Influence of Tooth Mold Materials in Composite Resin CAD/CAM Crown Destructive Test

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Abstract

A range of experimental designs have been used in destructive testing of composite resin CAD/CAM crowns. Various materials have been adopted for the abutment in such tests, including human or bovine dentin, stainless steel, PMMA, and composite resin, the selection of which is made in accordance with study objective or preference of the researcher. The purpose of this study was to determine how the material selected for the abutment material affected fracture load and maximum displacement. Destructive tests were conducted on composite resin crowns of the same design. Three types of material were used for the abutments together with 2 types of adhesive material. Images of each sample were acquired before destruction using a microfocus X-ray CT scanner to confirm the feasibility of a non-destructive test.

The load required to fracture the composite CAD/CAM resin crowns depended on the abutment material used, with a decrease being observed in the order of composite resin, stainless steel, and PMMA. Maximum displacement decreased in the order of PMMA, composite resin, and stainless steel. Differences in the material used for setting (adhesive resin or polycarboxylate cement) showed no effect on fracture load. These results indicate that the load required to achieve destruction of resin CAD/CAM crowns varies according to the abutment material used.

Key words: Composite resin crown — CAD/CAM — Destructive test — Resin build up

Introduction

The recent introduction of CAD/CAM into the dental field and its subsequent development has seen the application of this system to the design and fabrication of crowns from composite resin blocks. Some studies have investigated the occlusal surface thickness of CAD/CAM crowns\(^{1,3,9,21}\), while others have looked at axial surface design\(^{19}\). Mean-
while, from a clinical perspective, other studies have investigated how design might prevent crown detachment and the effect of various types of adhesive agent, while others have attempted to determine how design might increase durability.

Various materials have been adopted for the abutment in destruction experiments, including human or bovine dentin, stainless steel, PMMA, and composite resin, the selection of which is made in accordance with study objective or preference of the researcher.

The issues surrounding the quality of and quantity required for stainless-steel abutments are well known. They offer sufficient strength and the production process is well-established. They cannot be used in an oral environment, however, making them inappropriate for clinical simulation. Another problem is that adhesive agents are less effective with stainless steel.

Destructive tests using human dentin have been performed for a long time. Such tests are performed utilizing extracted teeth. This means that the crown design and adhesive system used will most closely conform to those used in clinical practice. However, it is difficult to harvest large numbers of caries-free human teeth, and quality will vary. This means that experimental reproducibility with this type of experimental design is low.

In many cases, assuming the need for an abutment, the composition of the crown will often include an abutment and construction material, in addition to human dentin. The representative abutment construction materials comprise metal, composite resin, cement, and amalgam. However, recently, abutment construction with composite resin has become more common, with either a direct or indirect preparation method being used.

A number of studies employing a range of experimental designs have investigated the utility of different abutment materials, the results of which remain to be fully evaluated in terms of how such materials affect fracture load and maximum displacement.

In this study, composite CAD/CAM resin crowns of the same design were fabricated using 3 types of abutment material and 2 types of adhesive agent. The purpose was to determine whether fracture load and maximum displacement varied with difference in abutment material used.

**Materials and Methods**

1. **Design of abutments**
   
   The abutment morphology was set as follows: crown vertical dimension, 5.0 mm; crown width, 7.0 mm; and axial surface taper, 6°. The occlusal surface of the abutment was flat and the abutment corner angle designed to form a perfect circle, with a curvature radius of 1.0 mm. The curvature radius of the marginal region was set at 0.45 mm (Fig. 1).

2. **Materials used for abutments**
   
   Abutments were prepared using the following 3 types of material (Fig. 2): 1) stainless steel, prepared employing the rotatory curving method (SUS303); 2) PMMA, prepared from PMMA-rods, employing the rotatory curving method. Here, the external form was duplicated by impression-taking using a stainless-steel abutment mold with the prepared design and a transparent curing silicone rubber impression material (Memosil2, Kulzer Japan Co., Tokyo, Japan); and 3) composite resin (CLEARFIL\textsuperscript{TM} DC Core Automix One Kuraray-Noritake Dental, Tokyo, Japan), which was poured into a mold and polymerized by light irradiation from all directions. The surfaces of all the abutments were cleaned with ethanol and then sandblasted (Jetblast, Morita, Tokyo, Japan) with 50 μm alumina powder at 0.3 MPa, followed by ultrasonic cleaning for 2 min.

3. **External form of CAD/CAM crown**
   
   The external form of the CAD/CAM crowns is shown in Fig. 3. It was set at a minimum thickness of 1.5 mm at the central groove of the occlusal surface and a maximum thickness of 2.5 mm at the cusp apex. The crown width was prepared as a perfect
circle with a diameter of 9.0 mm. The crown contour was prepared in a region 1-mm superior to the marginal region with a 1.0-mm thickness. Two cusps were prepared in the buccolingual central region and triangular and marginal ridges added to the occlusal surface. The outer circumference of the crown was designed to form a perfect circle as seen from the occlusal surface, so that the axial surface thickness was constant throughout the whole circumference.

The crown cement space was set at 20 μm up to the level of 1.0-mm superior to the marginal region and at 60 μm elsewhere. The prepared CAD/CAM crowns were placed on the abutments before adhesion and examined under a stereoscopic microscope to confirm the fit of the marginal region.

4. Preparation of CAD/CAM crowns

For the CAD/CAM crown-designing software, EXO CAD (exocad GmbH, Germany) was used. Firstly, the crown was waxed up on the mold abutment, followed by impression-taking of the core, replacing the wax with self-curing resin, and confirmation and adjustment of the crown occlusal surface and axial surface thickness. The external forms and abutments of the resin crowns, completed as designed, were digitized after powdering. CAD/CAM crowns were prepared utilizing the double-scan method. The crowns were processed based on the acquired data using a CAD/CAM crown cutting machine (EX Mile EXM-5S, MODIA SYSTEMS, Saitama, Japan). For the composite resin block for the CAD/ CAM crown, KZR-CAD HR (Yamakin, Osaka, Japan) was used. The sample surface was polished with a rotary cutter using a silicon point.

5. Luting of CAD/CAM crown on abutment

The prepared CAD/CAM crowns were adhered using an MMA resin (SB; Superbond C&B, Sun Medical, Shiga, Japan) or polycarboxylate cement (HB; Hy-bond carbo cement, Shofu, Kyoto, Japan) cement. The CAD/CAM crowns were cleaned with ethanol, followed by sandblasting (Jetblast, Morita, Tokyo, Japan) with 50-μm alumina powder at 0.3 MPa and ultrasonic cleaning for 2 min. The types of setting material are shown in Table 1.

In the setting procedure, when SB was used, a ceramic primer (Super Bond PZ Primer, Sun Medical, Shiga, Japan) was first applied to the inner surface of the CAD/
CAM crown. This primer includes a phosphate ester monomer. After drying, the mixing method was used. A quick monomer solution and catalyst were mixed at a ratio of 4 drops: 1 drop and stirred with a brush for 3 sec to prepare an activation solution. A cup of polymer powder was mixed with the activation solution and the resulting paste applied to the inner surface of the crown, followed by setting to the abutment.

With adhesion using HB, 3 drops of solution were mixed with the powder from the attached meter cup on a paper kneading board. The cement paste was applied to the inner surface of the CAD/CAM crown which was then set to the abutment. A 150-N load was added to each sample using a constant load tester (SV-20HTEST STAND, Imada-SS Co., Aichi, Japan). This condition was maintained for 8 min in the SB group and 4 min in the HB group.

Each group comprised 8 samples of CAD/CAM crowns set and left standing for 24 hr after kneading in 37°C distilled water.

6. Non-destructive observation

Each sample was imaged using a micro-CT device (HMX 225-AGTIS + 4, TESCO, Tokyo, Japan). The minimum slice thickness was 50 μm. The acquisition conditions were as follows: tube voltage, 110 kV; tube current, 80 μA; and SID/SOD, 170/600 mm. A 0.5-mm copper plate was used for the filter. Steric construction images of each sample were prepared from the slice images obtained employing the volume rendering method and 3-dimensional construction software (TRI 3D Bon, Ratoc, Tokyo, Japan). Arbitrary cross-sections of these images were observed from the external and inner regions.

7. Fracture load test

Static destructive tests were performed using a universal material tester (Autograph AG-I 20kN, Shimadzu, Kyoto, Japan). The sample and indenter were fixed using a jig (Tokyo giken, Tokyo, Japan) which set them vertical to the tooth axis direction (Fig. 4). The stainless-steel indenter was semi-cylindrical and had a 3-mm diameter. Before the static destructive test, the loading position and state of occlusal contact were confirmed together with equal contact at 2 specified sites.
on the occlusal surface using occlusal registration paper (ARTICULATING PAPER, GC, Tokyo, Japan). Loading was applied along the tooth axis direction at a crosshead speed of 0.5 mm/min. Fracture load and maximum displacement were measured at the time of confirming fracture of the CAD/CAM crown. After the fracture load test, the abutment tooth and inner surfaces of the CAD/CAM crown were observed macroscopically and under a stereoscopic microscope to confirm the pattern and appearance of cement destruction.

8. Statistical analysis

A two-way analysis of variance (ANOVA) was performed for the elements: the materials of the abutment and cement type (SPSS Statistics Ver.27, sandi, Tokyo, Japan). Multiple comparisons were performed when there was no interaction between these. The Tukey test was used to evaluate the results (p<0.01).

Results

The mean fracture loads using SB for the setting material were 2,801, 2,245, and 3,092 N for stainless steel, PMMA, and composite resin, respectively. When the setting material was HB, the mean fracture loads using stainless steel, PMMA, and composite resin were 2,579, 2,247, and 2,952 N, respectively. The maximum displacements using SB as a setting material were 0.61, 0.91, and 0.72 mm for stainless steel, PMMA, and composite resin, respectively. When the setting material was HB, the maximum displacements were 0.57, 0.97, and 0.88 mm when stainless steel, PMMA, and composite resin were used, respectively. No significant difference was noted in the fracture load or maximum displacement between SB and HB. The results of the two-way ANOVA are shown in Table 2. No interaction was noted between differences in abutment material or cement type.

A comparison of mean fracture load depending on type of abutment material is shown in Fig. 5. A significant difference was noted in mean fracture load in the order of composite resin, stainless steel, and PMMA.

A comparison of maximum displacement depending on type of abutment material used is shown in Fig. 6. Maximum displacement showed an increase in the order of PMMA, composite resin, and stainless steel, and sig-
Significant differences were noted between PMMA and stainless steel, and between composite resin and stainless steel.

Comparisons of mean fracture load and maximum displacement depending on type of setting material used are shown in Figs. 7 and 8, respectively. No significant difference was noted in either comparison.

Sample observation after destruction revealed that cement had adhered to the abutment and inner surfaces of the crown. Fracture along the central groove was frequently noted, regardless of the cement type (Fig. 9).

Micro-CT images of each sample acquired before the destructive test are shown in Figs. 10 and 11. In the SB group, the cement showed no contrast, whereas appropriate contrast was observed between the CAD/CAM crown and abutment material. All abutment materials (stainless steel, PMMA, and composite resin) could be distinguished from the CAD/CAM crown and cement. Halation in
the margin of the crown in the absence of a cement space interfered with accurate observation. The HB group showed the most appropriate contrast, regardless of abutment material used. In the stainless steel and composite resin samples, distinguishing the com-

![Image of samples](image)

**Fig. 9** Sample observation after destruction

![Image of micro-CT images](image)

**Fig. 10** Micro-CT steric construction images (SB group, lower row: strongly magnified images of crown margin)

![Image of micro-CT images](image)

**Fig. 11** Micro-CT steric construction images (HB group, lower row: strongly magnified images of crown margin)
posite resin and cement was difficult. With stainless steel, halation was noted near the crown margin, which interfered with accurate observation.

Discussion

In clinical practice, CAD/CAM crowns are widely used for first premolars. Therefore, the present study was designed with a first premolar as its central assumption. Hitherto, pros theses for first premolars have usually included a full-metal crown. Recently, however, the demand for prostheses with better esthetics has rapidly increased, and much work is now being done on metal-free crowns for first premolars.

In the present study, the occlusal surface of the abutment was flat, and the chamfer margin deep. The external form of a crown is usually determined by the adjacent teeth and must allow harmonization with the oral environment, including sufficient vertical dimension for occlusion and the dentition. In the present study, however, the external form of the CAD/CAM crowns was standardized based on the anatomical morphology to obtain more stable conditions for experimentation.

By setting the minimum thickness of the occlusal surface of the CAD/CAM crowns at 1.5 mm or greater, a fracture load capable of enduring occlusal forces can be acquired. Therefore, in the present study, the minimum thickness of the CAD/CAM crown was set at 1.5 mm. Morphologically, stress is usually concentrated in the region corresponding to the central groove of the occlusal surface. Therefore, the loads were spread equally over 2 buccolingual cusps to simply distribution of stress.

In an earlier study by this group, change in the axial surface thickness and margin morphology of the CAD/CAM crowns elicited no significant difference in fracture load. Accordingly, the experiment marginal region was set at 0.45 mm, corresponding to a deep chamfer.

Stainless steel, PMMA, and composite resin were selected for the abutment material here as many earlier studies have performed destructive tests using these in the experimental design of CAD/CAM crowns. Sample preparation using human or bovine dentin is useful, when possible. However, this was not done here as this makes processing the abutment impossible due to individual variation. It has been reported that the fracture load of crowns due to a metal abutment was significantly lower than that with acryl resin.

Some studies employing composite resin abutments have shown that the fracture load of a composite resin crown was comparable to that with a lithium disilicate all-ceramic crown. Therefore, the possibility of a higher fracture load with some other combination has been suggested, if the elastic modulus of the crown and building material are relatively close.

Regarding tooth mold design in the present study, to simplify stress distribution, a trapezoid occlusal surface morphology was adopted. An inverted roof-shaped occlusal surface morphology is effective in securing the height of the axial surface region. However, one study showed that when the fracture load was compared between adhesions to an inverted roof-shaped abutment and flat abutment, a significantly higher fracture load was acquired with a flat morphology than with an inverted roof-shaped morphology. In the present experiment, a sufficient fracture load was secured in all samples.

Non-destructive observation and static destructive tests have been evaluated. Data acquired by micro-CT were subjected to 3-dimensional construction and compared under arbitrary observation conditions, which enabled non-destructive evaluation. Correlating such results with those of subsequent destructive tests allows for more detailed investigation. Accurate observation and measurement of the resin cement near the abutment and inner surface of the crown may be difficult with stainless steel due to halation. The indenter in the static destructive test was stainless steel with a 3-mm diameter on the assumption of paring of the functional cusps.
of the upper first premolar. The slope in the buccolingual cusp of the crown sample was adjusted using a dedicated jig so as to make contact at 2 sites at the same position in all samples. Equal 2-site contact at the 2 occlusal contact points was confirmed using an occlusal registration paper. In addition, a pull-out test was performed using occlusal registration strips. The influence of differences in direction of loading and the slope in the cusp on fracture load have been reported\(^2\)\(^\text{4}\). However, in the present study, the loading direction was set to that of the tooth axis to simplify comparison of the influence of crown axial surface thickness.

The stress-strain curves in all samples were normal, indicating that the occlusal state set by the jig and failure of the materials was adequate, clarifying the validity of the experimental system used.

Mean fracture load differed depending on the type of cement used: it was 2,713 N with SB, a resin cement, and the mean was 2,592 N with HB, a polycarboxylate cement. Selection of resin cement for CAD/CAM crowns is recommended\(^2\)\(^,\)\(^5\),\(^2\)\(^8\)\(^\text{1}\). It has been reported that a higher fracture load can be acquired by adhesion of a CAD/CAM crown with resin cement than with glass ionomer cement\(^1\)\(^9\),\(^2\)\(^0\),\(^2\)\(^2\)–\(^2\)\(^4\),\(^3\)\(^3\)\(^\text{1}\). In addition, it has been reported that the adhesive strength of resin cement is higher than that of polycarboxylate cement\(^2\)\(^1\), so that a higher fracture load can be acquired by integrating the CAD/CAM crown and abutment\(^1\)\(^2\),\(^2\)\(^1\),\(^2\)\(^2\). No significant difference was noted in the fracture load between the resin and polycarboxylate cements in their study. The influence of the type of cement used was small, which may have been due to the load being applied vertically to the occlusal surface on the assumption of a premolar Sufficient fracture load was acquired. However, other parameters remain to be investigated in future study, such as those involving tensile tests and contamination of the abutment.

Reportedly, the normal occlusal force of the lower first premolar is 423–843 N\(^1\)\(^0\). The design of the external form of the CAD/CAM crowns in the present experiment was not that usually seen in clinical practice, however, so fracture load may not be directly compared.

An MMA resin cement, SB allows resistance to impact force due to abundant flexibility. According to a report on a comparison of resin cements, PANAVIA EX and super-bond C&B\(^3\)\(^1\), although the adhesive strength was different from that of Ni-Cr alloy, no significant difference was noted in the fracture load on a hammering test between the cements. A similar tendency was noted in the present experiment using a stainless steel mold, suggesting that although only an MMA resin cement was adopted for the resin cement, similar results could be expected if a composite resin cement were used.

The strength of the resin block is considered to affect fracture load. For the resin block in the present study, a block with a relatively high compressive strength among those disclosed by each manufacturer was used, and the physical properties of this resin block may have influenced fracture load.

Under a stereoscopic microscope, all samples showed cohesive failure. The polycarboxylate cement favorably adhered to a non-pre-cious metal, stainless steel abutment mold. The resin cement may also have favorably adhered. No significant difference was noted in the fracture load in the PMMA abutment group. However, regarding the pattern of destruction, the abutment, resin cement, and CAD/CAM crown remained integrated in the SB group, whereas most of the PMMA abutments were damaged, suggesting that the results for fracture load were strongly influenced by the fracture load of PMMA. The highest fracture load was noted in the composite resin abutment group. Integration due to the resin cement was expected to influence fracture load in the SB group, but fracture load in the HB group was also relatively high. This suggests that the engineering properties of the core material also exert a large influence on fracture load. No difference was observed in maximum displacement due to type of cement used. Difference in displacement due to type of abutment material
decreased in the order of PMMA, composite resin, and stainless steel. The correlation between displacement and abutment material under pressure may have resulted from application of the load onto the abutment from directly above in this experiment.

In terms of destruction, fracture along the central groove on the occlusal surface was noted, regardless of the cement type or axial surface thickness of the crown. The axial surface thickness of the crown was designed to be constant throughout the whole circumference. Stress may have been concentrated on the inner slope of the occlusal surface, transmitting tear stress along the central groove and spreading the fracture line to the mesiodistal region.

Micro-CT is frequently used in non-destructive tests. Three-dimensional steric construction of acquired data allows observation at an arbitrary cross-section. In addition, the contrast can also be arbitrarily adjusted.

The results of this study revealed no difference in fracture load between stainless steel and composite resin abutments. On the other hand, fracture load was lower with PMMA. This suggests that stainless steel abutments should be avoided in favor of composite resin abutments when an experimental design involving micro-CT is planned. However, it may be difficult to determine when composite resin cement has been used.

**Conclusion**

Basic static destructive tests on the assumption of a CAD/CAM crown set to the premolar were performed with abutments prepared with different types of abutment material and 2 types of cement and the following conclusions were acquired:

The fracture load of the composite resin CAD/CAM crown was influenced by the abutment material. The fracture load decreased in the order of the composite resin, stainless steel, and PMMA.

The type of setting material used, adhesive resin or polycarboxylate cement, showed no influence on fracture load.

On non-destructive observation using micro-CT, halation occurred when the stainless steel abutment was used. The contrast colors of the stainless steel composite resin abutment and polycarboxylate cement were close, making accurate reading relatively difficult.

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