Effects of Preparation and Luting System on All-Ceramic Computer-Generated Crowns

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Purpose: Computer-aided design/computer-integrated machining (CAD/CIM) allows defect-oriented custom-shaping of the inside surfaces of all-ceramic crowns. The purpose of this study was to examine the effect of inside crown form on fracture strength of cemented and bonded crowns.

Materials and Methods: Four preparation types were used: (1) "classic" with a butt shoulder of 1.2 mm, abutment height of 4 mm, and 6-degree convergence, (2) like type 1 with mesio-occlusodistal cavity, (3) like type 1 with height reduced by 50%, and (4) like type 1 with abutment reduced by 100% plus a pulp chamber cavity. Crowns were CAD designed on preparations 1 to 4 using identical outside morphology. Machined crowns were placed on abutments (a) without any media as controls (n = 15), (b) cemented (n = 15), and (c) bonded (n = 15), and were loaded until fracture. Results: Zinc phosphate-cemented crowns (1b, 2b, 3b, and 4b) showed significant (P < 0.001) increase of fracture load values compared to uncemented control crowns (1a, 2a, 3a, 4a). Fracture load values of bonded crowns (1c, 2c, 3c) were significantly (P < 0.001) higher than those for cemented crowns. Bonded crowns with thick occlusal dimensions (3c and 4c) showed the highest fracture load values. Conclusion: Bonded all-ceramic CAD/CIM crowns with defect-oriented inside morphology and increased occlusal dimensions showed high fracture load values. Int J Prosthodont 1998;11:333-339.

A study using finite element analysis has shown that in uncemented glass-ceramic crowns the maximum stresses occurred at or near the crown margin and decreased when the ratio of occlusal ceramic thickness to crown length was increased. Fracture load values of uncemented and of bonded glass-ceramic samples behaved as a function of sample thickness. In a clinical study by Brodersen it was concluded that doubling the thickness of adhesively luted Dicor-crowns increased their fracture load fourfold. Groten et al found that the fracture load of Empress crowns luted with composite resin to steel dies was significantly higher than when using phosphate cement or glass-ionomer cement.

Doyle et al reported that increasing the occlusal convergence angle of the abutment increased the fracture load of zinc phosphate-cemented Dicor crowns in vitro. For the preparation of adhesively luted Dicor crowns, a convergence angle of 20 degrees was recommended. However, the dentin should not be reduced to less than a minimum dentin thickness of 0.7 mm to avoid pulp damage. A convergence angle of 6 to 10 degrees seemed to provide the best combination of all-ceramic crown strength and remaining dentin thick-
The aim of this in vitro study was to evaluate the influence of four different preparation designs as well as three different placement methods on the fracture load of computer-generated all-ceramic molar crowns.

Materials and Methods

A maxillary right first molar (FDI tooth 16) each was prepared according to three different experimental preparation types (Figs 1b to 1d) in a row of teeth of a model (A3, Frasaco). A "classic" crown preparation, with a butt shoulder of 1.2 mm, preparation height of 4 mm, and 6-degree convergence, at the same tooth served as a control (Fig 1a). The preparation was done using a parallelogram (PFG 100, Cendres & Métaux). The occlusal reduction was 1.5 mm, measured in the deepest point of the main fissure. The preparation guidelines used for the control abutment were also followed for all test preparations except for the experimental modifications. The first experimental abutment (“MOD”) was prepared with a mesio-occlusodistal (MOD) cavity presenting a mesiodistal trench with a depth of 2.0 mm and width of 3.0 mm after preparation (Fig 1b). For the second experimental abutment (“reduced”), the abutment...
height was reduced to 2.0 mm and the occlusal thickness of the crown resulted in a total of 3.5 mm (Fig 1c). The third experimental preparation ("endo") represented a complete loss of the clinical crown. For macroretention and as a positioning aid, a central pulp chamber inlay cavity with 2.0-mm depth, a mesiodistal length of 4.0 mm, and an orofacial width of 5.0 mm was prepared. The "shoulder" width was 2.4 mm (Fig 1d).

For production of the abutment samples the prepared teeth were embedded with their roots into the center of a cut piece of a cylindrical plastic tube with a diameter of 25 mm and height of 25 mm using wax (Beauty Pink Wax). The wax was trimmed level to the bottom and upper rims of the tube, thus forming a base for the tooth. The preparation shoulder was 1.0 mm above the upper base level (Figs 1a to 1d). Impressions were taken from the master abutments using a silicone material (Protesil, Krupp-Medizintechnik). The impressions were used as molds that were filled with a fine hybrid composite resin (Tetric, Vivadent) in layers of 1.0 mm. Each layer was light cured for 60 seconds (Coltolux II, Coltène). To ensure complete cure at the surface, the abutment samples were insulated (Insulating-Gel, Kuizer) and additionally cured for 5 minutes in a light box (di-500, Coltène). To complete cure at the surface, the abutment samples were insulated (Insulating-Gel, Kulzer) and additionally cured for 5 minutes in a light box (di-500, Col tons). On a workbench (Emco FB-2, Emco Maier) the abutment samples were cut at their base parallel to the preparation shoulder using milling cutters (5400, Fraisa).

Standardized sample crowns for the load-to-fracture evaluations were designed and machined using two Cerec 2 computer-aided design/computer-integrated machining (CAD/CIM) units (Siemens). Crown software version C.O.S. 4.21+ (November 2, 1995) and the "Crown I/Correlation" mode was used for the construction of the control and experimental master crowns. A standardized wax crown was made with two buccal and one palatal cusp. The convex inner slopes of the cusps formed a tripod that could hold, via point contacts, a steel ball with a diameter of 7.2 mm in a defined position (Fig 2). This occlusal morphology was used as a correlate for the construction of all test crowns. Following the Correlation I mode, an optical impression was first taken of the preparation, and a second optical impression was taken of the waxed-up morphology. To enable electronic matching, the preparation and wax crown had to be fixed alternately in the row of teeth on the model. The Correlation I mode of the Cerec system then matched both optical impressions, producing control and test crowns with identical occlusal morphology but different inside morphologies and occlusal wall thicknesses.

For the machining of the sample crowns, ceramic blocks (Mark II, Vita-Zahnfabrik) measuring 10 x 12 x 15 mm were used. Based on trial experiments, settings for "occlusal dimension" (+500 µm) and "spacer" (+30 µm) were identified that provided the occlusal thickness of the type shown in Fig 1a of exactly 1.5 mm in the deepest point of the fissure line. Control measurements of the crowns using callipers confirmed the dimensional reproducibility. For every machining of the control and test crowns these settings were checked in the service window of the CAD/CIM unit to obtain external and internal crown shapes of identical dimensions for every preparation. For every control and test group, 15 identical crowns were produced. After two crowns were machined, the cooling water was replaced with new tap water and cooling lubricant (Cerec Dentagrind 2000, Siemens) was added. The machined crowns were visually controlled for their intactness and received no further finishing or polishing.

For the load-to-fracture evaluation, control and test crowns were seated on the abutment samples according to three categories: (a) uncemented, (b) zinc phosphate cemented, and (c) adhesively bonded. For cementation, zinc phosphate cement (De Trey, Dentsply) was used as follows: 8 drops of phosphoric acid were mixed with 0.7 g zinc oxide powder on a cooled glass plate for 1.5 minutes. The cement was applied to the inner crown surface using a brush, and gross excess was removed. For
adhesive bonding, Panavia 21 TC (Kuraray) was used (Tables 1 and 2). The inner surfaces of the crowns were etched for 60 seconds with a 4.9% hydrofluoric acid etch gel (Table 1), then rinsed for 60 seconds and air dried for 20 seconds. Thereafter a silane solution (Table 1) was applied for 60 seconds and air dried for 20 seconds. The dies were sandblasted with 50 μm alumina powder (Nobilium) at a pressure of 2 bar, then silanized (Tables 1 and 2). A bonding agent was then brushed on in a thin layer, gently air dried to avoid pooling, and precured on the die using visible light (Tables 1 and 2). Composite luting material was mixed for 30 seconds according to the recommendations of Chen and Schärer and the manufacturer's instructions and applied to the inner crown surface (Tables 1 and 2). The crowns were then placed on the dies using finger pressure (50 N). Excess luting composite was removed using a probe tip. To avoid polymerization inhibition at the surface of the adhesive interface, Oxyguard II (Kuraray) was applied for 7 minutes.

After storage of the abutment samples in a dry room at 22°C for a minimum of 24 hours and a maximum of 48 hours, the crowns were loaded to fracture in a universal testing machine (Trebel RM 50, Schenck). A steel ball with a diameter of 12 mm was placed on the occlusal surface and load was applied to the steel ball by a cylindrical bolt with a crosshead speed of 0.5 mm per minute until fracture occurred (Fig 2). The steel ball was supported by three defined points on the central convex cusp slopes. Load was transmitted vertically to the surface of the die support. The fracture load values were recorded in newtons.

The fracture load values were statistically tested by a two-way analysis of variance (ANOVA) and Scheffé test (Stat View 4.02, Brain Power). The Scheffé test was carried out to identify significant differences between the three placement modes and the four preparations.

Table 3 lists the mean (± SD) fracture load (N) and the coefficient of variation (CV %) for each group. Analysis of variance showed significant differences (P < 0.001) between placement modes and between preparation types. A significant (P < 0.001) cross-relation existed between preparation types and placement modes.

When loading uncemented crowns, the abutment samples remained undamaged. When loading crowns cemented with zinc phosphate cement, abutment samples of the classic preparation type remained intact, while in the other preparation types the fracture continued through the sample. In the adhesive test group, the samples of all preparation types fractured in continuation of the fracture line of the crown.

When loading uncemented crowns, the types with thick occlusal dimensions ("reduced," type 3

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### Table 1 Adhesive Components Used for Bonding

<table>
<thead>
<tr>
<th>Material</th>
<th>Function</th>
<th>Lot no.</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceramics Etch</td>
<td>4.9% hydrofluoric acid</td>
<td>4244</td>
<td>Vita-Zahnfabrik</td>
</tr>
<tr>
<td>Monobond S</td>
<td>Silane solution</td>
<td>717288</td>
<td>Vivadent</td>
</tr>
<tr>
<td>Heliobond</td>
<td>Light-curing enamel and dentin adhesive</td>
<td>729566</td>
<td>Vivadent</td>
</tr>
<tr>
<td>Panavia 21 TC</td>
<td>Chemical-curing two-component composite resin</td>
<td>0032 A, 0034 A</td>
<td>Kuraray</td>
</tr>
</tbody>
</table>

### Table 2 Procedures for Adhesive Bonding and Exposure Times of the Single Components

<table>
<thead>
<tr>
<th>Procedures</th>
<th>Abutment (s)</th>
<th>Crown (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid-etching</td>
<td>—</td>
<td>60</td>
</tr>
<tr>
<td>Rinse</td>
<td>—</td>
<td>60</td>
</tr>
<tr>
<td>Air dry</td>
<td>—</td>
<td>20</td>
</tr>
<tr>
<td>Apply silane</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Air dry</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Apply adhesive</td>
<td>20</td>
<td>—</td>
</tr>
<tr>
<td>Air dry</td>
<td>20</td>
<td>—</td>
</tr>
<tr>
<td>Light cure</td>
<td>60</td>
<td>—</td>
</tr>
</tbody>
</table>
and "endo," type 4) had significantly (P < 0.01, P < 0.001, respectively) higher fracture load values than the classic (1) and MOD (2) types of crowns. Fracture load values of classic (1) and MOD (2) types of crowns did not significantly (P > 0.05) differ from each other.

When loading crowns cemented with zinc phosphate, all crown types showed a significant (P < 0.001) increase of the fracture load values as compared to uncremented crowns. The fracture load values of zinc phosphate–cemented MOD and classic crowns differed significantly (P < 0.001) from those of the reduced and endo crowns. No significant (P > 0.05) differences existed between MOD versus classic and reduced versus endo types of crowns.

Adhesively seated crowns had the highest fracture load values compared to uncremented and zinc phosphate–cemented crowns. Among the adhesively seated crown types significant differences existed between fracture load values of MOD versus reduced (P < 0.001), MOD versus endo (P < 0.05), and classic versus reduced (P < 0.05) crowns.

**Discussion**

The aim of the present study was to examine the effects of variation of (1) preparation design and (2) placement mode on the fracture load of computer-generated all-ceramic crowns.

A loading procedure using a steel ball resting on point contacts on the internal three convex cusp slopes of the identically machined crowns provided a standardized test set-up. The abutment samples were made manually using fine hybrid composite resin. This material had a modulus of elasticity similar to dentin and as such provided a mechanical similarity of the abutment to the natural tooth.17,19 The experimental set-up was not intended to imitate any clinical parameters other than the modulus of elasticity. Furthermore, when adhesive technology is used to seat the crowns, the fine hybrid composite resin has the potential of a strong bond between abutments and ceramic that may not be attained in the same consistent strength in clinical situations.17,20 Care was taken to standardize production of abutment samples, storage time, machining of crowns, adhesive seating, zinc phosphate cementation, and finally loading to fracture of the control and test groups to allow relative comparison between the experimental variables under the conditions of the study. Dry storage of the samples until fracture appeared to be adequate under these conditions. The industrially manufactured ceramic has a consistent material quality with a high degree of homogeneity and only sparse single fine pores.21

Stress distribution and initiation of fracture were not specifically examined in this study. Uncremented crowns were included in the study as control for the effects of inside crown form and luting technique. Load-strain curves of 34 out of 60 uncremented crowns showed at least one small load peak, indicating the occurrence of a first crack, until maximum load and total fracture of the crown were reached. Load peaks were registered in 6 of 60 cases with zinc phosphate–cemented crowns and in no case with adhesively seated crowns, indicating a strengthening effect of the interfacial bond. Load peaks could not be related specifically to any of the preparation types used. Except for the monolithic endo-type crowns (types 4b and 4c), bonded crowns showed increased fracture load values compared to crowns cemented with zinc phosphate cement. The strengthening effect of ad-

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**Table 3** Fracture Load Values (Mean ± SD) and Coefficient of Variation (CV in %) of All-Ceramic CAD/CIM Crowns

<table>
<thead>
<tr>
<th>Preparation</th>
<th>Uncemented (a)</th>
<th>Zinc phosphate (b)</th>
<th>Adhesive bonding (c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classic</td>
<td>745 ± 109</td>
<td>1890 ± 300</td>
<td>3132 ± 604</td>
</tr>
<tr>
<td>MOD</td>
<td>518 ± 109</td>
<td>1296 ± 248</td>
<td>2645 ± 218</td>
</tr>
<tr>
<td>Reduced</td>
<td>1056 ± 190</td>
<td>2870 ± 509</td>
<td>3774 ± 937</td>
</tr>
<tr>
<td>Endo</td>
<td>1624 ± 372</td>
<td>2991 ± 937</td>
<td>3407 ± 618</td>
</tr>
</tbody>
</table>

*P < 0.05 (Scheffé test), **P < 0.01 (Scheffé test), ***P < 0.001 (Scheffé test).

Groups connected by vertical lines are significantly different. Groups a, b, and c are significantly different (P < 0.001) except 4b and 4c (P > 0.05). n = 15 in each group.
hesive placement was clearly confirmed by the present fracture load data, as reported in other studies.5,11,15,22

For the test preparation forms, the classic concept of preparation for all-ceramic crowns was modified. In the case of the MOD-type preparation, it was assumed that the tooth selected for crown preparation carried a large MOD amalgam filling that had to be removed. The "extended machining" capacity of the CAD/CIM unit offers the custom shaping of even complex forms13; therefore it was decided that the internal crown surface would be machined according to the abutment morphology after removal of the filling. This procedure offered a very quick and rational preparation of the abutment without any additional build-up. The concept of this type of preparation was: "let the machine do the work." However, the fracture load data showed that this configuration caused the lowest fracture load values of all preparation/crown types whether the crowns were uncremented, cemented, or adhesively seated. Possibly the free-standing cavity walls on top of the abutment caused additional stress or were too weak to support the crown under load. From these results, it is recommended (even in the clinical situation) that acute parts protruding toward the occlusal be avoided or at least rounded and/or leveled.21

Several reasons led to the decision to crown the 50%-reduced abutment directly without any prior build-up: (1) build-up restorations are currently made using dentin bonding and composite resin; (2) CAD/CIM extended machining allows custom-shaping of a ceramic crown on any "reduced" preparation form and the crown is adhesively seated using dentin bonding and composite resin; (3) computer-generated crowns can be produced and seated in one appointment, therefore classic abutments necessary for macroretention of provisional crowns are not needed; and (4) the method saves time, effort, and expenses needed for the build-up procedure.

Reduced abutment height means an increase of the occlusal thickness of the crowns.4,22 In the present study the additional 2 mm led to the overall occlusal thickness of 3.5 mm and increased load-to-fracture values significantly by 42%, 71%, and 21% in the uncremented, cemented, and adhesively seated groups, respectively. This is in accordance with findings of other laboratory studies23 and also with clinical results.4,24 However, reduction of the abutment by 50% down to an abutment height of only 2 mm reduced the available macro-mechanical geometric retention form as well as the dentinal adhesive surface of the abutment. To the authors' knowledge, the relationship between the amount of surface area (square millimeters) of the abutment and clinical retention in bonded all-ceramic crowns has not yet been established.

The idea of production of an all-ceramic crown combined with an "integrated" ceramic abutment build-up and pulp chamber retention inlay was based on the versatility of the extended machining mode of the CAD/CIM unit. This process can be considered a consequent continuation of the reduced abutment procedure. Compared to the situation of the natural tooth, a very large part of the tooth, the entire clinical crown, and the inner part of the root basis is replaced by the rigid ceramic material. This causes a change in the physical properties of the clinical crown and creates an unknown situation with respect to stress distribution via static and dynamic occlusion. The fact that this ceramic workpiece is bonded to nonvital teeth makes this procedure even more questionable with respect to chances for survival in a clinical application. With the endo-type crown, the ability for retention seems to be even more critical than with reduced preparations. More information about retention and adhesion forces is needed and clinical experience would be necessary for final validation of this method. Once the feasibility of this method in known conditions is clear and favorable, the time, effort, and cost saved could be high compared to traditional post-and-core build-up procedures. This is all the more true considering that the efficiency and benefit of root posts has been challenged by several studies.25–27

To summarize, CAD/CIM technology offers new treatment concepts for all-ceramic crowns that appear to merit further laboratory and clinical evaluation.

Conclusions

This paper described the effect of four all-ceramic crown preparation designs and two different luting techniques upon the fracture load of ceramic CAD/CIM crowns:

1. Zinc phosphate-cemented crowns (all preparation designs) showed a significant (P < 0.001) increase of fracture load values compared to uncremented crowns (all preparation designs).

2. Fracture load values of bonded crowns (classic, MOD, and reduced preparation except endo preparation) were significantly (P < 0.001) higher than those for zinc phosphate-cemented crowns.

3. Bonded crowns with thick occlusal dimensions (reduced preparation) and endo-type crowns showed the highest fracture load values.
Acknowledgments

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References
