the thickness limit of the silicone material. This limit (hereafter known as the "thickness limit of readable range") was the thickness that could be penetrated by red light to a degree sufficient to be recognized as the occlusal contact area by the bite force measurement system (Fig. 7)\textsuperscript{21-23}.

For all the four types of loaded silicone impression materials, their measurements were performed under an applied voltage of 12 V for the built-in light transmission device with the bite force measurement system. This applied voltage was determined to be optimal from the experimental results using a flat indenter with the above system. The obtained occlusal contact area and the radius of the spherical indenter were then applied in Nakao’s formula to calculate the thickness limit of readable range. The above measurements and calculations were performed 10 times for each material, and the results were examined and compared.

Statistical analysis
To compare the values of occlusal contact area and calculated thickness limit of readable range among the materials, analysis of variance followed by multiple comparison analysis were performed.

\begin{equation}
\text{RESULTS}
\end{equation}

**Occlusal contact area using a flat indenter**

1) Occlusal contact areas of silicone impression materials with varied applied voltages

With the white silicone impression material, the occlusal contact areas were 1.74 mm\(^2\) for 0 V, 1.84 mm\(^2\) for 6 V, and 1.93 mm\(^2\) for 12 V (Fig. 8). With the light gray silicone impression material, the occlusal contact areas were 1.59 mm\(^2\) for 0 V, 1.69 mm\(^2\) for 6 V, and 1.81 mm\(^2\) for 12 V (Fig. 9). With the dark gray impression material, the occlusal contact areas were 1.40 mm\(^2\) for 0 V, 1.57 mm\(^2\) for 6 V, and 1.73 mm\(^2\) for 12 V (Fig. 10). For these three types of silicone impression materials, the occlusal contact areas were measured as follows:

\begin{equation}
\text{Fig. 8} \quad \text{Occlusal contact areas of white silicone impression material with varied applied voltages. The occlusal contact area obtained from white impression material increased significantly (p<0.05) as the applied voltage of the light transmission device increased.}
\end{equation}

\begin{equation}
\text{Fig. 9} \quad \text{Occlusal contact areas of light gray silicone impression material with varied applied voltages. The occlusal contact area obtained from light gray impression material increased significantly (p<0.05) as the applied voltage of the light transmission device increased.}
\end{equation}

\[ h = R - \sqrt{R^2 - \frac{a}{\pi}} \]

Fig. 7 The method used was based on Nakao’s formula to calculate the thickness limit of readable range of silicone impression material.
area increased significantly as the applied voltage of the light transmission device increased. As for the black silicone impression material, the occlusal contact areas were 0.006 mm$^2$ for 0 V, 0.012 mm$^2$ for 6 V, and 0.006 mm$^2$ for 12 V (Fig. 11). There was difficulty in detecting the occlusal contact area for the black impression material.

2) Occlusal contact areas of flat indenter, silicone impression materials, and pressure-sensitive sheet

The cross-sectional area of the flat indenter was calculated to be 1.95 mm$^2$. The occlusal contact area obtained from the pressure-sensitive sheet was 1.76 mm$^2$, indicating a significantly smaller value compared with the area of the flat indenter. At the maximum applied voltage of 12 V, the occlusal contact area was 1.93 mm$^2$ with the white impression material, 1.81 mm$^2$ with the light gray impression material, and 1.73 mm$^2$ with the dark gray impression material. The occlusal contact area became significantly smaller as the color of the impression material became darker.

Between the white impression material and the flat indenter, there were no significant differences in the occlusal contact area as their values were very close. Between the pressure-sensitive sheet and the

![Fig. 10](image1.png)

Fig. 10 Occlusal contact areas of dark gray silicone impression material with varied applied voltages. The occlusal contact area obtained from dark gray impression material increased significantly ($p<0.05$) as the applied voltage of the light transmission device increased.

![Fig. 11](image2.png)

Fig. 11 Occlusal contact areas of dark black silicone impression material with varied applied voltages. There was difficulty in detecting the occlusal contact area for the black impression material.

![Fig. 12](image3.png)

Fig. 12 Occlusal contact areas of a flat indenter, silicone impression materials, and pressure-sensitive sheet. There were no significant differences in the occlusal contact area of white impression material compared with that of the flat indenter. There were also no significant differences between the occlusal contact areas of the pressure-sensitive sheet and the light or dark gray impression material.

![Fig. 13](image4.png)

Fig. 13 Occlusal contact areas of silicon impression materials and pressure-sensitive sheet using a spherical indenter. There were no significant differences between the light gray impression material and the pressure-sensitive sheet.
light or dark gray impression material, there were also no significant differences in the occlusal contact area as their values were very close. However, the occlusal contact area of white impression material was significantly greater than that of the pressure-sensitive sheet (Fig. 12).

Occlusal contact area and thickness limit of readable range using a spherical indenter
At the maximum voltage of 12 V, the occlusal contact areas were 2.88 mm² for white impression material, 0.95 mm² for light gray impression material, and 0.66 mm² for dark gray impression material. The occlusal contact area became significantly smaller as the color of the silicone impression material became darker. There were no significant differences between the occlusal contact area obtained from the light gray impression material and that of 1.10 mm² obtained from the pressure-sensitive sheet. However, the occlusal contact area of the dark gray material was significantly smaller than that of the pressure-sensitive sheet, whereas the occlusal contact area of the white impression material was significantly greater (Fig. 13).

Thickness limits of readable range obtained from the impression materials were 116.4 μm for white impression material, 37.8 μm for light gray impression material, and 26.1 μm for dark gray impression material. Thickness limit at the point of occlusal contact became significantly smaller as the color of the silicone impression material became darker. There were no significant differences between the thickness limit of readable range obtained from the light gray impression material and that of 44.1 μm obtained from the pressure-sensitive sheet. As for the thickness limit of readable range of the dark gray impression material, it was significantly smaller than the thickness of 44.1 μm obtained from the pressure-sensitive sheet. As for the thickness limit obtained from the white impression material, it was significantly larger than that obtained from the pressure-sensitive sheet (Fig. 14).

DISCUSSION
Examination of occlusal contact areas using a flat indenter
With the black silicone impression material, it was difficult to detect the occlusal contact area under all conditions. Based on this result, it was thought that apart from the factors of light transmission and color at the point of occlusal contact, the color of the silicone impression material surrounding the occlusal contact point was also an important factor which affected the measurements. In addition, the occlusal contact areas of the silicone impression materials, except for the black impression material, increased with increasing applied voltage of the light transmission device. It is also noteworthy that the value of occlusal contact area tended to become closer to the area of the flat indenter with increasing applied voltage.

When the maximum voltage (12 V) was applied, the occlusal contact areas of the white and light gray impression materials were more similar to the area of the flat indenter than that of the pressure-sensitive sheet. This result was thought to arise because of one of these factors: (1) as the applied voltage increased, the amount of light transmission at the point of occlusal contact increased; or (2) the color changed to one that was suitable for measurement reading using the bite force measurement system. Based on these findings, the applied voltage was fixed at 12 V, the maximum possible applied voltage. As for the influence of the silicone impression material on occlusal contact area measurement, measurement accuracy could be further enhanced by selecting an appropriate color of the impression material.

Examination of thickness limit of readable range and occlusal contact area using a spherical indenter
With the spherical indenter, the occlusal contact areas were 2.88 mm² for the white impression material, 0.95 mm² for the light gray impression material, and 0.66 mm² for the dark gray impression material. Thickness limits of readable range obtained from the silicone impression materials were 116.4 μm for the white impression material, 37.8 μm for the
light gray impression material, and 26.1 μm for the dark impression material. These findings indicated that as the color of the silicone impression material became darker, both the occlusal contact area and the thickness limit of readable range became significantly smaller. Since the maximum applied voltage was fixed at 12 V, the contributing factor for this trend was thought to be the decrease in light transmission at the point of occlusal contact with thin impression material, especially as the color of the silicone impression material became darker. Thickness limits of readable range obtained from the light and dark gray impression materials were significantly smaller than that of the pressure-sensitive sheet. In light of this finding, it was further confirmed that the occlusal contact area of posterior teeth near the hinge axis could be overly detected due to the thickness of the material used for occlusal examination.

**Examination of the characteristics of each silicone impression material**

According to Tosa et al.\(^{21,22}\), features close to that of true occlusal contact could be obtained if the thickness limit of readable range of a silicone impression material was small when calculated using Nakao’s formula. However, pertaining to the ideal state of the thickness limit, a consensus has not been reached among the different researchers\(^{12,21-23}\).

With the white impression material, the occlusal contact area obtained using the flat indenter was similar to the area of the flat indenter itself. Thickness limit of readable range using the spherical indenter was 116.4 μm, indicating a very large value. On the other hand, with the dark gray silicone impression material, the occlusal contact area obtained using the flat indenter was 0.22 mm² less than the area of the flat indenter. Thickness limit of readable range using the spherical indenter was 26.1 μm, indicating a very small value. With the light gray impression material, the occlusal contact area and thickness limit of readable range were between the values of the white and dark gray silicone materials. However, since there was a very small amount of black silicone material in the light gray silicone material, it was difficult to obtain a stable color tone.

Based on the findings obtained in this study, we thus determined that measurements should be performed using the dark gray silicone material. This was chiefly because the thickness limits of readable range of the light and dark gray impression materials were significantly smaller than those of the pressure-sensitive sheet. This was a particularly important consideration, as the occlusal contact area of the posterior teeth near the hinge axis could be overly detected due to the thickness of the material used for occlusal examination. In summary, to avoid the over-detection effect rendered by the pressure-sensitive sheet, occlusal contact areas are recommended to be measured under these conditions: gray silicone impression material for the bite force measurement system coupled with a built-in light transmission device at a maximum applied voltage of 12 V.

**CONCLUSION**

To establish a method for measuring occlusal contact areas objectively and quantitatively, this study investigated the use of silicone impression materials for the bite force measurement system together with a light transmission device to read the silicone impression materials. To examine the effectiveness of this novel method, the occlusal contact areas of the silicone impression materials and their thickness limits of readable range were measured and compared. Results of this study suggested that easy and highly accurate measurements of occlusal contact area could be obtained by selecting an optimal applied voltage of the light transmission device and an appropriate color of the silicone impression material.

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