Research and Education

Fatigue resistance of ultrathin CAD/CAM complete crowns with a simplified cementation process

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Technological improvements associated with more conservative approaches to treat dental diseases and the progress of new adhesive materials have led to the development of ultraconservative dentistry. Lately, applying ultraconservative principles of direct techniques to indirect restorations has also increased. Therefore, more conservative indirect preparations have been advocated. Currently, the trend is to avoid traditional complete crown preparations whenever possible. Yet replacement of existing complete crowns is common in dental practice. Many restorative materials may be used in traditional preparations, usually featuring at least 1 to 2 mm of axial and occlusal clearance, such as found under metal ceramic crowns. In other instances, the existing preparation may be conservative such as for gold crowns. Other similar situations include the ultraconservative approach in situations of severe erosion that involve the entire tooth circumference. In most of these examples, the use of traditional metal ceramic would result in significant additional reduction of intact tooth substance to provide clearance for the esthetic veneering material. Instead, supported by 3M ESPE and Brazilians Federal Agencies for Support (CNPq 20092/2011-6, CAPES 3110/2010, and CAPES 4979/11-7).

Statement of problem. Traditional tooth preparation for complete crowns requires a substantial amount of hard tissue reduction. This is in contrast with the principles of minimally invasive dentistry. An ultrathin complete crown preparation is proposed instead.

Purpose. The purpose of this in vitro study was to assess the fatigue resistance and failure mode of computer-aided design and computer-aided manufacturing (CAD/CAM) ultrathin complete molar crowns placed with self-adhesive cement. Different restorative materials (resin nanoceramic [RNC], feldspathic ceramic [FEL], and lithium disilicate [LD]) were compared.

Material and methods. Forty-five extracted molars with a standardized crown preparation were restored with the Cerec 3 CAD/CAM system using FEL, LD, or RNC (n=15). FEL and LD restorations were etched with hydrofluoric acid and silanated. RNC restorations and all preparations were treated with airborne-particle abrasion. All restorations (thickness=0.7 mm) were cemented with RelyX Unicem II Automix cement and submitted to cyclic isometric loading, beginning with a load of 200 N (5000 cycles) and followed by stages of 400, 600, 800, 1000, 1200, and 1400 N at a maximum of 30,000 cycles each. The specimens were loaded until failure or for a maximum of 185,000 cycles. The failure mode was categorized as “catastrophic,” “possibly reparable,” or “reparable.” The groups were compared using life table survival analysis (log rank test at α=0.05). Previously published data from the same authors about traditional complete crowns (thickness=1.5 mm) using the same experimental design were included for comparison.

Results. All specimens survived the fatigue test until the 600 N step. RNC, LD, and FEL failed at an average load of 1014 N (1 survival), 1123 N (2 survivals), and 987 N (no survivals), and no difference in survival rate was found. No catastrophic failures were reported after the fatigue test. Comparison with previously published data showed that 1.5-mm thick complete crowns demonstrated higher survival rates than the ultrathin restorations, independent of the material.

Conclusions. The fatigue resistance of ultrathin complete molar crowns (placed with a simplified cementation process) made of RNC, LD, and FEL was not significantly different. All materials survived the normal range of masticatory forces. All failures were re-restorable. Regular crowns of 1.5 to 2.0 mm thickness may present higher survival rates than ultrathin ones. (J Prosthet Dent 2015;114:574-579)


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Clinical Implications

This study revealed that the minimally invasive CAD/CAM crowns made from resin nanoceramic (RNC), lithium disilicate (LD), or feldspathic ceramic (FEL) can survive the normal range of masticatory force.

ultrathin complete crown restorations using esthetic materials could provide an aesthetic and conservative alternative because no additional preparation of tooth substrate is required. The minimal design of the preparation, however, may affect the stability, resistance/ strength, and longevity of ultrathin dental restorations.

From a practical standpoint, previous findings showed producing thin restorations (approximately 0.6 mm) is possible with the Cerec system (Sirona Dental Systems GmbH). Various computer-aided design and computer-aided manufacturing (CAD/CAM) blocks are available to fabricate those crowns. However, thicknesses of less than 1.5 mm do not comply with the manufacturer’s instructions for use and data are lacking about the use of those materials for ultrathin crowns. The aim of this study was to assess the influence of CAD/CAM restorative materials-RNC, FEL, and LD-on the fatigue resistance and failure mode of ultrathin complete veneer molar crowns placed with a self-adhesive cement. The null hypotheses were that no significant difference would be found among the fatigue resistance and failure mode of the 3 materials tested and that the fatigue resistance of these restorations would not be influenced by the thickness of the material. Data regarding 1.5 mm thick complete veneer crowns previously published by the same authors using a similar experimental design were used to test this second null hypothesis.

MATERIAL AND METHODS

Forty-five freshly extracted carious-free human maxillary molars were selected and stored in a solution saturated with thymol after approval from both the ethical committee of the Piracicaba Dental School (Campinas State University) and the University of Southern California review board. The teeth were mounted in a positioning device with acrylic resin (Palapress; Heraeus Kulzer GmbH), and the root was embedded up to 3.0 mm below the cement-enamel junction.

A minimally invasive complete crown preparation was applied to all specimens (Fig. 1A) with an axial reduction of 0.7 mm, a circular chamfer size of 0.5 mm following the cement-enamel junction, and a convergence angle of 6 degrees between the tooth axis and lateral wall. Anatomic occlusal reduction was carried out, and the buccal and palatal cusp tips were maintained at approximately 4.5 mm from the gingival margin and the central groove at approximately 2.5 mm from the gingival margin. Care was taken to obtain a smooth and rounded internal line angle. Margins were finished with the Cerec 3 system (Sirona Dental Systems GmbH), and software (v3.6; Sirona Dental Systems GmbH) was used to fabricate crowns with an average thickness of 0.7 mm at the central groove and a maximum of 1.0 mm at the cusp tips (measured with a caliper after milling and polishing). A standardized occlusal anatomy was used (third maxillary molar, Lee Culp Youth database). The occlusal surface was moved and rotated with the design tools of the Cerec software to make the cusp tips parallel to the preparation surface and to align the central groove (Fig. 1B). Fifteen monolithic crowns were fabricated from ceramic Vita-blocs Mark II blocks (Vita Zahnfabrik) (group FEL), another 15 from the IPS e.max CAD blocks (Ivoclar Vivadent AG) (group LD), and 15 from nanoceramic resin Lava Ultimate blocks (3M ESPE) (group RNC). All restorations were milled in Endo mode with the sprue located at the lingual surface and inspected to detect possible milling cracks. Following the manufacturer’s instructions, the milled LD crowns underwent crystallization firing in a ceramic furnace (Austromat 624; Dekema Dental-Keramiköfen GmbH). For the RNC group, the polishing procedure was carried with a commercial polishing kit (Dialite, Ultra Polisher; Brasseler), and for groups FEL and LD, the specimens were glazed with the recommended glazing kit (Akzent; Ivoclar Vivadent AG and IPS e.max CAD Crystall Glaze; Ivoclar Vivadent AG) according to the manufacturer’s instructions.

All crowns were cemented with a dual-polymerizing self-adhesive resin cement (RelyX Unicem 2 Automix cement; 3M ESPE). Before cementation, each crown was fitted on its respective tooth to evaluate its marginal adaptation and then steam cleaned. The intaglio of the ceramic crowns was etched with 5% hydrofluoric acid (IPS Ceramic etching gel; Ivoclar Vivadent AG) for 60 seconds (FEL) or 20 seconds (LD), rinsed, cleaned in an ultrasonic bath in distilled water for 1 minute, and then silanized (RelyX Ceramic Primer; 3M ESPE) according to the manufacturer’s instructions. For the RNC group, the crowns were airborne-particle abraded with 50-μm aluminum oxide (Danville), rinsed, and cleaned in an ultrasonic bath in distilled water for 1 minute. The prepared teeth were airborne-particle abraded with 27 μm aluminum oxide, rinsed, and dried. The cement was applied to the intaglio of the crowns, which were then seated on the tooth with an approximate force of 70 N. Cement excess was removed after a brief exposure (approximately 2 seconds) to an LED light (Valo Curing Light; Ultradent Products Inc), followed by light polymerization for 20 seconds on each surface. An air-blocking barrier (K-Y Jelly; Johnson & Johnson Inc) was applied to all specimens (Fig. 1A) with an axial reduction of 0.7 mm, a circular chamfer size of 0.5 mm following the cement-enamel junction, and a convergence angle of 6 degrees between the tooth axis and lateral wall. Anatomic occlusal reduction was carried out, and the buccal and palatal cusp tips were maintained at approximately 4.5 mm from the gingival margin and the central groove at approximately 2.5 mm from the gingival margin. Care was taken to obtain a smooth and rounded internal line angle. Margins were finished with the Cerec 3 system (Sirona Dental Systems GmbH), and software (v3.6; Sirona Dental Systems GmbH) was used to fabricate crowns with an average thickness of 0.7 mm at the central groove and a maximum of 1.0 mm at the cusp tips (measured with a caliper after milling and polishing). A standardized occlusal anatomy was used (third maxillary molar, Lee Culp Youth database). The occlusal surface was moved and rotated with the design tools of the Cerec software to make the cusp tips parallel to the preparation surface and to align the central groove (Fig. 1B). Fifteen monolithic crowns were fabricated from ceramic Vita-blocs Mark II blocks (Vita Zahnfabrik) (group FEL), another 15 from the IPS e.max CAD blocks (Ivoclar Vivadent AG) (group LD), and 15 from nanoceramic resin Lava Ultimate blocks (3M ESPE) (group RNC). All restorations were milled in Endo mode with the sprue located at the lingual surface and inspected to detect possible milling cracks. Following the manufacturer’s instructions, the milled LD crowns underwent crystallization firing in a ceramic furnace (Austromat 624; Dekema Dental-Keramiköfen GmbH). For the RNC group, the polishing procedure was carried with a commercial polishing kit (Dialite, Ultra Polisher; Brasseler), and for groups FEL and LD, the specimens were glazed with the recommended glazing kit (Akzent; Ivoclar Vivadent AG and IPS e.max CAD Crystall Glaze; Ivoclar Vivadent AG) according to the manufacturer’s instructions.

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used to cover all margins, and additional polymerization was carried out for 20 seconds per surface. The margins were finished and polished with diamond ceramic polisher (CeramiPro Dialite W16DM; Brasseler) and a polishing brush (soft bristle brush) with diamond paste (Diamond Twist SCL; Premier, EC Representative: MDSS GmbH) and buffed with a muslin rag wheel.

All specimens were stored in distilled water at ambient temperature for at least 24 hours after cementation. Masticatory forces were applied using closed-loop servo hydraulics (Mini Bionix II; MTS Systems). The mastication 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 until the specimen was completely submerged. Cyclic loading was carried out at a frequency of 10 Hz, beginning with a load of 200 N for 5000 cycles (preconditioning phase to ensure 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. The specimens were loaded until fracture or to a maximum of 185 000 cycles. The number of endured cycles and failure mode were recorded. After 2 examiners had examined the specimens under an optical microscope and come to agreement, the specimens were analyzed for 1 of the 3 failure modes: 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).

The fatigue resistance of the 3 groups was compared by 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 the log rank test ($\alpha$=.05). The data were analyzed with statistical software (MedCalc v11.0.1; MedCalc Software). Differences were localized using pairwise post hoc comparisons with the same test at a significance level of .016 (Bonferroni correction for 3 comparisons). Supplementary data from a previous study of 1.5 mm thick complete molar crowns by the same authors under identical experimental conditions were combined with the present data for additional computation and comparison.

**RESULTS**

For the RNC, LD, and FEL groups, the specimens failed at an average load of 1014 N ($\pm$146) to 106 589 cycles, 1123 N ($\pm$130) to 120 390 cycles, and 987 N ($\pm$200) to 100 362 cycles, respectively, and survival rates did not differ statistically among themselves ($P$=.17) (Fig. 2; Table 1). In groups RNC and LD, all specimens survived until the 800 N step, while for the FEL group, specimens started to fail at the 600 N step. None of 15 FEL crowns survived the fatigue test, but 1 of the RNC and 2 of the LD crowns survived all 185 000 load cycles. For 1 of the 2 surviving LD crowns, multiple cracks were visible at the surface of the restoration at the end of the fatigue test. With regard to the failure mode of the crowns, analysis showed no catastrophic failure for any of the 3 materials. Only adhesive failure could be observed, sometimes with small subgingival delamination fractures and cracks (Table 2; Fig. 3), especially in the case of the RNC specimens.

Additional comparisons of 0.7 mm thick and 1.5 mm thick complete coverage crowns for each material...
DISCUSSION

This in vitro study investigated the survival rate and failure mode of ultrathin, cemented complete veneer molar crowns. The first null hypothesis was partially rejected because no significant difference was found in the fatigue resistance of the 3 materials tested; however, differences in failure mode were observed. The second part of the null hypothesis was rejected because the crown thickness (combined data with previously published work by the same authors using a similar experimental setup) did influence the survival rate.

Previous studies showed that the Cerec system was able to mill ultrathin restorations. As suggested by Tsi- trotou and Van Noort, the endo milling mode was selected to produce better milling quality. Each restoration was carefully examined after milling, and the quality was confirmed because no cracks were observed. However, it appeared that the milled RNC crowns had the best margins compared with the ceramic crowns, which tended to have minor marginal defects (Fig. 4).

In a previous study, the survived rate for complete crown (1.5 to 2.0 mm) made of RNC, LD, and FEL and...
cemented with RelyX Unicem II was 80%, 93%, and 6.6% respectively. RNC and LD crowns did not differ statistically and had significantly higher fatigue resistance compared with FEL. In the present study, the survival rate of ultrathin complete veneer crowns (0.7 mm) made of the same 3 materials was 6.6%, 13.2%, and 0%, respectively. There was no significant difference among them. The results of these 2 studies indicate that the fatigue resistance of crowns made of RNC, LD, or FEL may be influenced by the thickness of those materials, which is in agreement with Schlichting et al.9 and Federlin et al.12 Tsitrou et al.,13 however, found that the use of minimal preparation design did not compromise the structural integrity of crown-restored teeth when a composite resin (Paradigm MZ100, 1.5 to 2 mm compared with 0.4 to 0.6 mm) cemented with a self-adhesive dual-polymerizing resin cement (RelyX Unicem II) or leucite glass-ceramic (Pro-CAD, 1.5 to 2 mm compared with 0.8 to 1.2 mm) cemented with a dual-polymerizing luting composite (Variolink II) was used. A probable explanation of this finding could be that no aging methods were used before the load to failure test. According to Kelly,14 these kinds of tests have little clinical relevance because they are not consistent with actual swallowing and mastication cycles or maximum force recorded during clenching.

When subjected to the same experimental design of the present study, occlusal veneers (1.2 mm thick) made of composite resin (Paradigm MZ100), LD (e.max CAD), and FEL (Empress CAD) demonstrated survival rates of 100%, 30%, and 0%, respectively.3 Similar ultrathin occlusal veneer (0.6 mm thick) showed survival rates of 60% (Paradigm MZ100), 0 (e.max CAD), and 0 (Empress CAD), reiterating the superiority of the composite resin material.9 There are 2 major differences between those studies and the present work. First, none of the specimens in the previous studies presented with fractured fragments. All specimens survived the accelerated fatigue test, but cracks were sometime visible. The failure criterion was therefore adapted to this situation, with failure defined as a crack larger than 2 mm at the surface of the restoration. In the present work, cracks were not observed, and failures occurred suddenly with the loss of a fragment, which leads to the second difference between those studies: the luting procedure. Magne et al.3 and Schlichting et al.9 used the immediate dentin sealing (IDS) technique associated with a preheated light-polymerized composite resin as a luting agent. Such procedures resulted in the development of a strong interface that survived even at the highest loads and despite multiple cracking (no fragments separating from the tooth). This constitutes a demonstration of the biomimetic behavior of the restoration and underlying tissue, simulating to some degree the enamel cracks that stop at the dentin-enamel junction.

Although adhesive luting associated with IDS is a clinically successful option for fracture prevention, the use of self-adhesive resin cements is sometimes necessary. It is a faster and more efficient technique, especially regarding the removal of excess cement. Because of the use of a simplified cementation process, all failures would likely have been repairable, and the restored tooth could have

been maintained. There was small subgingival margin dentin fracture and chipping that could be smoothed, or the margin elevation technique could be applied.  

The results of this study require careful clinical interpretation. RNC and LD ultrathin complete veneer crowns started to fail at 800 N, while all FEL survived to 800 N. All complete crowns (1.5 mm thick) survived to 800 N. Masticatory forces during normal function range from 50 to 250 N and 500 to 800 N in bruxism.  

Those results suggest that it may be possible to use RNC and LD cemented with RelyX Unicem II to restore posterior teeth with regular or ultrathin crowns even under relatively high load requirements. However, a self-adhesive cement should not be used with FEL porcelain veneer ultrathin crowns; rather, the IDS technique should be used with preheated composite resin as a luting agent. 

From a clinical perspective, RNC has a significant number of practical advantages compared with LD, such as reduced milling time, less milling tool usage, no need for firing, improved polishability, ease of occlusal adjustment, repairability, and wear-friendliness to antagonistic teeth. Authors in the present study observed wear facets both at the restorations and resin sphere antagonists. As was the case in their previous study, RNC demonstrated more material wear but less antagonistic wear. Worn contact areas in LD and FEL were barely noticeable but at the cost of more antagonistic wear (resin sphere). Clinical data are required to assess the fatigue resistance of ultrathin restorations.  

CONCLUSIONS
Within the limitations of this simulation study, the following conclusions were drawn:

1. No difference was found in terms of fatigue resistance among a RNC material, LD, and FEL for ultrathin complete molar crowns placed with a simplified cementation process.
2. All failures were re-restorable.
3. Standard dimension crowns with a 1.5 to 2.0 mm preparation on the occlusal surface had higher survival rates than ultrathin ones.
4. The feasibility was confirmed of minimally invasive CAD/CAM crowns whenever excessive reduction of intact hard tissues is desirable, as in patients with severe erosion or in the replacement of thin existing restorations such as gold crowns.

REFERENCES

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