Effect of Differences in Axial Thickness and Type of Cement on Fracture Resistance in Composite Resin CAD/CAM Crowns

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Abstract

The purpose of this study was to investigate the influence of differences in axial thickness and type of cement on fracture load in CAD/CAM crowns. Assuming the mandibular first premolar to be the abutment tooth, 4 types of crown with different axial thicknesses and radii of curvature were prepared. To unify external design, the morphology of the crown margins was set at 0.15, 0.30, 0.45, or 0.60 mm, thus maintaining uniform axial form of the crowns. The CAD/CAM crowns and abutment teeth were bonded using each of 2 types of resin cement or polycarboxylate cement. The fracture load value was measured using a universal testing machine and the destruction phase observed.

No significant difference was observed with change in axial thickness. The fracture load values with each of the 2 types of resin cement used were significantly higher than that with polycarboxylate cement (p<0.01). These results suggest that the fracture load values of CAD/CAM crowns are not influenced by differences in the axial thickness of the crown, and that they are higher when bonding is achieved with resin rather than polycarboxylate cement.

Key words: CAD/CAM — Composite resin crown — Design of crown — Fracture resistance

Introduction

The CAD/CAM system has recently been introduced in the field of dentistry, and this has led to the clinical application of crowns prepared with composite resin blocks (CAD/CAM crowns). Moreover, indications for their use have expanded as the esthetics of compos-
ite resin blocks have improved and fracture strength become comparable to or higher than that achievable with glass-ceramic materials.\(^5,7,10,11,25,29\)

To achieve a fracture strength capable of withstanding occlusal force, the occlusal thickness of a CAD/CAM crown has been reported to be 1.5–2.0 mm.\(^1,3\) It has been reported that differences in the occlusal thickness of the crown influence fracture strength.\(^3,8,14,17\) A deep chamfer is generally suggested for the marginal morphology of such crowns. The influence of various factors on fracture strength has been reported, including the effect of differences in the angle of taper of the axial surface of the abutment tooth\(^14\) and marginal morphology.\(^14,19\) In addition, studies on fracture strength\(^18\), strength over time, and repeated fracture testing\(^12,18,21\) have been performed.

It has been reported that the CAD/CAM crown-retentive force of composite resin is influenced by the strength of cement in addition to abutment design.\(^30\) and the use of resin cement is recommended because its composition is the same as that of crown materials.\(^14,19\) Some studies comparing the different properties of resin cements have indicated that cement selection is critical.\(^12,24\)

Guidelines with regard to the selection of the form of the abutment tooth and luting material for CAD/CAM crowns have been established with a view to promoting their use.\(^26\) To our knowledge, however, no study to date has investigated the relationship between differences in axial thickness and type of cement on fracture strength in CAD/CAM crowns.

The purpose of this study was to investigate the effect of differences in axial thickness and type of cement on the fracture load value in CAD/CAM crowns with the same external design for a mandibular first premolar.

**Materials and Methods**

1. **Abutment tooth**

Abutment teeth were prepared using a stainless steel abutment mold (SUS303). The form of the abutment tooth was set as follows: tooth crown height, 5.0 mm; crown width, 7.0 mm; and axial surface taper, 6°. The occlusal form of the abutment teeth was set to be flat, with a radius of the curvature of 1.0 mm of the abutment tooth corner angle, close to a perfect circle (Fig. 1). To change the axial thickness of the crowns while retaining a constant taper, 4 types of marginal morphology were adopted: a radius of the curvature of 0.15, 0.30, 0.45, or 0.60 mm (Fig. 2).
2. External design of crown

The external design of the CAD/CAM crowns is shown in Fig. 3. The thickness at the central groove was 1.5 mm, while that at the apex of the cusp was 2.5 mm. The crown width was set at a perfect circle with a 9.0-mm diameter. The crown contour, which had a thickness of 1.0 mm, was set at a region 1.0 mm above the margin. Two cusps were designed at the center of the buccolingual width of the crown and triangular and marginal ridges added to the occlusal surface. Since the outer circumference of the crowns was designed to constitute a perfect circle when observed from the occlusal view, axial thickness was kept constant throughout the entire circumference.

The crown cement space was set at 20 µm in the region 1.0 mm above the margin and 60 µm in other regions. The prepared CAD/CAM crown was tried on the abutment tooth to confirm the conditions before luting. The absence of a rise in the margin was confirmed under a stereoscopic microscope.

3. Preparation of CAD/CAM crowns

The EXO CAD (Exocad GmbH, Darmstadt, Germany) was used to design the CAD/CAM crown. Firstly, the crown was waxed up on the abutment mold. Then, an impression of the core was taken, the wax replaced with self-curing resin, and the occlusal surface of the crown and axial surface thickness confirmed and adjusted. The external design of the crown and 4 types of abutment tooth were digitized individually and the CAD/CAM crowns prepared using the double scan technique. The external design of the prepared crowns was identical, whereas the form of the abutment tooth differed, resulting in differences in axial thickness. Crowns with a radius of the curvature of the abutment tooth margin of 0.15, 0.30, 0.45, and 0.60 mm were designated as Type 015, 030, 045, and 060, respectively (Fig. 4). Based on the collected data, the crowns were processed using a cut processing machine for CAD/CAM crowns (EX Mile EXM-5S, MODIA SYSTEMS, Saitama, Japan).

The KZR-CAD HR (Yamakin, Osaka, Japan) was used to prepare composite resin blocks for the CAD/CAM crowns.

4. Luting of CAD/CAM crown on abutment

The prepared CAD/CAM crowns were bonded to the abutment teeth using each of 2 types of resin cement—primer combination-type (PV) composite resin cement (Panavia V5®; Kuraray Noritake Dental, Tokyo, Japan) or MMA resin (SB) cement (Super-Bond; Sun Medical, Shiga, Japan)—or polycarboxylate (HB) cement (Hy-bond carbo Cement; Shofu, Kyoto, Japan). The abutment tooth and inner surface of the CAD/CAM crown were cleaned with ethanol and sandblasted with 50-µm alumina powder (Jetblast, Morita, Tokyo, Japan) at 0.3 MPa followed by ultrasonic cleaning for 2 min. The types of luting material used are shown in Table 1.

When PV was used in the luting procedure, the inner surface of the CAD/CAM crown was treated with a phosphoric acid etching agent (K ETCHANT Syringe; Kuraray Noritake Dental) for 5 sec, washed with water, and dried with oil-free air. An MDP-functional monomer-containing ceramic primer (Clearfil® Ceramic Primer Plus; Kuraray Noritake Dental) was then applied to the inner surface of the crown and an MDP-containing dental metal bonding primer (Panavia V5® Tooth Primer; Kuraray Noritake Dental) to the abutment for 20 sec, followed by drying with oil-free air. Panavia (Panavia V5® Paste; Kuraray Noritake Dental) was applied to the inner surface of the crown, after which it was mounted on the abutment tooth. Two buccolingual sites were irradiated with light for
3–5 sec (PENCURE2000; Morita) for preliminary curing, and after removal of excess cement, cure was completed by similar photopolymerization.

For crowns bonded with SB, a phosphate ester monomer-containing ceramic primer (Super-Bond PZ Primer; Sun Medical) was applied to the inner surface of the crown, followed by drying with oil-free air. The mixing method was used for SB. Activation solution was prepared by mixing quick monomer solution and a catalyst at a ratio of 4 drops to 1, followed by stirring with a disposable brush. The activation solution was combined with one spoon of attached polymer powder, the mixed sludge applied to the inner surface of the crown, and the crown mounted on the abutment tooth. For bonding with HB, using the attached powder meter, one spoon of powder and 3 drops of solution were placed on a paper mixing pad and mixed. The cement sludge was applied to the inner surface of the CAD/CAM crown and the crown mounted on the abutment tooth. Using a constant load testing device (SV-20HTEST STAND; Japan Instrumentation System Co., Ltd., Nara, Japan), a 150-N load was applied to each sample for 3 min (PV), 8 min (SB), or 4 min (HB).

Each group, which consisted of 8 samples after CAD/CAM crown luting, was left to stand for 24 hr in 37°C distilled water after cementation.

5. Apparatus of static fracture load test

The static fracture test was performed using a universal testing machine (Autograph AG-I 20kN; Shimadzu, Kyoto, Japan). The sample and indenter were fixed vertically to the tooth axis direction using a jig (Tokyo Giken, Tokyo, Japan) (Fig. 5). The stainless steel-made indenter was semi-cylindrical with a diameter of 3.0 mm. The loading position and occlusal contact condition were confirmed prior to commencing the static fracture test. Homogeneous contact at 2 sites of the specified occlusal surface was confirmed using an occlusal registration paper (ARTICULATING PAPER; GC, Tokyo, Japan). The load was applied along the tooth axis direction at a cross-head speed of 0.5 mm/min, and the fracture-load
value measured at the time of confirming fracture of the CAD/CAM crown.

6. Classification and observation of fracture location

To confirm the fracture pattern and phase of the cement, the abutment tooth surface and inner surface of the CAD/CAM crown were observed macroscopically and under a stereoscopic microscope after measurement of the fracture load value. The region with fracture line formation was investigated by setting a fracture region and equally dividing the occlusal surface of the sample into 4 regions (buccal side (B), distal side (D), lingual side (L), and mesial side (M)) (Fig.6). Correlations between the destruction phase/number of fracture fragments and the mean fracture-load value were investigated.

7. Statistical analysis

A two-way layout analysis of variance (two-way ANOVA) was performed with axial thickness of crowns and type of cement as factors. When no interaction was detected between these factors, a multiple comparison was performed. Tukey’s test was used for the evaluation (p<0.01). The Spearman’s rank correlation coefficient was calculated to evaluate the presence or absence of a correlation between the number of fragments and mean fracture load.

Results

The mean fracture load value in each group is shown in Fig. 7. A significant difference was noted in the fracture load value between SB and HB in Type 015, 045, and 060 (p<0.05).

The results of the two-way ANOVA of the mean fracture load value in each group is shown in Table 2. No significant difference was observed in the fracture load value due to differences in axial thickness. A significant difference was observed in fracture load, however, due to the differences in type of cement used (p<0.01). No interaction was noted between the 2 factors (differences in axial thickness and type of cement).

Table 2  Two-way layout analysis of variance

| Source                  | Sum of squares | DF | Mean square | F value | p value |
|-------------------------|----------------|----|-------------|---------|---------|
| Factor A (axial thickness of crowns) | 667,765        | 3  | 222,588     | 0.7074  | 0.5503  |
| Factor B (type of cement)   | 6,348,300      | 2  | 3,174,150   | 10.0875 | <0.001  |
| Factor A × Factor B        | 1,507,723      | 6  | 251,287     | 0.7986  | 0.5737  |
| Error                    | 26,431,613     | 84 | 314,662     |         |         |
| Total                    | 34,955,403     | 95 |             |         |         |

*p<0.05  n=8
thickness of crown and type of cement).

The mean fracture load value by difference in axial thickness was as follows: Type 015, 2,710 N; Type 030, 2,717 N; Type 045, 2,758 N; and Type 060, 2,541 N (Fig. 8). No significant difference was noted due to the 4 types of axial thickness.

The mean fracture load value by type of cement was as follows: PV, 2,765 N; SB, 2,947 N; and HB, 2,333 N (Fig. 9). The fracture load values for luting with PV and SB were significantly higher than that for luting with HB. No significant difference was noted in the fracture load value between the 2 types of resin cement used (PV and SB).

The destruction pattern was cohesive in all samples in the resin cementation group. In the HB group, interfacial failure was observed in most of the samples, although cohesive failure was seen in some and mixed fracture in approximately 17%. Cement was observed to have adhered to the abutment tooth surface and inner surface of the crown (Fig. 10). To evaluate the destruction phase, the position of the fracture line and relationship between the number of fracture fragments
and mean fracture load value were adopted as reference items. The fracture line was present along the central groove in many samples, regardless of the cement type, and the rate was as follows: PV, 88%; SB, 81%; and HB, 88%. The correlation between the number of fracture fragments and mean fracture load value is shown in Fig. 11. The Spearman’s rank correlation coefficient was high, as follows: PV, \( r = 0.93 \); SB, \( r = 0.88 \); and HB, \( r = 0.92 \).

**Discussion**

Although first premolars can be restored with full-metal crowns, social demand has led to an upsurge in demand for prostheses with greater esthetic qualities. The present experiment was designed on the assumption that the mandibular first premolar would serve as the abutment tooth. The form of the abutment tooth was designed to provide a flat occlusal surface and deep chamfer in the crown margin.

A reversed roof-like occlusal surface morphology is effective in securing the height of the axial surface. It has been reported that crowns bonded to abutment teeth with flat occlusal surfaces showed significantly higher fracture strength than those with reversed roof-like surfaces, however \(^{24}\). In the present study, to simplify the distribution of stress from application of the load to the occlusal surface, a table-shape was adopted as the occlusal surface morphology.

To unify the external axial surface inclination of the crowns, axial thickness was specified by setting 4 margin morphologies: 0.15, 0.30, 0.45, or 0.60 mm, thus maintaining uniform axial form of the crowns. The margin morphology was set referring to burs for abutment tooth preparation (201R, 102R, 106RD, 107RD; Shofu).

Regarding the material of the abutment tooth, it has been reported that the fracture strength of a crown on a metal abutment tooth was significantly lower than that on an acrylic resin abutment tooth \(^{22}\). Since the objective of the present experiment was to measure the CAD/CAM crown fracture load value, stainless steel (SUS303), with which many abutment teeth with specified morphology can be prepared, was selected as the material for the abutment.

The external design of the crown is determined by the adjacent teeth, vertical dimension, and dentition, with the aim of achieving harmonization with the oral environment. Thus, the axial thickness of a CAD/CAM crown can be changed by the axial design of the abutment tooth.

To investigate the influence of differences in the axial thickness of the crown, the circumference of a perfect circle was chosen as the external design. Since CAD/CAM crown design software contains no program for adjusting the axial thickness of the crown, the CAD/CAM crowns here were prepared using the double scan technique.

Fracture strength against occlusal forces can be acquired by setting the minimum occlusal thickness of the CAD/CAM crown at 1.5 mm \(^{13}\). The appropriate occlusal thickness of all-ceramic crowns has been reported to be 1.5–2.0 mm \(^{6,16}\). In the present study, the external shape of the CAD/CAM crown had a thickness of 1.5 mm at the central groove and 2.5 mm at the apex of the cusp. Morphologically, stress is likely to concentrate in the region corresponding to the central groove on the occlusal surface. To simplify stress distribution, the occlusal surface was prepared so as to receive an equal load at the 2 buccolingual cusps.

The axial thickness of the Type 015 crown was approximately 1.65 mm. On the premise
that this value represents 100%, the thicknesses of Type 030, 045, and 060 would be approximately 105% (1.74 mm), 110% (1.83 mm), and 115% (1.91 mm), respectively.

The static fracture test was employed for evaluation. A stainless indenter with a 3.0-mm diameter was used on the assumed functional cusp of the maxillary first premolar as the opposed tooth.

The inner slope of the buccolingual cusps of the sample crown and indenter were set to make contact at 2 identical positions in all samples using an exclusive jig. Homogeneous contact at the 2 occlusal contact points was confirmed using an occlusal registration paper. Furthermore, a pull-out test was performed using occlusal registration strips. The influence of differences in the loading direction on the inner slope of the cusp on fracture strength has been reported. In the present study, the loading direction was set to the direction of tooth axis to simplify the influence of differences in axial thickness of the crown, however.

The stress-strain curve was normal in all samples. This means that an incorrect occlusal state due to the jig and unfavorable material were avoided here, demonstrating the validity of the experimental design. The fracture load by differences in axial thickness was as follows: Type 015, 2,710 N; Type 030, 2,717 N; Type 045, 2,758 N; and Type 060, 2,541 N, showing no significant difference among them. One earlier study on the axial thickness of monolithic zirconia crowns also reported that differences in axial thickness showed no association with fracture strength. The results of the present study were similar, suggesting that it is not necessary to increase cutting to secure the axial thickness of a CAD/CAM crown.

Regarding the influence of differences in cement on fracture load, the strength of the resin cements, PV and SB, was approximately 2,800 N and 2,900 N, respectively, while that of polycarboxylate cement, HB, was approximately 2,500 N. Resin cement is recommended as the type of cement for CAD/CAM crowns. It has been reported that CAD/CAM crowns acquire higher fracture strength when bonded with resin cement than with glass ionomer cement. In addition, it has been reported that the adhesive strength of resin cement is higher than that of polycarboxylate cement. This suggests that CAD/CAM crowns can acquire higher fracture strength through integration with abutment teeth. In the present study, the fracture load was higher in crowns bonded with PV or SB than in those bonded with HB.

Generally, the occlusal force of the normal human mandibular first premolar is 423–843 N. Since the external design of the CAD/CAM crowns in the present experiment was not aimed at clinical application, however, a direct comparison of fracture load may not be possible.

Panavia is a composite resin cement, and the compressive strength after polymerization is high because it contains filler. Silane treatment of the filler surface by water absorption may cause hydrolysis and decrease bonding strength. Superbond is an MMA resin cement. Its flexibility makes it robust against impact force, but water absorption-induced changes in its physical properties are large. Some studies have compared Superbond C&B and Panavia F2.0. The results revealed that Superbond C&B showed a significantly higher adhesive strength and fracture strength, in which the latter was considered to be due to the elastic modulus of the luting material.

One earlier study comparing the resin cements Panavia EX and Superbond C&B found no significant difference in fracture strength on a hammering test, despite differences being present in Ni-Cr alloy-bonding strength. A similar tendency was also noted in the present experiment using a stainless steel mold.

The MDP introduction site in Panavia F2.0 is different from that in Panavia V5, which was used in this experiment. According to reports on their comparison, physical properties, such as adhesive strength, improved, but MDP may have had a significant influence in a study using Zirconia as the adherent.
Therefore, the influence in the present experiment using resin blocks is unclear. Generally, the results of experiments using Panavia V5 are still lacking, and so reports of studies using Panavia F2.0 and Panavia EX were referred to.

No significant difference was observed in fracture load between the crowns using PV and SB. The fracture strength of a resin block depends on its physical properties. The KZR-CAD HR used in this experiment has relatively high fracture strength among composite resin blocks sold in Japan, and this may have been the cause of the absence of a difference between the PV and SB groups.

Based on the above findings, the material of the abutment tooth, the presence or absence of filler, hydrolysis, and the properties of the CAD/CAM block may all be factors influencing fracture-load.

Observation under a stereoscopic microscope revealed cohesive failure in all samples. The polycarboxylate cement was favorably bonded with the abutment mold made of a non-noble metal, stainless steel, and the resin cements may also have favorably bonded.

Fracture along the central groove on the occlusal surface was noted, regardless of the type of cement and differences in thickness of the crown. Axial thickness was constant throughout the whole circumference of the crown. Since stress was loaded on the inner slope on the occlusal surface, tear stress may have been transmitted along the central groove, with which the fracture line may have extended toward the mesiodistal region.

Regarding the correlation between the number of fracture fragments and mean fracture load value, the mean fracture load value tended to increase as the number of fracture fragments increased. The Spearman’s rank correlation coefficient was as follows: PV, 0.93; SB, 0.88; and HB, 0.92. These are higher than 0.7, indicating the presence of a strong correlation between those factors. It is possible that compressive deformation occurred, making the crowns more resistant to loads than they might have been with more brittle materials such as ceramics or zirconia. Since CAD/CAM crowns are durable against compression, fracture load may have shown relatively high values in samples without stress concentration. The appearance of several fracture lines seems to indicate the maximal limit of the fracture load of a CAD/CAM crown. Although the present results are not conclusive, it appears that the breakup of a CAD/CAM crown into many fragments in clinical practice may be due to high occlusal force. Further investigation is necessary, however, to confirm these findings.

**Conclusion**

Static fracture tests were performed on CAD/CAM crowns in which different axial thicknesses and luting cements had been used. The following conclusions were obtained: the fracture load of a CAD/CAM composite resin crown is not influenced by differences in axial thickness; and fracture load is higher in resin cement-bonded crowns than in polycarboxylate cement-bonded crowns.

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