Mechanical properties of artificial porcelain denture teeth

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Artificial porcelain denture teeth have many outstanding properties. In addition to being hygienic, they are the most resistant to abrasion of all currently used dental materials, maintain long-lasting cusps, and are resistant to denture plaque deposition and discoloration. However, they are vulnerable to impact and easily fracture, tend to make occlusal sounds, and do not bind to denture resins. For these reasons they are rarely used. We focused this study on their susceptibility to fracture, which is one reason preventing their more widespread use, and investigated the fractures that occurred. The experimental materials were the upper and lower first molars of six commercially available brands of porcelain teeth.

Experiments were carried out using an abrasion-testing device developed in our laboratory, adapted to deliver a specific impact force. An upper artificial tooth was placed on the top of the abrasion-testing device and a lower artificial tooth was placed on the bottom in normal physiologic relation. The device was set to deliver occlusal contact at a load of 162.2 N. The upper artificial tooth made repeated occlusal contact with the lower artificial tooth 60 times/minute in a tapping movement, which was repeated until one of the teeth fractured or for a maximum of 2,000 times, and the number of impacts until fracture was counted. This test was carried out on ten teeth for each of the six brands of porcelain teeth.

Of the six brands, five teeth from one brand, three from another, and one from a third did not fracture, even after 2,000 impacts. For all brands, more fractures occurred among upper teeth than among lowers. A total of 56 upper and lower artificial teeth fractured, with these fractures occurring at the marginal ridge in 25 cases, associated with the marginal ridge in 19, and not associated with it in 12. Aside from the teeth that did not fracture even after 2,000 impacts, analysis of the number of impacts until fracture showed that the teeth that lasted longest before breaking underwent an average 1,029 impacts. The next longest withstood an average of 794 impacts. The artificial tooth that fractured after the smallest number of impacts withstood only 16 taps. The next smallest number was 121 impacts.

Our results indicate that the susceptibility to fracture varies among the different brands of artificial teeth, and that in many cases, fracture is associated with occlusal contact with the marginal ridge. (J Osaka Dent Univ 2015; 49: 245–251)

Key words: Artificial teeth; Fracture; Porcelain; Ceramic; Mechanical properties

INTRODUCTION

Japan's “8020 Campaign" to encourage people to keep at least 20 of their own teeth until the age of 80 is achieving results.¹ The elderly now account for an increasing proportion of the population.² However, the increased number of remaining teeth has still not reduced the demand for the prosthetic treatment of missing teeth. Missing teeth can be replaced with a bridge, a denture or an implant. As many older people
have numerous missing teeth, although implants are now becoming more widely used, the vast majority of treatment still involves dentures. More than half of people aged 80–84 years use removable partial dentures, whereas the majority of those aged 85 years and over wear complete dentures.

The masticatory capacity of dentures does not compare with that of bridges and implants, and is only about one-sixth that of dentulous individuals. Dental material companies sell a wide range of artificial teeth of various shapes and materials. In terms of shape, they can be broadly divided into anatomical artificial teeth with a cusp angle of at least 30°, functional artificial teeth with a cusp angle of 20°, and non-anatomical artificial teeth with a cusp angle of 0°. With respect to materials, they are generally categorized as porcelain teeth, hard resin teeth and resin teeth. Porcelain teeth in particular have many outstanding properties as an artificial dental material, as they are highly resistant to abrasion, maintain long-lasting cusps, and are resistant to denture plaque deposition and discoloration, in addition to being hygienic. However, they are vulnerable to impact and easily fractured, tend to make occlusal sounds, and do not bond to denture resins. For this reason, a recent market survey found that porcelain teeth account for only 2% of the artificial teeth shipped.

In this study, we focused on susceptibility to fracture, one of the reasons preventing the more widespread use of porcelain teeth despite the superior quality of their material, and investigated the fracture of commercially available artificial teeth in order to identify those that are less likely to break. There were no conflicts of interest with any company in this study.

MATERIALS AND METHODS

Experimental materials
The experimental materials used consisted of the upper and lower first molars of 6 brands of commercially available artificial porcelain denture teeth: Veracia SA Porcelain Posterior (Shofu, Kyoto, Japan, Veracia); Ace Kyuushi® (Shofu, Ace); Bioace® 20° (Shofu, Bio-Ace 20); Bioace® 35° (Shofu, Bio-Ace 35); Livdent FB-20 Porcelain 100° (GC, Tokyo, Japan); and Livdent 20°; and Livdent FB-30 Porcelain 100° (GC, Livdent 30).

Experimental method

Abrasion test device
Experiments were carried out using an abrasion testing device developed in our laboratory, adapted to deliver a specific impact force. Figure 1 shows the experimental device. The abrasion testing device was designed such that the rotation of a geared speed control monitor was transmitted to a rotating shaft via a belt, which rotated a cam that was integrated with the rotating shaft. This pushed up an arm that was in contact with the cam, elevating an upper part that was integrated with the arm. As the cam rotated further, the contact between it and the arm was cut, allowing the arm to fall onto the test stage in the lower part of the device. A weight was placed on top of the tip of the arm, allowing the load (impact) on the test stage underneath to be adjusted.

We first carried out preliminary experiments to measure the association between the weight at the tip of the arm and impact on the test stage underneath. The method of measurement is shown in Fig. 2. A steel ball 11 mm in diameter was attached to the upper part, and various weights were placed on the top of it. A film for measuring occlusal force (Dental Preccale® 50 H Type R; GC, Tokyo, Japan) was placed on the metal plate installed in the lower part of the testing device, and the load when the upper part was allowed to fall was measured. An Occluder® FPD-703 occlusal force measurement system (GC) was used.
for analysis. Measurements were performed three times for each weight.

Fracture tests on artificial teeth

Fracture tests on artificial teeth were carried out based on the load measurements obtained using the steel ball, by repeated loading to simulate mastication. The method of measurement is shown in Fig. 3. New Fuji-Rock IMP® ultra-hard plaster (GC) was used to create an external frame for fixation on the test stage, with the center scooped out with a laboratory carbide bur and the resulting cavity filled with Unifast III® self-curing resin (GC), into which the lower artificial tooth was fixed such that the occlusal surface was parallel with the test stage on the lower part of the test device. Next, Utility wax® (GC) was used to position the upper artificial tooth such that it came into occlusal contact with the lower artificial tooth in centric occlusion, and it was then fixed in place on the upper arm with self-curing resin.

A 400 g weight was placed on the top of the arm, such that the load on the occlusal surface after a fall of 17 mm was 162.2 N. The device was adjusted to ensure that the upper artificial tooth made occlusal contact with the lower artificial tooth 60 times per minute in a tapping movement. Although the test device had 6 arms, only one was used to stop the apparatus when a fracture occurred. Occlusal contact was repeated until the artificial tooth fractured or a maximum of 2,000 contacts had been made, and the number of impacts required for fracture to occur was counted. The fractured artificial tooth was photographed with a digital camera and the fracture line was observed. Measurements were carried out in 10 samples each of the 6 brands of porcelain teeth. One-way analysis of variance was carried out with the number of impacts until fracture as the factor, and Scheffe’s method was used for multiple comparisons.

RESULTS

Relationship between the weight on tip of the arm and the load imparted on the test stage in the lower part of the testing device

Figure 4 shows the results of measurements on the relationship between the weight on the tip of the arm and the load imparted on the test stage in the lower part of the testing device. Although there was almost no difference in load between no weight and a weight of 100 g, further increases in weight resulted in increased load. The greater the weight, the more the load increased. The coefficient of variation for each weight was extremely low, with a maximum of 5.3%.
Fracture tests on the artificial teeth
Table 1 shows the number of artificial teeth that fractured after fewer than 2,000 impacts. One of the Bio-Ace 20 was omitted from the figures because the resin fixing it to the test stage fractured during the experiment, causing it to fall off. Only nine Bio-Ace 20 were tested. Five of the ten Veracia, three of the ten Bio-Ace 35, and one of the ten Livdent 20 did not fracture, even after having undergone 2,000 impacts. For all brands, more fractures occurred in upper than in lower artificial teeth.

Fracture lines were categorized as those limited to the marginal ridge, those associated with the marginal ridge, and those completely separated from the marginal ridge.

Table 1  Number of fractured artificial teeth

<table>
<thead>
<tr>
<th></th>
<th>Veracia</th>
<th>Ace</th>
<th>Bio-Ace 20</th>
<th>Bio-Ace 35</th>
<th>Livdent 20</th>
<th>Livdent 30</th>
</tr>
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<td>Fractured</td>
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<td>10/10</td>
<td>9/9</td>
<td>7/10</td>
<td>9/10</td>
<td>10/10</td>
</tr>
<tr>
<td>Upper</td>
<td>3/10</td>
<td>7/10</td>
<td>7/9</td>
<td>5/10</td>
<td>6/10</td>
<td>10/10</td>
</tr>
<tr>
<td>Lower</td>
<td>2/10</td>
<td>4/10</td>
<td>2/9</td>
<td>2/10</td>
<td>3/10</td>
<td>4/10</td>
</tr>
</tbody>
</table>

Number of fractured teeth / Number of specimens

Fig. 4  Relationship between the weight and amount of load applied to the lower sample stage.

Fig. 5  Examples of the location of the fracture lines. (A) Fracture line in the marginal ridge, (B) Fracture line connected to the marginal ridge, (C) Other.
Fig. 6 Number of cycles until fracture of each artificial tooth.

ginal ridge. Figure 5 shows examples of each. Fractures occurred in a total of 56 upper and lower artificial teeth, of which 25 were in the marginal ridge, 19 were connected to the marginal ridge, and 12 were not associated with it.

Figure 6 shows a graph of the number of impacts required until fracture. If artificial teeth did not fracture even after 2,000 impacts, the number of impacts was counted as 2,000.

As shown on the graph, Veracia lasted longest before fracture occurred, requiring an average of 1,029 impacts. Five of the 10 Veracia did not fracture even after 2,000 impacts, meaning that the actual figure should be higher. The second most durable brand was the Bio-Ace 35, which required an average 794 impacts. Three of the 10 Bio-Ace 35 did not fracture, meaning that the actual figure should be higher. The brand that fractured after the smallest number of impacts was the Livdent 30, which required only 16 impacts. The brand that lasted the second shortest time was the Bio-Ace 20, which required 121 impacts.

One-way analysis of variance of the number of impacts until fracture with the brand of artificial tooth as a factor was significant at the 1% significance level. Multiple comparisons using Scheffe’s method also found that there was a significant difference between the Livdent 30 and the Veracia brands in terms of the number of impacts until fracture at the 5% significance level.

DISCUSSION

Porcelain teeth have many superior properties when used in removable partial and full dentures, particularly full dentures. They suffer almost no reduction in occlusal vertical dimension due to abrasion, and even with long-term use, it is common to find clear occlusal facets developing on the occlusal surfaces. They also do not develop the anti-Monson curves that appear on resin teeth as a result of abrasion. Nevertheless, porcelain teeth are rarely used. This is because of qualitative problems including their tendency to fracture, occlusal noise, and adhesion to denture resins. However, the brittle nature of porcelain is difficult to improve.

In this study, we investigated the susceptibility of commercially available artificial teeth to fracture, with the objective of studying the relationship between shape, occlusal contact and fractures to obtain ideas for reducing the frequency of fractures in porcelain teeth. Although occlusal wear and abrasion in artificial teeth have been well studied, impact tests have been lacking in recent years. Most studies on the fracture of artificial teeth have involved impact tests using a steel ball above an artificial tooth below, with almost none using artificial teeth on both the top and bottom. As the state of occlusal contact is believed to have a major influence on the fracture of artificial teeth, in this study, we attempted to carry out our investigation in a fashion similar to clinical circumstances, with artificial teeth used for both the upper and lower jaws.

With respect to the load applied, Sato et al. reported that the occlusal force was 165 N in patients with complete dentures whose course was uneventful 3 months after new dentures were fitted. In another study by Yamamoto et al. the occlusal force was 166.4 ± 117.6 N, while according to Fukushima et al. it was 199 N. A study by Fukami found that the occlusal force in the first molar region of complete dentures in the intercuspal position was 144–148 N (14.7–15.1 kgf). In our study, we therefore used a weight of 400 g to impose a load of 162.2 N, based on the results of a preliminary study. However, although 162.2 N is the load applied to all artificial teeth when the whole jaw is closed, in this study it occurs when occlusal force is applied to the first molar alone. In practice, it is rare for occlusal contact to be made with such an impact on an artificial tooth. This study may therefore be considered as an accelerated test for the
purpose of comparing artificial teeth; Livdent 30 does not actually fracture after 16 occlusal contacts.

Our experimental results demonstrated that the susceptibility of porcelain teeth to fracture greatly varies between different commercially available brands of artificial teeth. A comparison with similar fracture tests of other types of artificial teeth indicates that porcelain teeth are vulnerable to impact. Livdent 30, an artificial tooth with a 30° cusp angle, was the brand that fractured most easily. Strong anatomical artificial teeth with cusp angles of 30° or more have excellent masticatory efficiency. However greater lateral pressure is imposed on the cusp slope, and semi-anatomical artificial teeth with cusp angles of 20°–25° have lower lateral pressure, although their masticatory efficiency is inferior. Livdent 30 fractured more easily than did Livdent 20, which has a smaller cusp angle. This may have been because of the greater lateral force imposed on the cusp slope. Bio-Ace 35, however, which has a 35° cusp angle, fractured less easily than did Bio-Ace 20, which has a 20° cusp angle, indicating that cusp angle does not necessarily influence fractures.

Observation of the fracture lines showed that they occurred in or near the marginal ridge in 44 of the 56 artificial teeth that fractured. The angle of the corner between the occlusal surface and the adjacent surface is small in the marginal ridge area and lacking in thickness, and in this study it was also not supported by adjacent teeth. This may have made it easier for the marginal ridge area to fracture during occlusal contact. When there was strong occlusal contact on the internal slope of the cusp as well as the marginal ridge, the fracture line may have extended into the central sulcus, causing the cusp to fracture. This suggests that during occlusal adjustment, the closer the line of occlusal contact with the marginal ridge is to the corner between the adjacent surface and the occlusal surface, the greater the risk of fracture. Firm contact with the adjacent tooth may also be important in preventing fracture.

Livdent artificial teeth were more likely to fracture than other brands. Livdent teeth are artificial teeth with clearly shaped facets. In view of the preceding discussion, they may have been more vulnerable to fracture because there is no rounding of the corners between the facets and the neighboring surface or the buccolingual surface, meaning that they are lacking in thickness.

In the event that facets appear on other types of porcelain teeth as a result of selective grinding, automatic grinding, or attrition due to long-term use, they too may exhibit a similar tendency to fracture. Some porcelain teeth, depending on their shape, did not fracture even after 2,000 impacts. Therefore, it is possible to produce dentures utilizing porcelain teeth that are unlikely to fracture by means of appropriate shaping of the occlusal surface after occlusal adjustment, enabling a high occlusal vertical dimension to be maintained in the long term.

REFERENCES


