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Influence of Adhesive Core Buildup Designs on the Resistance of Endodontically Treated Molars Restored With Lithium Disilicate CAD/CAM Crowns

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Clinical Relevance

Lithium disilicate computer-aided design/computer-aided manufacturing (CAD/CAM) crowns with or without composite resin buildup exceeded expectations in restoring endodontically treated molars. The 2-mm buildup provided the highest load to failure and good fatigue resistance, so it can be indicated in cases of high occlusal loading.

SUMMARY

Objective: To assess the influence of adhesive core buildup designs (4-mm buildup, 2-mm buildup, and no buildup/endocrown) on the fatigue resistance and failure mode of endodontically treated molar teeth restored with lithium disilicate computer-aided design/computer-aided manufacturing (CAD/CAM) complete crowns placed with self-adhesive cement.

Methods and Materials: Forty-five extracted molars were decoronated at the level of the cementoenamel junction and endodontically treated. Specimens received different Filtek Z100 adhesive core buildups (4-mm buildup;

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DOI: 10.2341/14-277-L

2-mm buildup; and no buildup endocrown preparation) and were restored with Cerec 3 CAD/CAM lithium disilicate crowns (IPS e.max CAD). The intaglio surfaces of restorations (n=15) were conditioned by hydrofluoric acid etching and silane, and prepared teeth were treated with airborne-particle abrasion, followed by cementation with RelyX Unicem 2 Automix. Specimens were then subjected to cyclic isometric loading at 10 Hz, beginning with a load of 200 N (×5000 cycles), followed by stages of 400, 600, 800, 1000, 1200, and 1400 N at a maximum of 30,000 cycles each. Specimens were loaded until failure or to a maximum of 185,000 cycles. The chewing cycle was simulated by an isometric contraction (load control) applied through a 10-mm in diameter composite resin sphere (Filtek Z100). Surviving specimens were axially loaded until failure or to a maximum load of 4500 N (crosshead speed 0.5 mm/min). The failure mode was assessed, and fractures were designated as catastrophic (tooth/root fracture that would require tooth extraction) or reparable (cohesive or cohesive/adhesive fracture of restoration only). Groups were compared using the life table survival analysis (log-rank test at *p*=0.05). Surviving specimens were loaded to failure and compared with one-way analysis of variance.

Results: The survival rates after the fatigue test were 100%, 93%, and 100% for 4-mm, 2-mm, and no buildup (endocrown), respectively and were not statistically different (only one specimen failed with a 2-mm buildup under a crown that cohesively fractured at 1,400 N). Postfatigue load to failure averaged 3181 N for 4-mm buildups (15 specimens), 3759 N for 2-mm buildups (12 specimens), and 3265 N for endocrowns (14 specimens). The 2-mm buildups were associated with higher loads to failure than endocrowns and 4-mm buildups, but no differences were found between 4-mm buildups and endocrowns ($p<0.05$.) One endocrown and 2 restorations with a 2-mm buildup survived the load-to-failure test (at 4500 N). Only catastrophic fractures occurred after the load-to-failure test.

Conclusions: The buildup design influenced the performance of endodontically treated molars restored with lithium disilicate CAD/CAM complete crowns placed with self-adhesive resin cement. The 2-mm buildups were associated with higher loads to failure than the endocrown and the 4-mm buildup, but all restoration designs survived far beyond the normal range of masticatory forces.

INTRODUCTION

Long-term success of endodontic treatment is highly dependent on the restorative treatment that follows.[1] There is wide general agreement that the ferrule effect is a critical element in the performance of crowned endodontically treated molars (ETMs).[2,3] In dentistry, the ferrule refers to the cervical tooth structure that provides retention and resistance form to the restoration and protects it against fracture. However, in cases when the ferrule is absent, there is no consensus about the optimal buildup design required to rehabilitate these ETMs with extensive loss of coronal structure. Although insertion of a post does not strengthen or reinforce an ETM, posts are frequently used to retain coronal buildup materials, which in turn are used to retain a restoration.

With advances in the mechanical properties of composite resins and bond strength of dentin adhesive resins, it is logical to question whether these materials can be used to develop an internal adhesive ferrule effect without a post. Molars usually have a substantial amount of dentin (including the pulp chamber) available for bonding. In addition to substituting the pulp ceiling, the composite resin core buildup allows clinicians to remove retention from the endodontic preparation and control the restoration thickness. A different strategy to restore ETMs is an endocrown restoration.[4,5] This alternative approach utilizes the surface available inside the pulp chamber and restores both the core and the crown as one component. There is little information about the clinical quality of endocrowns generated with the CEREC (ceramic reconstruction) system; however, it appears to be feasible and at an acceptable level.[6,7]

The aim of this study was to evaluate the influence of a 4-mm buildup, a 2-mm buildup or no buildup (endocrown) on the mechanical performance and failure mode of ETMs restored with lithium disilicate computer-aided design/computer-aided manufacturing (CAD/CAM) complete crowns placed with self-adhesive resin cement. The null hypotheses were that there is no significant difference in the fatigue resistance and failure mode of ETMs among the three different buildup designs tested in this *in vitro* study.

METHODS AND MATERIALS

Once approval was obtained from the ethics committee of the Piracicaba Dental School (Campinas State University) and the University of Southern California review board, 45 freshly extracted, sound human maxillary molars stored in solution saturated with thymol were used. Teeth were mounted in a special positioning device with acrylic resin (Palapress, Heraeus Kulzer, Armonk, NY, USA), and the root was embedded up to 3.0 mm below the cementoenamel junction (CEJ).

Tooth Preparation

A standardized tooth preparation was applied to all specimens. The intact crowns were removed by a horizontal section 1 mm above the CEJ using a diamond saw (Isomet, Buehler Ltd, Lake Bluff, IL, USA) under water lubrication. A standard-access opening was prepared to simulate root canal treatment in each tooth. Teeth were accessed using slow-speed round and GK269 burs to de-roof the pulp chamber and smooth the internal walls. Canals were located and patency achieved using #10 K-files (Dentsply Tulsa Dental, Johnson City, TN, USA). Coronal flare was created using Gates #3 (Dentsply), and canals were chemomechanically debrided using 04 rotary files (Protaper Niti Rotary, Dentsply) and NaOCl (5.25%) to within 3 mm of the apex. A final rinse with water was performed and canals were dried using paper points. Warm vertical obturation of the canals was then performed using gutta percha to the orifice level and condensed. An additional horizontal reduction of 1.0 mm was obtained (flat preparation following the CEJ, no ferrule) with the aid of a coarse round diamond bur (Brasseler, Savannah, GA, USA). Finally, a glass-ionomer barrier 1.0-mm to 1.5-mm thick (Ketac Molar, 3M ESPE, St Paul, MN, USA) was applied to the base of the pulp chamber.

The teeth were randomly divided into three groups according to restorative technique (n=15 each):

- Group I had 4-mm buildup (4-mm height from CEJ at cusp tips, 2-mm height from CEJ at central groove) + complete crown restorations (1.5-mm thick) (Figure 1A);
- Group II had 2-mm buildup (2-mm height from CEJ at cusp tips, 1-mm height from CEJ at central groove) + complete crown restorations (2.5-mm to 3.5-mm thick) (Figure 1B);
- Group III had endocrown restoration (about 5-mm to 5.5-mm thick) (Figure 1C).

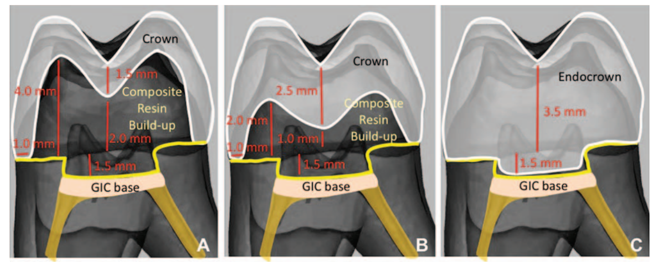

Figure 1. *Restorative techniques. (A) Group I. (B) Group II. (C) Group III.*

Buildups for groups I and II were made using Optibond FL adhesive system (Kerr Corp, Orange, CA, USA) and Filtek Z100 composite resin (3M ESPE) placed in 1.5-mm increments polymerized for 20 seconds each with 1000 mW/cm^2 (Valo, Ultradent Products, Inc, South Jordan, UT, USA).

Design and Manufacturing of Restorations

The molars were restored using the Cerec 3 CAD/CAM system (Sirona Dental Systems GmbH, Bensheim, Germany). The specimens were fitted with a crown or endocrown of standardized thickness and occlusal anatomy (third maxillary molar, Lee Culp Youth database). Using the Crown Master Mode and the Design Tools of the CEREC software (version 3.6, Sirona Dental Systems), the occlusal surface was moved and rotated to make parallel the cusp tips and the preparation surface as well as to align the central groove. All restorations were milled in lithium disilicate ceramic IPS e.max CAD blocks (Ivoclar Vivadent, Schaan, Liechtenstein) using the Endo mode with the sprue located at the lingual surface, then polished mechanically with a diamond ceramic polisher (CeramiPro Dialite W16DM, Brasseler) and glazed with IPS e.max CAD Cristall/Glaze (Ivoclar Vivadent) according to the manufacturer's instructions. The lithium disilicate crowns require crystallization firing. Thus, after milling and glazing, the IPS e.max CAD ceramic crowns were fired in a ceramic furnace (Austromat 624, DEKEMA Dental-Keramiköfen GmgH, Freilassing, Germany) following the manufacturer's instructions.

Crown Placement

All crowns were cemented with a dual-cure self-adhesive resin cement (RelyX Unicem 2 Automix cement, 3M ESPE). Before cementation, each crown was fit on its respective tooth to check its marginal adaptation. The inner surface of the crowns were then cleaned in a steam cleaner and etched with 5% hydrofluoric acid (IPS Ceramic etching gel, Ivoclar

Vivadent) for 20 seconds, rinsed, cleaned in an ultrasonic bath in distilled water for 1 minute, and then silanized (RelyX Ceramic Primer, 3M ESPE, Seefeld, Germany) according to the manufacturer's instructions. The prepared teeth were sandblasted with 27 μm aluminum oxide, rinsed, and dried. The cement was applied to the inner surface of the crowns, which were then seated on the tooth with an approximate pressure of 70 N. Cement excess was removed after a brief light exposure (approximately 2 seconds) with a light-emitting diode curing unit (Valo, Ultradent Products). Air-blocking barrier (KY Jelly, Johnson & Johnson Inc, Montreal, QC, Canada) was used to cover all margins and additional polymerization was carried out for 20 seconds per surface. The margins were finished and polished with a diamond ceramic polisher (CeramiPro Dialite W16DM, Brasseler), polishing brush (soft bristle brush) with diamond paste (Diamord Twist SCL, Premier, EC Representative, MDSS GmbH * Schiffgraben, Hannover, Germany), and buffed with a muslin rag wheel.

Testing

Fatigue Testing—Each specimen was stored in distilled water at ambient temperature for at least 24 hours after adhesive restoration placement. Masticatory forces were then simulated with an artificial mouth using closed-loop servo hydraulics (Mini Bionix II, MTS Systems, Eden Prairie, MN, USA). Each specimen was placed into the load chamber and situated with a positioning device (sliding table). The chewing cycle was simulated by an isometric contraction (load control) applied through a composite resin sphere (Filtek Z100, 3M ESPE) with a diameter of 10.0 mm. Because of the standardized occlusal anatomy, all specimens could be adjusted (through the positioning device) in the same reproducible position with the sphere contacting the mesiobuccal, distobuccal, and palatal cusps (tripod contact). The load chamber was filled with distilled water to submerge the sample during testing. Cyclic load was applied at a frequency of 10 Hz, starting with a load of 200 N for 5000 cycles (preconditioning phase to guarantee predictable positioning of the sphere with the specimen), followed by stages of 400, 600, 800, 1000, 1200 and 1400 N at a maximum of 30,000 cycles each. Samples were loaded until fracture or to a maximum of 185,000 cycles. The number of endured cycles and failure mode were recorded. After a two-examiner agreement under optical microscopy, a distinction was made between catastrophic failure (crown/root fracture that would require tooth extraction) or reparable failure (cohesive or cohesive/adhesive failure).

Load-to-Failure Testing of Surviving Specimens (in the case where a Major Percentage of Specimens Survived Fatiguing)—After the fatigue test, surviving specimens were axially loaded until failure or to a maximum load of 4500 N with a 10-mm composite resin sphere. The sphere had the same three-point occlusal contacts as in the fatigue test. The cross-head speed was 0.5 mm/min. The maximum post-fatigue load before failure was recorded in Newtons, and mean values were calculated per group. After load tests, the specimens were analyzed for one of the three failure modes as in the fatigue test.

Statistical Analysis

The fatigue resistance of the three groups was compared using the life table survival analysis. At each time interval (defined by each load step), the number of specimens starting the interval intact and the number of specimens fracturing during the interval were counted. This allowed survival probability (%) to be calculated at each interval.

The postfatigue load-to-failure resistance of the surviving specimens was compared using one-way analysis of variance (ANOVA) (data tested normal) and the Tukey honestly significant difference test for post hoc analyses. For all statistical analyses, the level of significance was set at 95%. The data were analyzed with statistical software (MedCalc, version 11.0.1, MedCalc Software, Mariakerke, Belgium).

RESULTS

The survival rates after the fatigue test for ETMs with 4-mm buildups, 2-mm buildups, and endocrowns were 100% (15 samples), 93% (14 samples), and 100% (15 samples), respectively, and no statistical differences in survival were found among them (p=0.98) (Table 1). There was only one failure during the fatigue test (a specimen with 2-mm buildup that fractured cohesively, crown and buildup, at 1400 N). All specimens demonstrated limited wear of the crown material (mainly glaze) but marked concave wear faceting on the resin sphere antagonist (Figure 2).

Postfatigue load to failure averaged 3181 N for 4-mm buildups (15 specimens), 3759 N for 2-mm buildups (12 specimens), and 3265 N for endocrowns (14 specimens). One-way ANOVA revealed the higher load-to-failure resistance of 2-mm buildups (2-mm high) compared with the 4-mm buildup and endocrown designs (p=0.02), but no difference was found between the 4-mm buildup and endocrown.

Table 1: *Pairwise Post Hoc Comparisons*[a]

	LD Endocrown	LD 2 mm Build-up	LD 4 mm Build-up
LD Endocrown		.98	.98
LD 2 mm Build-up	<.05		.98
LD 4 mm Build-up	> .05	<.05	

Abbreviation: LD, lithium disilicate.
[a] *Shaded squares = fatigue post hoc tests (log rank test); clear squares = load-to-failure post hoc tests (Tukey honestly significant difference).*

One endocrown and two restorations with 2-mm buildup survived the load-to-failure test at 4500 N. Failure-mode analysis showed that all of the specimens exhibited nonrestorable catastrophic fractures after load-to-failure testing.

DISCUSSION

Today, both composite resin and ceramic materials can be used in the CAD/CAM technique. *In vitro* and *in vivo* research[8-10] tends to favor composite resin blocks over porcelain ones, especially when restoring ETMs. Additional CAD/CAM materials have emerged, such as resin nanoceramics and lithium disilicates. Previous conclusions about CAD/CAM porcelain blocks may not apply to all ceramic materials. Therefore, the biomechanical behavior of those materials and the most appropriate restorative strategy (core buildup vs endocrown) must be investigated to ensure appropriate clinical use.

In the present study, the influence of three buildup designs and restorative material on the fracture resistance of ETMs with extensive loss of coronal structure and no ferrule effect was evaluated. The load-to-failure value of fatigued 2-mm buildup restorations was higher compared with 4-mm buildup restorations and to endocrown (no-buildup design) restorations. Thus, the null hypotheses, which state that there would be no significant difference in the fatigue resistance and failure mode of ETMs among the three different designs tested in this *in vitro* study was partially rejected because the fatigue test alone did not demonstrate significant differences, and neither did the failure mode.

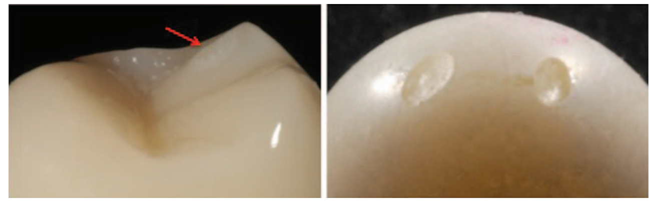

Figure 2. *Photographs of crown (IPS e.max CAD) and antagonist (resin sphere) wear.*

The present testing method allows a physiologic representation of mastication by a servohydraulic control system.[11] It uses a stepped load protocol, which is a compromise between the traditional time-consuming low-load/high-cycle fatigue test and the conventional load-to-failure test (which may be relevant in trauma situations). Although it is not possible to make a direct clinical correlation about the significance of the load range used in this study, Sakaguchi et al.[12] correlated 250,000 cycles at only 13.6 N with 1 year of clinical service using a similar machine. Given the extreme range of load in the present study, the accelerated life cycle of the restored tooth may certainly have been simulated. Careful tooth selection and a CAD/CAM CEREC machine were used in this study to standardize the dimensions and anatomy of occlusal surfaces of all specimens. The load was applied simultaneously at the buccal and palatal cusps by a composite resin spherical antagonist[9,13] to generate the cuspal flexure and stresses that challenged the coronal integrity.[14-16] Posts were intentionally not used in the present study because minimally invasive approaches were studied. Placing a post often involves removing more tooth structure, thereby weakening the tooth and presenting additional risks of root fractures and/or root perforations.[17] Furthermore, it is well known that posts do not bond well to buildup materials. In addition, omitting the post opens the possibility of using endocrown restorations, which may present even greater fracture strength than the conventional crowns supported on posts and filling cores.[4]

As in a previous study,[18] this study demonstrated that no differences in fatigue survival were found among the three types of crowns. However, the load-to-failure test of the fatigued restorations with a 2-mm buildup showed the best results. All restorations survived far beyond maximum masticatory human forces; one endocrown restoration and two restorations with 2-mm buildup even survived the load-to-failure test at 4500 N. The use of endocrown restorations presents the advantage of simplicity. On the other hand, a 2-mm buildup, besides providing the best fracture resistance, helps remove possible retention from the endodontic preparation, offers some kind of positive geometry (ie, will facilitate seating of the restoration), and decreases restoration thickness, which allows the blue light to pass through the indirect restoration to polymerize the underlying resin cement.[19] The 4-mm buildup restoration certainly provides even better provisional stabilization; however, this is at the cost of polymerization shrinkage due to the large amount of composite resin.

After the fatigue test, it was observed that the buildup design could influence the load-to-failure resistance of restored ETMs with lithium disilicate. The 2-mm buildups performed better than endocrowns and 4-mm buildups. The explanation may lie in the fact that in the 2-mm buildup, the restoration is still relatively thick, providing additional resistance; also, the buildup itself acts as a bonded connector (Optibond FL included) with the tooth. Conversely, the combination of those two elements is missing in the 4-mm buildup (which are a well bonded but thinner restoration) and the endocrown (a thick restoration but lacks bonding because of the self-adhesive cement).

Loaded restorations and resin sphere antagonists showed well-defined wear facets, which supports the clinical relevance and validity of this simulation. It is always more realistic to simulate tooth contacts through wear facets distributing the load without reaching the compressive limit of the tissues or restorative materials.[13] Wear facets were predominant on the antagonist (resin) sphere compared with the lithium disilicate restoration itself.

Considering the results of this *in vitro* simulated fatigue study on no-ferrule and no-post complete crowns, further research could be carried out to confirm that the use of a post is not required. However, it is difficult to envision how another restorative strategy could yield better results than those obtained with lithium disilicate ceramics without ferrules or posts.

CONCLUSION

It can be concluded that the buildup design influenced the performance of lithium disilicate CAD/CAM complete crowns placed with self-adhesive cement, even though all three buildup designs exceeded all expectations. The use of 2-mm buildups was the most robust approach. Not only did it yield higher loads to failure than endocrown and 4-mm buildup restorations, but it may also be useful to provide enhanced geometry, remove undercuts from the endodontic preparation, and facilitate provisionalization.

Acknowledgements

This study was supported by CNPq 20092/2011-6, CAPES 3110/2010, and CAPES 4979/11-7. The authors thank 3M ESPE, St Paul, Minnesota, for providing, Rely X Unicem 2 Automix, Filtek Z100, and Rely X Ceramic Primer.

Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of the University of Southern California Health Sciences Campus Institutional Review Board. The approval code for this study is HS-12-00278.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

(Accepted 27 March 2015)

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