Wear of Denture Teeth by Use of Metal Plates

Part 3: Abrasive Wear of Posterior Teeth and Wear of Opposing Metal Plates

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Abstract

An in vitro evaluation of abrasive wear resistance of high-strength denture (HS) teeth and wear of metal plates (Pd alloy) on the opposing side was conducted. A total of 8 types of teeth were used in the experiments including 3 types of HS teeth, 3 types of conventional plastic denture (PL) teeth, porcelain teeth and metal teeth (Pd alloy). Sliding-induced wear tests were conducted by sliding these teeth over the metal plates. Abrasive wear resistance of the teeth was evaluated in terms of wear depth and weight loss. A comparison of wear depth showed that the abrasive wear resistance of HS teeth was 4.7 times that of PL teeth, 0.7 times that of porcelain teeth and 8.3 times that of metal teeth. Weight loss showed that the abrasive wear resistance of HS teeth was 3.3 times that of PL teeth, 0.2 times that of porcelain teeth and 11.4 times that of metal teeth.

The weight loss of the metal plates was minimal when they slid over HS teeth, but increased in the order PL teeth, porcelain teeth and metal teeth.

Introduction

The purpose of removable partial dentures as a posterior prosthesis is reconstruction of occlusion with artificial teeth. That is, posterior artificial teeth are designed to maintain the form and function of the stomatognathic system including restoration of masticatory function, maintenance of the vertical dimension and prevention of temporomandibular joint dysfunction caused by occlusal disharmony.

Plastic and porcelain materials have been used conventionally for posterior artificial teeth. High-strength denture teeth have been developed, which retain some of the advantages of plastic teeth, such as easy occlusal adjustment and cost,
while achieving improved hardness and abrasive wear resistance[1–3].

Findings of basic studies on these HS teeth have been reported in terms of impact resistance[4], bonding strength with denture base resin[5,6], hardness[1–3,5,6], and wear resistance of anterior teeth[7]. However there seem to have been few studies on the abrasive wear resistance of posterior high-strength denture teeth[8,9]. Therefore, we conducted in vitro experiments in order to evaluate the abrasive wear resistance of 8 types of posterior denture teeth by sliding them on metal plates made of Pd-Au-Ag alloy. We evaluated the abrasive wear resistance of the teeth by wear depth and weight loss. In addition, we evaluated the wear depth and surface roughness profile of the metal plates.

**Materials and Methods**

1. Materials

A total of 8 types of artificial teeth were used in our experiments as posterior teeth, 3 types of high-strength denture (HS) teeth, 3 types of conventional plastic (PL) teeth, 1 type of porcelain teeth and 1 type of custom-made metal teeth made of Pd-Au-Ag alloy, whose shape was comparable to that of porcelain teeth (Table 1). From each type, 5 upper right first premolars were chosen, totaling 40 posterior teeth. Accordingly, 40 metal plates each measuring 15×15×2 mm made of Pd-Au-Ag alloy were made to match the number of posterior teeth, and used to make contact with the bucco-lingual cusps of the posterior teeth. The metal plates were heat-treated for aging and finished to reduce the surface roughness (Ra) to less than 0.1 μm with waterproof sandpaper and buff polishing.

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2. Methods

1) A total of 30 teeth consisting of HS teeth and PL teeth were immersed in distilled water prior to the wear test. Water sorption was measured every 48 h for about 3 months according to JIS T 6508. Wear tests were conducted when each of the posterior teeth reached a constant weight.

Wear tests were conducted with a sliding-induced wear testing apparatus (Tokyo Giken). Each metal plate was fixed with a jig to the upper holder of the testing apparatus, while the posterior tooth was fixed to the lower holder, enabling
both the bucco-lingual cusps of the posterior tooth to make contact with the metal plate. Both the upper and lower holders were immersed in distilled water, and the upper holder to which the metal plate was fixed was moved to apply 200,000 strokes to the posterior tooth in a mesio-distal direction under conditions of 300 stroke/min, stroke length 3.0 mm and constant loading of 1 kgf/tooth.

2) Measurement of wear depth of the posterior teeth

Wear depth was measured before initiation of the wear test (at 0 stroke), and upon completion of 10,000 strokes, 50,000 strokes, 100,000 strokes and 200,000 strokes, respectively.

Wear depth was measured in the following manner. The profile of the lingual cusp was traced at an enlargement of 20 times in a bucco-lingual direction with a surface roughness measuring apparatus (Surflyzer Surfcom 2000 A, Tokyo Seimitsu) using a probe diameter of 50 μm, and a tracing head speed of 0.3 mm/s. Then each traced image was fed into an image analysis system (LA-500, PIAS) using a CCD TV camera (PX-370, pixels H512×V512, PIAS). The image of the posterior tooth entered at each measurement point was subjected to binary picture analysis, and then the image of the tooth at 0 stroke and that at each measurement point was synthesized for each tooth.

Wear depth was measured based on the image synthesized from the two images. For this, a line was drawn in increments of 2 pixels from the lingual cusp tip at 0 stroke to the lingual cusp tip after a given number of strokes in a bucco-lingual direction. Then the lengths of all these lines were measured to calculate the mean length. This mean length was then divided by the enlargement ratio of 20 to obtain the measurement value.

3) Measurement of weight loss of the posterior teeth

Measurement was made after 10,000 strokes, 50,000 strokes, 100,000 strokes and upon completion of 200,000 strokes for each tooth. The weight loss was calculated for each tooth by dividing the difference between weights at 0 stroke and after a given number of strokes by the specific gravity.

4) Measurement of weight loss of metal plates

The weight loss of metal plates which had slid over the denture teeth was measured after 1, 5 and 19 wear strokes as well as after completion of $20\times10^4$ strokes.

The weight of the plates was measured before the wear stroke test and after a given number of wear strokes. Then the weight loss was calculated as the volume by dividing the weight loss by the specific gravity.

5) Profile of surface roughness of metal plates

The profile of surface roughness of metal plates which were opposed to the 8 types of denture teeth was measured with a surface roughness measurement device using a probe 5 μm in diameter and a measurement length of 4.0 mm. Measurement was made only after completion of $20\times10^4$ wear strokes.

6) Microscopic observations of cuspal forms of posterior teeth

The cuspal forms of posterior teeth were observed using a microscope (BH, Olympus) at ×2.5 magnification after completion of 200,000 wear strokes.

7) Observations of wear surfaces of metal tooth cusps
For analysis of the wear surface of metal tooth cusps, two-dimensional Fourier transformation was performed in order to identify any cyclic or specific wear pattern in the image as physical information obtained from the original image.

The wear surface of the metal tooth was transmitted from a microscope (BH, Olympus) to an image analysis system (LH-500, PIAS).

The image was then analyzed with software (PIAS) designed for two-dimensional Fourier transformation.

Results

1. Wear depth of posterior teeth

Table 2 and Figure 1 show the wear depth of teeth after 10,000, 50,000, 100,000 and 200,000 strokes.

2. Weight loss of posterior teeth

Table 3 and Figure 2 show the weight loss of each tooth after completion of 10,000, 50,000, 100,000 and 200,000 strokes.

3. Weight loss of metal plates

Table 4 and Figure 3 show the weight loss of metal plates after 1, 5, 10 and \(20 \times 10^4\) wear strokes. Figure 4 shows the weight loss of teeth and metal plates after completion of \(20 \times 10^4\) wear strokes.

4. Profile of surface roughness of metal plates

Figure 5 shows a sample profile of surface roughness of metal plates which had slid over 3 types of HS teeth after 0 and \(20 \times 10^4\) sliding strokes, respectively. Figure 6 shows the sample profile of surface roughness of metal plates which had slid over PL teeth, porcelain teeth and metal teeth after \(20 \times 10^4\) sliding strokes.
5. Microscopic observations of cuspal forms of posterior teeth

Figure 7 shows the cuspal forms of 3 types of HS teeth, and Fig. 8 shows that of 3 types of PL teeth. Figure 9 shows the cuspal forms of metal teeth.

6. Observations of wear surface of metal tooth cusps

With regard to the wear surface of metal teeth cusps, Fig. 10 shows the original image and the image after two-dimensional Fourier transformation.

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Unit: $\times 10^{-5} \text{cm}^3$ ( ) : SD
Fig. 1 Wear depth of posterior teeth

Fig. 2 Weight loss of posterior teeth
Fig. 3  Weight loss of metal plates

Fig. 4  Weight loss of posterior teeth and metal plates after $20 \times 10^4$ strokes
Fig. 5 Profile of surface roughness (metal plates)

Fig. 6 Profile of surface roughness (metal plates)
Fig. 7 Cuspal forms of three types of HS teeth
Fig. 8 Cuspal forms of three types of PL teeth

a) AR

b) WL

c) BB
Fig. 9 Cuspal forms of metal and porcelain teeth

a) MT

b) BA
Dentures with PL teeth show significant wear at an early stage due to mastication and swallowing in comparison with dentures with occlusal surfaces restored using other materials. Porcelain teeth, on the other hand, show little wear themselves, but clinically it is often observed that they cause wear of opposing teeth.

Since the clinical use of HS teeth has been increasing, we considered it important to evaluate the abrasive wear resistance of these teeth. Experiments were therefore conducted, using PL teeth, porcelain teeth and custom-made metal teeth as control materials. The cuspal inclination of these artificial teeth was based on the functional cusp angle usually employed in partial dentures.

1. Method for measurement of weight loss

Types of wear test apparatus used for evaluation of the abrasive wear resistance of artificial teeth differ according to the objectives of study and among laboratories.

The extent of abrasive wear found in the mouth is influenced by various factors including occlusal biting force\cite{11,12}, friction with food\cite{13}, individual masticatory efficiency, type of occlusion and type of retainer used\cite{14}. Therefore SATOH\cite{15} has claimed that an in vitro test method which is easy to perform and highly reproducible has yet to be established. With this in mind, we used a sliding-induced wear test apparatus which reproduces sliding-induced wear. In conducting wear tests, the metal plate and the posterior teeth maintained very close contact during the sliding motion, so that it was difficult to place an intermediary material between them\cite{16,17}. The two-body abrasion method was adopted for this reason, and also in order to eliminate any influence of an intermediary material on wear behavior.

With regard to the experimental conditions of the wear test, stroke length was set at 3.0 mm in line with previous studies and reports on mastication\cite{18}, and the number of strokes was set at 200,000, which is clinically comparable to the number...
of chewing strokes per year\textsuperscript{19}. The constant load was set at 1.0 kgf/tooth with reference to the report of Harrison et al.\textsuperscript{20}

As to measurement of the amount of wear, determination of weight loss\textsuperscript{21} and tracing of cusp profile have been conventionally performed. In consideration of the fact that wear of the upper lingual cusps of artificial teeth, i.e. the working cusps, results clinically in a loss of vertical dimension, we calculated the decrease in height of the cusp tips as wear depth.

2. Wear depth and weight loss of posterior teeth

The wear depth (Table 2 and Fig. 1) of 3 types of HS teeth and porcelain teeth was less than 0.0 \( \mu \)m after completion of 10,000, 30,000 and 100,000 strokes. A comparative evaluation could not be made among the different types of teeth. Therefore the mean values for each tooth after completion of 200,000 wear strokes were compared. The 3 types of HS teeth showed a wear depth of 50\textasciitilde73 \( \mu \)m. PL teeth, on the other hand, showed a wear depth of 220\textasciitilde364 \( \mu \)m, which was 4.7 times the wear depth of HS teeth. The wear depth of porcelain teeth was 42 \( \mu \)m, which was 0.7 times the wear depth of HS teeth, whereas the wear depth of metal teeth was 527 \( \mu \)m, i.e. 8.3 times that of HS teeth.

As to the weight loss of posterior teeth (Table 3 and Fig. 2), we compared the mean value for each tooth after completion of 200,000 wear strokes by considering the wear depth of the teeth. Weight loss for the 3 types of HS teeth was in the range 22.2\textasciitilde26.4\times10^{-5} \text{cm}^3, whereas those for PL teeth, porcelain teeth and metal teeth were 60.6\textasciitilde100.5\times10^{-5} \text{cm}^3, 6.0\times10^{-5} \text{cm}^3 and 291.9\times10^{-5} \text{cm}^3 respectively. HS teeth showed 3.3 times greater abrasive wear resistance than PL teeth. This result was comparable to that for abrasive wear resistance of anterior artificial teeth\textsuperscript{17}. The abrasive wear resistance of HS teeth was 0.2 times that of porcelain teeth. This result also agrees with the clinical findings of Yokoyama\textsuperscript{14} that the occlusal wear of HS teeth is slightly greater than that of porcelain teeth and significantly less than that of PL teeth, and a report indicating that the wear of porcelain is slight when opposed with materials such as metal or resin with a low Vickers hardness\textsuperscript{22}. HS teeth showed 11.4 times greater abrasive wear resistance than metal teeth. It has been reported that metal teeth suffer greater abrasive wear due to contact with the same type of metals\textsuperscript{23}.

It is conceivable, therefore, that cohesion between metals was a significant factor in our experiment\textsuperscript{23}. It is suggested that during our sliding-induced wear test, a contaminating layer about 300 \( \AA \) thick on the surface of the metal plate and an oxide layer about 100\textasciitilde200 \( \AA \) thick were removed during sliding, so that adhesive wear between the two metals was strong\textsuperscript{23}.

In reality, however, the upper and lower posterior teeth do not maintain close contact all the time, and saliva or oily food residue is usually present on the metal occlusal surface.

These adhesive materials will serve as lubricant agents between the two opposing surfaces\textsuperscript{23}, so that the wear behavior could be different from that observed in this study.

3. Weight loss of metal plates

The weight loss of metal plates (Table 4 and Fig. 3) and posterior teeth after
20×10^4 sliding strokes (Fig. 4) and the sample profile of surface roughness of metal plates (Figs. 5, 6) were determined.

The weight loss of metal plates opposed with 3 types of HS teeth was in the range 1.65×10^{-5} ~ 2.67×10^{-5} cm³, whereas that of metal plates opposed with PL teeth was in the range 5.61×10^{-5} ~ 7.62×10^{-5} cm³. Thus the former was approximately 1/3 of the latter.

This tendency was also evident in the profile of surface roughness for both specimens. The metal plates which were opposed with 3 types of HS teeth showed no significant change between 0 wear stroke and 20×10^4 wear strokes. On the other hand, the metal plates which were opposed with PL teeth showed a significant change. There was also a significant difference in comparison with the result for metal plates which were opposed with 3 types of HS teeth. It is assumed that the metal plates had a wider range of contact with PL teeth in comparison with HS teeth, resulting in the greater weight loss.

The weight loss of metal plates which were opposed with porcelain teeth was 13.01×10^{-5} cm³, which was about 6 times greater than that of HS teeth. Comparison of the profile of surface roughness between the two specimens revealed very little wear of porcelain teeth per se, as shown in Table 2, whereas deep and significant wear was observed in metal plates which were opposed with porcelain teeth, although the area of wear was quite limited.

It is suggested that the porcelain cusp tip surface was made rough by wear strokes, which in turn increased the wear on the metal plates[14]. Therefore the greater the number of sliding strokes, the greater the resulting wear. The weight loss of metal plates which were opposed with metal teeth was 143.50×10^{-5} cm³, which was about 66 times greater than that of HS teeth. It is considered, as mentioned before, that the two surfaces of the same metal in contact with each other generated significant adhesive wear[23], which was also clearly evident in the profile of surface roughness.

4. Observations of wear surfaces of metal teeth

Two-dimensional Fourier transformation was performed for analysis of the wear surfaces of metal teeth in order to identify any cyclic or specific wear pattern in the image, using an image analysis system (Fig. 10). The results revealed a specific wear pattern of scratches generated by sliding contact with the metal plates aligned in a mesio-distal direction on the cuspal surfaces of metal teeth.

Conclusion

This study was conducted to evaluate the abrasive wear resistance of HS teeth used as posterior artificial teeth. Three types of HS teeth, 3 types of PL teeth, 1 type of porcelain teeth and 1 type of custom-made metal teeth were used as specimens for sliding-induced tests, using metal plates made of Pd-Au-Ag alloy.

The following conclusions were obtained from the findings of comprehensive evaluation of the abrasive wear resistance of posterior teeth and wear of the opposing metal plates:

1. A comparison of wear depth showed that the abrasive wear resistance of HS teeth was 4.7 times that of PL teeth, 0.7 times that of porcelain teeth, and 8.3 times
that of metal teeth. Comparison of weight loss showed that the abrasive wear resistance of HS teeth was 3.3 times that of PL teeth, 0.2 times that of porcelain teeth and 11.4 times that of metal teeth.

2. The weight loss of metal plates which were opposed with 3 types of HS teeth showed a minimum value of $1.65 \times 10^{-5}$ to $2.67 \times 10^{-5}$ cm$^2$.

The metal plates which were opposed with PL teeth showed a weight loss of $5.61 \times 10^{-5}$ to $7.62 \times 10^{-5}$ cm$^2$, whereas the metal plates opposed with porcelain teeth and metal teeth showed weight losses of $13.01 \times 10^{-5}$ cm$^2$ and $143.50 \times 10^{-5}$ cm$^2$, respectively.

References


