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Laboratory Research

Influence of No-Ferrule and No-Post Buildup Design on the Fatigue Resistance of Endodontically Treated Molars Restored With Resin Nanoceramic CAD/CAM Crowns

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Clinical Relevance

Endodontically treated molars with extensive loss of coronal structure and no ferrule effect could be restored successfully with resin nanoceramic CAD/CAM crowns, with or without underlying composite resin buildup.

SUMMARY

Objectives: To evaluate 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 resin nanoceramic (RNC) CAD/CAM complete crowns placed with self-adhesive resin cement.

Methods and Materials: Forty-five extracted molars were decoronated at the level of the cementoenamel junction, and the roots were endodontically treated. Specimens received different Filtek Z100 adhesive core buildups (4-mm buildup, 2-mm buildup, and no buildup, endocrown preparation) and were restored with Cerec 3 CAD/CAM RNC crowns (Lava Ultimate). Restorations (n=15) and prepared teeth were treated with airborne-particle abrasion, followed by cementation with RelyX

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Unicem 2 Automix. Specimens were then subjected to cyclic isometric loading at 10 Hz, beginning with a load of 200 N (for 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 (10-mm-diameter composite resin sphere antagonist). The failure mode was assessed: "catastrophic" (tooth/root fracture that would require tooth extraction), "possibly reparable" (cohesive/adhesive failure with fragment and minor damage, chip or crack, of underlying tooth structure), or "reparable" fracture (cohesive or cohesive/adhesive fracture of restoration only). Groups were compared using the life table survival analysis. Intact specimens were loaded to failure and compared with one-way analysis of variance.

Results: All specimens survived the fatigue test until the 800 N-step. The survival rates for 4-mm, 2-mm, and no buildup (endocrown) were 53%, 87%, and 87%, respectively, and were not statistically different even though crowns with 2-mm buildups only started to fail at 1200 N. Minor cohesive chips were detected in many samples despite having survived all 185,000 cycles. Postfatigue load-to-failure ranged from 2969 N with 4-mm buildup (eight specimens), 2794 N for 2-mm buildup (13 specimens), and 2606 N for endocrowns (13 specimens) and were also not statistically different. There were only two catastrophic failures during the fatigue test and small subgingival delamination fractures and cracks (only with 4-mm buildup). All specimens in the load-to-failure test exhibited nonrestorable catastrophic fractures.

Conclusions: There was no influence of the buildup design on the performance of endodontically treated molars restored with RNC CAD/CAM complete crowns placed with self-adhesive cement. All restoration designs survived the normal range of masticatory forces. Failure mode tended to be more favorable with the 2-mm buildup or no buildup (endocrown).

INTRODUCTION

The decision of how to rehabilitate endodontically treated molars (ETM) with extensive loss of coronal structure is a challenge for restorative dentistry. Those teeth are considered to have a higher risk of fracture than vital teeth because of their inherently poor structural integrity, with loss of root and coronal dentin resulting from preexisting caries and/or tooth preparation.[1-4] There is controversy regarding which technique would be ideal for ETM restoration.

Although earlier publications have called for stabilization of ETM with intracanal posts and ferrule, other evidence has demonstrated that post reinforcement is not beneficial.[3,5] Even though posts are frequently used to retain coronal buildup materials, they do not reinforce roots and may even weaken them through loss of radicular dentin necessitated by post space preparation.[5,6] In addition, preparing a post space also involves a certain degree of risk of accidental root perforation. The loss of tooth structure during preparation affects tooth stiffness, reduces its resistance to fracture, and consequently limits its prognosis. Other studies[7-9] have confirmed that ETM restored without posts have similar fracture resistances and failure modes compared with those with posts, which suggest that posts are not necessarily required. Lima and others[7] confirmed that the presence of a ferrule (with a composite resin buildup) is more critical than the use of a post. However, there is no consensus about the optimal buildup design necessary to restore ETM in the absence of any ferrule. The endocrown restoration is another alternative restorative treatment for ETM.[10,11] Pissis[10] was a pioneer in proposing this "monobloc" porcelain technique in 1995. This type of restoration preserves root tissue and limits internal preparation of the pulp chamber to its anatomic shape. It constructs both the crown and core build-up as a single unit. Even though the original technique described the use of porcelain, *in vitro* fatigue tests showed that endocrowns made of more flexible composite resin or newer resin nanoceramic (RNC) materials may also have a great potential for this indication.[11-14] Another consideration is the possible use of a core buildup to remove retention from the endodontic preparation, provide some kind of positive geometry, decrease restoration thickness (allowing for the use of light-polymerized luting composites), and facilitate provisionalization. Yet there is a lack of data about the biomechanical behavior of different buildup designs to restore ETM.

Therefore, 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 ETM restored with RNC CAD/CAM complete crowns placed with self-adhesive cement. The null hypothesis was that there is no significant difference in the fatigue resistance and

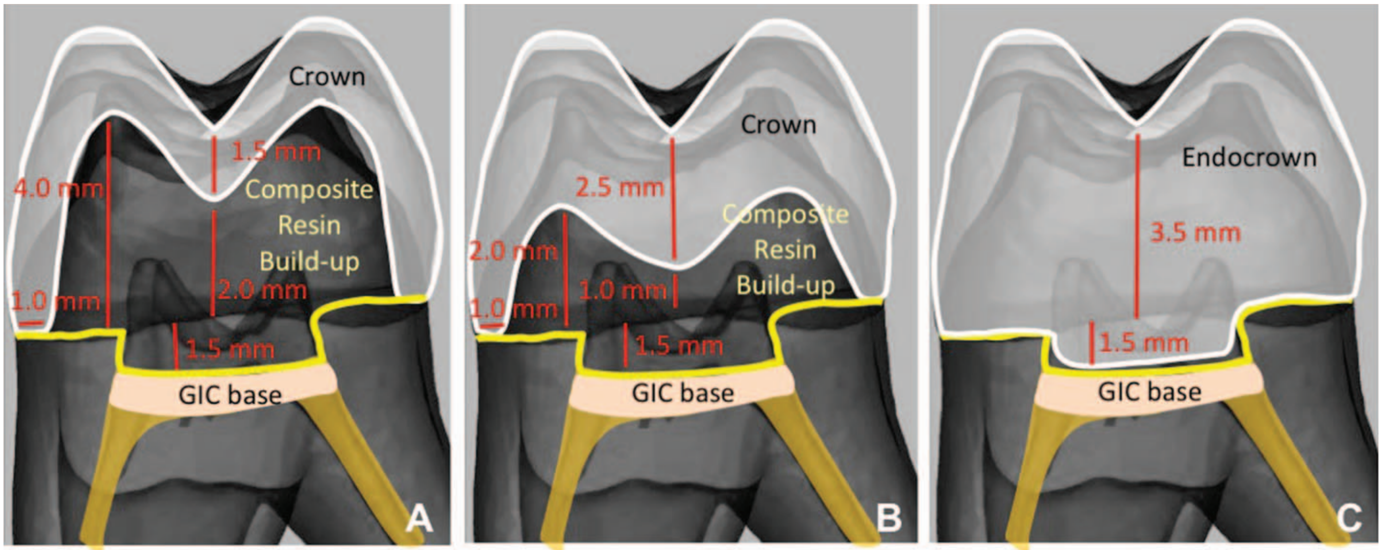

Figure 1. *Restorative techniques. (A): Group I. (B): Group II. (C): Group III.*

failure mode of ETM among the three different designs tested in this *in vitro* study.

METHODS AND MATERIALS

Once approval was obtained from both the Ethical 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) embedding the root 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 deroof the pulp chamber and smoothen 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 Tulsa Dental), and canals were chemomechanically debrided using 04 rotary files (Protaper Niti Rotary, Dentsply Tulsa Dental) and NaOCl (5.25%) to within 3 mm of the apex. A final rinse with H_2O 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 1.0- to 1.5-mm-thick glass-ionomer barrier (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 the different restorative techniques (n=15):

- Group I: large 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: short buildup (2-mm height from CEJ at cusp tips, 1-mm height from CEJ at central groove) + complete crown restorations (2.5-3.5 mm thick; Figure 1B)
- Group III: endocrown restoration (ca. 5- to 5.5-mm thickness; Figure 1C)

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 at 1000 mW/cm^2.

Design and Manufacturing of Restorations

The molars were restored using the Cerec 3 CAD/CAM system (Sirona Dental Systems GmbH, Ben-

Table 1: *Failure Mode During Fatigue Testing*

	Reparable				Not Reparable
	Cohesive Failure at Crown	Cohesive Failure at Crown and Buildup + Adhesive Failure at Dentin Margin	Adhesive Failure Between Crown and Buildup + Adhesive Failure at Dentin Margin	Cohesive Failure at Crown and Buildup + Dentin Chip	Catastrophic Failure
Endocrown	1	—	—	1	—
2-mm Buildup	2	—	—	—	—
4-mm Buildup	1	3	1	—	2

sheim, 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 (v. 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 RNC (Lava Ultimate blocks, 3M ESPE) using the Endo mode with the sprue located at the lingual surface, then polished mechanically with a diamond ceramic polisher (CeramiPro Dialite W16DM; Brasseler), polishing brush (soft bristle brush) with diamond paste (Diamond Twist SCL, Premier, EC Representative: MDSS GmbH * Schiffgraben, Hannover, Germany), and buffed with a muslin rag wheel.

Crown Placement

All crowns were cemented with a dual-cure self-adhesive resin cement (RelyX Unicem 2 Automix, 3M ESPE). Before cementation, each crown was fitted on its respective tooth to check its marginal adaptation and steam cleaned. The inner surface of LU crowns were sandblasted with 50 μm aluminum oxide (Danville, San Ramon, CA, USA), rinsed, and cleaned in an ultrasonic bath in distilled water for one minute. 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 excesses were removed after a brief light exposure (approximately two seconds) with an LED light (VALO Curing Light, Ultradent Products Inc, South Jordan, UT, USA) and followed by light polymerization for 20 seconds on each surface. 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), and buffed with a muslin rag wheel.

Testing

Fatigue Testing—Each specimen was stored in distilled water at room temperature for at least 24 hours following 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. Following a two-examiner agreement using 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 with or without fragment and minor damage, chip or crack, of underlying tooth structure; Table 1).

Load-to-Failure Testing of Intact Postfatigue Specimens (in Case of Major Percentage of Specimen Surviving Fatigue)—After the fatigue test, intact 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

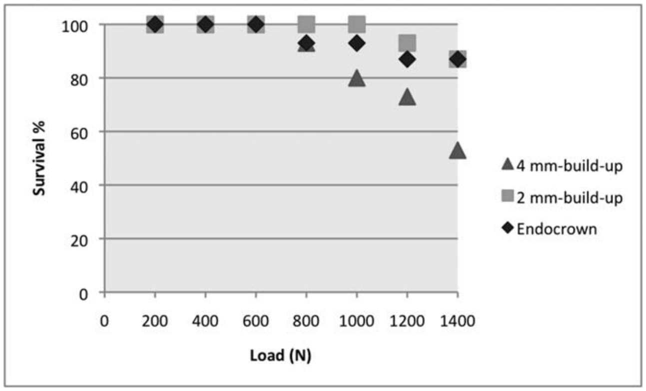

Figure 2. *Life table survival distributions by materials at each load step (n=15).*

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, allowing the calculation of survival probability (%) at each interval. The influence of the restorative material on the fracture strength (load step at which failure occurred) was analyzed by using the log-rank test at a significance level of 0.05. The postfatigue load-to-failure resistance of the survived specimens was compared using one-way analysis of variance (ANOVA; data tested normal). For all statistical analyses, the level of significance was set at 95%. The data were analyzed with statistical software (MedCalc, V. 11.0.1; MedCalc Software, Mariakerke, Belgium).

RESULTS

The survival rates after the fatigue test for ETM with 4-mm buildups, 2-mm buildups, and endocrowns were 53% (eight samples), 87% (13 samples), and 87% (13 samples), respectively, and no statistically significant differences were found among them ($p>0.05$; Figure 2). In groups with large buildups and endocrowns, all specimens survived until the 800 N-step, while for specimens with short buildups, samples started to fail only at the 1200 N-step. At the end of the fatigue test, minor surface chips were detected (two specimens with large buildups and nine specimens with short buildups or endocrowns). All specimens demonstrated less wear at the resin sphere antagonist than the restoration itself (Figure 3).

Postfatigue load-to-failure averaged 2969 N with 4-mm buildups (eight specimens), 2794 N for 2-mm buildups (13 specimens), and 2606 N for endocrowns (13 specimens). One-way ANOVA revealed that there were no statistically significant differences among all three restorative techniques. Failure mode analysis showed that there were only two evident catastrophic failures during the fatigue test. All failure modes found at the fatigue test are given in Table 1. All of the specimens after the load-to-failure test exhibited nonrestorable catastrophic fractures.

DISCUSSION

Based on the results of this study, the null hypothesis was accepted for the fatigue resistance but rejected for failure mode analysis of ETM. The failure modes slightly varied, with less favorable outcomes when using a large core buildup.

In an effort to standardize and approximate the clinical situation as much as possible, natural teeth of similar dimensions were selected, the anatomy of the occlusal surface and the thickness of those restorations were standardized by the Cerec ma-

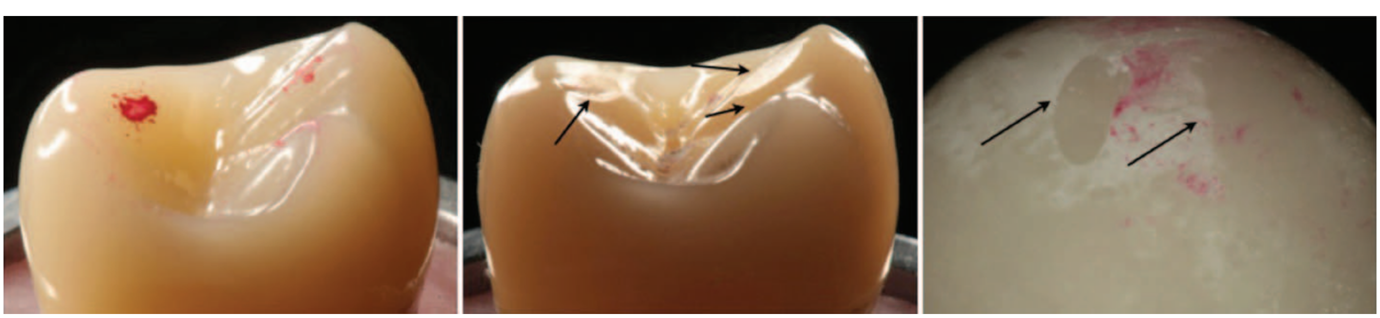

Figure 3. *Photographs of crown and antagonist (resin sphere) wear.*

chine, and the consistent load configuration of all samples was applied. As previously suggested,[13,15] the use of a composite resin sphere antagonist was preferred rather than a stainless-steel one. A more realistic simulation of tooth contacts is enabled by the lower stiffness and higher wear of the composite resin.[16] No failure of the spheres was noted during the test. Because of the simulated natural tooth anatomy of the restorations, a standardized three-point/facet contact could be created and a progressive load protocol generated (from 200 N to 1400 N, maximum 185,000 cycles). Loaded restorations and teeth should show wear facets and not point contacts.[15] Such wear facets both at the restorations and resin sphere antagonists were observed. As was the case in previously published data,[17] the RNC material demonstrated more material wear than the antagonistic wear (resin sphere). This can be explained by the fact that the RNC material has 80% filler content by weight (20% resin matrix) compared with 85%/15% for Filtek Z100 composite resin (antagonist sphere).

The present protocol seems to be the best compromise between available *in vitro* fatigue testing methods and clinical reality and can be called accelerated fatigue. Even though it is not possible to make a direct clinical correlation about the significance of the load range used in this study, this test lies in between load-to-failure (very high single load until failure, not clinically relevant unless during trauma) and fatigue tests (time-consuming low load/high cycles). A true fatigue correlation for one year of clinical service is 250,000 cycles at only 13.6 N.[18] Therefore, given the extended range of load in the present study, the accelerated life cycle of the restored tooth may have been simulated.

A higher frequency (10 Hz) in the cyclic loading test, which was suggested by Kelly and others,[19] was used in this study. It decreases the time of the experiment, allowing testing of three specimens per day. One may wonder whether such high frequency might lead to more heat generation compared with 1 to 2 Hz and possibly exclude time for stress relaxation.[20] Another limitation of this study is that the load was applied only axially, limiting the clinical implication to a vertical loading situation. Biacchi and Basting[21] used an oblique compression force to compare the fracture strength of endocrown and complete crowns retained by glass fiber posts. However, as in the present study, the endocrown restorations performed well, even presenting greater fracture strength than the conventional crowns supported on posts and filling cores.

Another specific element in this study was the use of self-adhesive resin cement. It allows for a convenient, fast, and efficient delivery of complete crowns. This is especially significant when considering excess cement removal in the case of subgingival margins (a common situation when replacing existing complete crowns), for which adhesive luting becomes more technique sensitive. RelyX Unicem 2 was chosen also because of its self-polymerization component, which was desirable for the thick endocrowns. The same cement was used to deliver the other crowns on the different buildups in order not to introduce a new variable.

The results of this study demonstrated that the presence of a buildup does not necessarily enhance the fracture resistance of ETM with extensive loss of coronal structure when using RNC crowns. However, the mean fracture loads for the 4-mm buildup (1171 N), 2-mm buildup (1300 N), and endocrown (1000 N) failed fatigued restorations far exceeded regular masticatory forces. The latter, during normal function, range from 50 N to 250 N and from 500 N to 800 N in bruxism behavior.[22,23] The 4-mm buildup and endocrown restorations started to fail at 800 N, while all short buildups did not show fracture before 1200 N. Those results suggest that it may be possible to use all three types of RNC restorations with self-adhesive cementation for ETM with extensive loss of coronal structure even under high load requirements. It is noteworthy to compare the performance of those restored nonvital teeth with that of crowned vital molars from another study by the same author in strictly identical conditions: 1.5-mm RNC crowns with self-adhesive cementation.[17] Simulated fatigue survival of the crowned vital teeth was 80% (53%-87% in the present study), and the average load-to-failure of intact postfatigue specimens was 3122 N (2606-2969 N in the present study). This indicates that the restorative modalities proposed for ETM in the present study may allow approaching the performance of vital teeth despite the absence of a ferrule effect.

There is evidence that the use of posts does not influence the performance of restored ETM.[3,5,21] In addition, the placement of a post is always associated with a risk of perforation and cracking of the root. Therefore, no posts were used in the present study. No-post endocrown restorations allow for maximum tooth structure preservation, reduce the requirement for macro retentive geometry, provide an efficient and esthetic outcome, and seem clinically viable.[24-26] From a clinical perspective, the endocrown design seems to have practical advantages over restorations with a core buildup: it is cheaper, it takes less time to complete, and there is no composite resin shrinkage associated with this technique. The endocrown is also a useful option when there is simply no occlusal clearance (extra-short clinical crowns). On the other hand, there are advantages of using an adhesive composite resin core buildup when possible. The buildup is preceded by the use of a dentin adhesive system that safely seals the dentin. It reduces the thickness of the overlaying restoration, allowing for a more efficient light polymerization during cementation. It is known that even for dual-polymerization cements, the light-polymerization component is a determinant in obtaining an acceptable degree of conversion.[27-29] In view of the present results, small composite resin buildups should be preferred. They also induce less polymerization shrinkage than large ones, and they are useful for providing enhanced geometry, removing undercuts from the endodontic preparation, and facilitating provisionalization (by stabilization) when necessary.

Failure modes tended to be more favorable with the 2-mm buildup or no buildup (just cohesive failures). Only one endocrown failed with a small subgingival margin dentin chipping, which was still considered re-restorable because it would be feasible to smooth this margin or, in the worst case scenario, use periodontal surgery or the margin elevation technique.[30] Small superficial chipping of the RNC material around the contact points was frequently observed. Because there was no effect on the integrity of the restoration and stable occlusal contacts were maintained, the fatigue machine did not stop. From a clinical perspective, those defects would be easily corrected and polished, since Lava Ultimate proved extremely polishable, which is another advantage of the RNC material.

Further research should explore the use of different core buildups (such as autocure composite resins), restorative materials, and adhesive luting procedures. Even though more flexible materials seem to be indicated to restore the severely broken down ETM, rather than traditional porcelain,[11-14] the use of ceramics with stronger mechanical properties, such as lithium disilicate, may be a potential alternative.

CONCLUSION

Within the limitations of this *in vitro* study, it can be concluded that there is no influence of the buildup design on the performance of ETM restored with RNC CAD/CAM full crowns placed with self-adhesive resin cement. All restoration designs survived the normal range of masticatory forces. Failure mode tended to be more favorable with the 2-mm buildup or no buildup (endocrown). The endocrown has many practical advantages (simpler, quicker, more economic), while the use of a small composite resin buildup may be useful to provide enhanced geometry, remove undercuts from the endodontic preparation, and facilitate provisionalization when necessary.

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Conflict of Interest

The authors of this article 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.

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