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Effects of Thermocycling and Occlusal Force on Adhesive Composite Crowns

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Abstract. The aim of this in vitro study was to provide first quantitative data on the marginal adaptation and the required load to fracture of adhesive composite crowns with and without adhesive composite cores. Eighteen caries-free extracted human premolars were restored using fine hybrid composite crowns with margins located entirely in dentin. Six crowns were adhesively luted to dentin stubs, six to endodontically treated teeth with adhesive titanium posts and adhesive composite cores, and six to adhesive composite cores without posts. Another ten unprepared teeth served as a control. All restored teeth were subjected to long-term occlusal and thermal stresses. The marginal adaptation was evaluated in the SEM before and after loading. Load to fracture was recorded at the end of the stress. Before stressing, 72.2 to 85.0%, and after stressing, 51.9 to 66.2% of "continuous margin" were recorded at the dentin-luting composite interface. The best results after stressing were achieved with crowns luted to adhesive composite cores without titanium posts. At the luting composite-composite crown interface, 61.6 to 88.7% of "continuous margin" before and 57.7 to 75.5% after stressing were recorded. The required load to fracture the restored teeth ranged from 72.0 to 89.2% of the unrestored, unloaded control. Adhesive composite cores without titanium posts yielded the best results.

Key words. Composites, Crowns, Fatigue, Electron Scanning Microscopy.

Introduction

Tooth-colored, metal-free crowns are usually manufactured from glass ceramics or reinforced porcelain (Adair and Grossman, 1984; Hobo and Iwata, 1985; Maruyama et al., 1991; Claus, 1990; Wohlgend and Schärer, 1990). However, due to the complex laboratory technique, ceramic crowns are extremely expensive and therefore unaffordable for many patients (Grey et al., 1993). Thus, the development of significantly cheaper tooth-colored, metal-free composite crown systems has a high priority (Ellis et al., 1992; Linde, 1993).

Correctly light-cured and/or post-cured fine hybrid composites possess enamel-like wear resistance in the occlusal contact area (Krejci et al., 1994a). They also have a low abrasiveness against antagonistic enamel cusps (Krejci et al., 1994a). Recently developed dentin adhesives contribute to good marginal adaptation in dentin (Krejci et al., 1993a, 1994b). Furthermore, adhesive posts and composite cores were evaluated and described (Liberman et al., 1989; Tan et al., 1991). Based on these developments, adhesive composite crown systems are now within reach. The aim of this in vitro study was to evaluate the marginal adaptation and the required load to fracture of adhesive composite crowns with and without adhesive composite cores.

Materials and methods

Twenty-eight intact caries-free human premolars with similar clinical and radiographic dimensions were randomly divided into three groups of 6 each and one group of 10 teeth (Table 1). The root canals of the specimens in groups 2 and 3 were prepared by the step-back technique, with file No. 50 as the master file, and subsequently were laterally condensed by AH 26...
Table 1. Description of the experimental groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (n = 6)</td>
<td>Dentinal abutment, adhesive composite crown</td>
</tr>
<tr>
<td>2 (n = 6)</td>
<td>Endodontic treatment, adhesive titanium post, countersink &amp; adhesive composite core, adhesive composite crown</td>
</tr>
<tr>
<td>3 (n = 6)</td>
<td>Endodontic treatment, countersink &amp; adhesive composite core, adhesive composite crown</td>
</tr>
<tr>
<td>4 (n = 10)</td>
<td>Natural, unprepared tooth (control)</td>
</tr>
</tbody>
</table>

(DeTrey/Dentsply, Konstanz, Germany), Gutta Percha Point 50 (VDW GmbH, München, Germany), and Gutta Percha Points Fine-Fine (Hygienic Corp, Akron, OH, USA).

After the roots were cut to a length of 9 mm, all teeth were cast, 2 mm below the enamel/cementum junction, with a cold polymerizing resin (Paladur, Kulzer & Co GmbH, Wertheim, Germany) on custom-made specimen-holders. Conventional crown stubs were prepared in the parallelogrammer (PPG 100, Cendres & Metaux, Biel, Switzerland) with diamond burs (Inlay Set, Intensiv SA, Viganello, Switzerland) under water-spray cooling for the specimens in groups 1, 2, and 3. The concity of the stubs was 6°, while the circular ledge width was 0.5 mm. The ledge was level with the enamel/cementum margin and located entirely in dentin. In group 1, the stub was shortened occlusally to a height of 4 mm from the preparation margin. In groups 2 and 3, the crown stubs were similarly shortened, but to 1.0 mm. Central inlays, 4.0 mm deep with linguo-occlusal and mesio-distal breadths of 4.0 mm and 1.5 mm, respectively, were prepared in the open pulp cavities. In group 2, a silanated (Rocatec, Espe, Seefeld, Germany) titanium post (Cytco Set 117, Maillefer, Ballaigues, Switzerland) was adhesively luted by a dentinal bonding system (Syntac, Vivadent, Schaan, Liechtenstein) and a dual-cured fine hybrid resin composite (VP150, Vivadent, Schaan, Liechtenstein). The crown stubs of groups 2 and 3 were rebuilt with an adhesively retained (Syntac, Vivadent, Schaan, Liechtenstein) composite core (Coradent, Vivadent, Schaan, Liechtenstein). After preparation, the dimensions of the cores corresponded exactly to those of group 1. The teeth in group 4 were left intact as a control. The composite crowns, standardized in form and size, were built up directly on the insulating Gel, Kulzer GmbH, Wertheim, Germany) teeth with a light-cured fine hybrid composite (Tetric, Vivadent, Schaan, Liechtenstein). The restorations were then removed from the teeth and post-cured in boiling water for 10 min. A 45° incline to the tooth’s long axis was cut into the occlusal area (Fig.) by means of a parallelogrammer.

The inner surfaces of the composite crowns were dry-roughened by a fine diamond (25 μm, Inlay Set, Intensiv SA, Viganello, Switzerland) and wetted with a composite primer (Special Bond II, Vivadent, Schaan, Liechtenstein). The composite crowns were then adhesively luted using the Syntac adhesive system (Vivadent, Schaan, Liechtenstein) and an experimental dual-cured fine hybrid resin composite (VP150, Vivadent, Schaan, Liechtenstein). Before the luting composite was applied, HelioBond was pre-cured on the tooth surface by visible light for 60 s each from the buccal, lingual, mesial, distal, and occlusal surfaces. The luting composite was light-cured after cementation from the buccal, lingual, mesial, distal, and occlusal surfaces from a distance of 1.0 mm for 120 s each. Fine diamond burs (25 μm, Inlay Set, Intensiv SA, Viganello, Switzerland) and flexible discs (Sof-Lex Discs, 3M, St. Paul, MN, USA) were used to remove excess luting composite and for polishing.

After storage in water at 37°C for two weeks, the restored teeth were mechanically and thermally stressed, simultaneously, at a frequency of 1.7 Hz for 1,200,000 chewing cycles, with a maximal chewing force of 490 N and 3000 thermal load cycles of 5°-55°-5°C for two minutes each in a chewing simulator (Krejci et al., 1990a, b, 1992, 1993b). The margin of each restoration was evaluated before and after the loads by means of replicas and an SEM at 300x magnification (Krejci et al., 1993b). The percentages of “continuous margin”, defining a margin free of gaps and marginal fractures, were evaluated separately for the dentin-luting composite and luting composite-composite crown interfaces. At the same time, the width of the luting composite, representing the marginal fit of the luted crowns, was measured (Krejci et al., 1993b).

After the stresses were completed, the restored teeth and the unstressed control specimens were mounted on brass specimen-holders, fixed, and loaded in a universal testing machine (145502-B, Zwick, Ulm, Germany) at 45° to the longitudinal tooth axis until fractures occurred. The feed velocity was 0.5 mm/min. The location and the morphology of the fractures as well as the load required to fracture were
Table 2. Standardized dimensions of the samples

<table>
<thead>
<tr>
<th>Measuring Spot</th>
<th>Dimension (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crown length</td>
<td>4.0</td>
</tr>
<tr>
<td>Root length</td>
<td>9.0</td>
</tr>
<tr>
<td>Mesio-distal at cervical crown margin</td>
<td>4.5</td>
</tr>
<tr>
<td>Lingual-facial at cervical crown margin</td>
<td>8.0</td>
</tr>
<tr>
<td>Lingual-facial in the pulpal chamber (radiograph)</td>
<td>4.0</td>
</tr>
</tbody>
</table>

recorded. The results were statistically tested by non-parametric tests (Stat View II, Brain Power Inc., Calabasas, CA, USA) on a work station (Quadra 800, Apple Computer Inc., Cupertino, CA, USA).

Results

Table 3 lists the percentages of "continuous margin" before and after load for both interfaces and for each group. The interface of dentin and luting composite had no significant differences between the groups (Kruskal-Wallis; p > 0.05), either before or after loading. Among groups, only group 1 showed a significant decrease of "continuous margin" after loading (Wilcoxon signed-rank; p < 0.05).

At the interface between luting composite and composite crown, the results of group 3 were significantly different from those of groups 1 and 2 before loading (Kruskal-Wallis, Mann-Whitney; p < 0.05). After loading, however, no significant differences were observed. The influence of loading was significant in groups 1 and 2 (Wilcoxon signed-rank; p < 0.05).

The width of the luting composite, which also characterized the marginal fit of the restorations, varied from group to group (Table 3). However, because of the large deviation of the data within the groups, the differences between the groups were not significant (Kruskal-Wallis; p > 0.05). There was no significant relationship between marginal fit and marginal adaptation.

The load to fracture the restored teeth ranged from 72.0 to 89.2% of that for the unrestored control teeth. No significant differences were recorded between the restored groups; however, all restored groups were significantly different from the unrestored control (Kruskal-Wallis, Mann-Whitney; p < 0.05). The fracture patterns were characterized as follows: In group 1, the composite crowns fractured 5 times without the dentinal stubs being involved. The main fracture line corresponded to the direction of applied force, i.e., 45° to the longitudinal tooth axis, beginning at the point of load application. The dentin stub was damaged in only one specimen. In group 2, four teeth showed the predominant fracture behavior of group 1. In one specimen, the stub and the root were also involved in the fracture line, while another specimen fractured within the root, with the fracture starting just above the preparation margin. In group 3, only the composite crowns fractured without involving the stubs or the roots. In group 4, various fracture patterns were observed: With seven teeth, the fracture line followed the direction of the applied load at 45° to the longitudinal tooth axis. In one specimen, the fracture ran through the groove in the root, while in another specimen, only the cusp sheared off. One specimen had a horizontal fracture just below the dentino-enamel junction. Although different fracture patterns were observed in the restored groups, the differences were not statistically significant (Fisher's exact test; p > 0.05).

Discussion

In adhesive systems, the macromechanical retention of conventional gold or FPM restorations luted with zinc oxyphosphate cement is substituted by bonding to tooth structure. Adhesion allows for sealing of dentin, which protects the pulp from the consequences of microleakage and bacterial penetration (Brännström and Nordenvall, 1978; Pasley et al., 1992). In comparison with conventional techniques, bonded restorations strengthen the prepared tooth (Morin et al., 1984; Haller et al., 1990). Furthermore, brittle ceramics, which are prone to fracture, can withstand occlusal loads in the mouth for years, due to the adhesive luting procedures (Mörmann and Krejci, 1992). This does not require extremely high reinforced substructure, which is necessary in conventionally luted systems (Claus, 1990; Schwickerath, 1992).

The authors postulate reliable, clinically relevant adhesion to dentin and to composite crown for successful composite crowns. As reported earlier, the adhesive system

Table 3. Results of the SEM margin analysis and load to failure values

<table>
<thead>
<tr>
<th>Interface Dentin/Composite Luting Agent</th>
<th>Interface Composite Luting Agent/Crown</th>
<th>Marginal Fit [μm] (mean ± SD)</th>
<th>Load to Failure [N] (mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[% &quot;continuous margin&quot;]</td>
<td>[% &quot;continuous margin&quot;]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(mean ± SD)</td>
<td>(mean ± SD)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group before loading</td>
<td>after loading</td>
<td>before loading</td>
<td>after loading</td>
</tr>
<tr>
<td>1</td>
<td>850 ± 10.0</td>
<td>519 ± 239</td>
<td>887 ± 239</td>
</tr>
<tr>
<td>2</td>
<td>778 ± 86</td>
<td>65.4 ± 158</td>
<td>968 ± 2.6</td>
</tr>
<tr>
<td>3</td>
<td>752 ± 211</td>
<td>66.2 ± 196</td>
<td>61.6 ± 23.9</td>
</tr>
<tr>
<td>4</td>
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</table>
used in this study had ~ 95% and ~ 80%, respectively, of "continuous margins" in dentin of mixed class V cavities before and after long-term thermal and mechanical loading. These values were not statistically different from those in enamel margins (Krejci et al., 1993a). By mechanical roughening and chemical re-activation of the composite surface, a strong adhesion was achieved between lab-made composite inlays and composite luting agents (Krejci et al., 1994a). Thus, the two postulates mentioned above—namely, reliable adhesion to dentin and to composite crown—appeared fulfilled. However, in this study only 75.2% to 85.0% of "continuous margin" at the dentin-luting composite interface were recorded before loading. In addition, an imperfect marginal adaptation was also found at the interface between luting composite and composite crown. The differences between inlays and crowns can be explained by the more critical shape of the composite crowns. Because of their geometry, the polymerization shrinkage of the luting composite can hardly be compensated for by deformation of the tooth or the crown itself (Lutz et al., 1991). In addition, because of total bonding to the stubs and to the composite crown, the free surface of the in situ-cured luting composite was small. Therefore, its polymerization shrinkage was unlikely to be compensated for by flow (Feilzer et al., 1989), thus inducing polymerization stress at the interfaces. Further, it is known, from inlay manufacturing, that an impoverishment of radicals takes place in a post-cured composite with time (Bürtscher, 1990). This lack of radicals may have decreased the adhesion to the post-cured composite crowns. By roughening the surface and using composite primers, which chemically re-activate the composite surface, adhesion to post-cured composite may be improved (Krejci et al., 1994a).

However, this pre-treatment, which was derived from the composite inlay technique, did apparently not suffice for composite crowns. Therefore, post-curing in boiling water instead of heat or light and heat needs to be reconsidered. In addition, other composite pre-treatment methods, such as micro-sandblasting or etching with hydrofluoric acid, must be evaluated (Swift et al., 1992a,b).

Group 1 showed a significant decrease of "continuous margin" at the interface of dentin and resin composite after loading. Initially, this group had the best marginal adaptation, which was probably due to the large dentinal surface (Krejci et al., 1991). Under load, however, stresses were obviously built up at the adhesive interface, significantly reducing the percentage of "continuous margin". The smaller decrease of "continuous margin" between tooth and resin composite after load in groups 2 and 3 may be explained by the small difference in physical properties of composite crowns and composite cores. In addition, the weak adhesion between the composite core and the composite crown, as determined in unpublished studies by the authors, may have acted as a stress-breaker within the restoration system (Krejci et al., 1988). It was interesting that adhesive composite cores with titanium posts (group 2) did not improve the marginal adaptation compared with an adhesive composite core (group 3). It was also remarkable that no core retention failures occurred in group 3.

The average luting gap of the composite crowns ranged from 50.5 to 95.0 μm and corresponded to the values found in tooth-colored adhesive inlays (Krejci et al., 1994a). It is conceivable that, with improved manufacturing techniques, these values may be further decreased, approximating those of all-ceramic crowns (Davis, 1988).

When fracture resistance of the loaded specimens was tested, no significant differences were recorded between the restored groups with respect to load to fracture and fracture patterns. However, some trends were present: The forces in group 2 seemed to be increasingly transferred to the roots by the titanium posts, which then induced root fractures. Clinically, this fracture pattern would necessitate extraction of the tooth. In group 3, on the other hand, all fractures were within the restored tooth crown. In vivo, this would allow for a re-make of the restoration.

A comparison of the present results with those of other studies is difficult, since, in contrast to adhesive composite cores and posts (Ben-Amar et al., 1986; Liberman et al., 1989; Tjan et al., 1991; Bex et al., 1992), there is practically no relevant literature on adhesively luted composite crowns. The results achieved with provisional acrylic resin crowns are not comparable, because, in these systems, no adhesion was established between tooth and crown (Blum et al., 1991; Hung et al., 1993). Furthermore, there are no data available for conventional gold, PFM, or all-ceramic crowns using similar testing procedures. Nevertheless, the test method does allow some conclusions to be drawn concerning clinical relevance of the results. The simultaneous long-term application of thermal and mechanical stresses was a severe test. In addition, the evaluation method of the marginal adaptation by SEM was rigorous, since only marginal gaps or continuous margins were scored, without differentiating between the widths of the marginal gaps, which in most cases amounted to only 1-5 μm. Finally, the load to fracture tests were carried out on fatigued restorations with the force applied at a critical angle of 45° to the long axes of the teeth (Sorensen and Engelman, 1990). Considering all these extreme conditions, the results of this in vitro study are encouraging for clinical use. This is particularly so because the results were achieved with systems not primarily designed for crowns.

Possible indications of composite crowns could be for geriatric patients, who need low-cost therapy because of financial considerations and/or because of limited life expectancy. Furthermore, composite crowns for children and adolescents as semi-permanent restorations of large accidental crown fractures would cost less and would require less invasive tooth preparation compared with conventional restorative techniques. Finally, a composite
crown suprastructure may be considered for implants for better absorption of chewing forces (Gracis et al., 1991).

References


