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Fatigue Resistance and Microleakage of CAD/CAM Ceramic and Composite Molar Crowns

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Abstract

Purpose: The aim of this study was to determine effect of compressive cyclic loading on fatigue resistance and microleakage of monolithic CAD/CAM molar ceramic and composite crowns.
Materials and Methods: Thirty-two extracted molars were prepared to receive CEREC crowns according to manufacturer's guidelines using a special paralleling device (Parallel-A-Prep). Sixteen feldspathic ceramic crowns (VITABLOCS Mark II) (VMII) and 16 resin-composite crowns (Paradigm-MZ100 blocks) (PMZ) were milled using a CEREC-3D machine. Eight crowns of each group were cemented to their respective teeth using self-etching resin cement (Panavia-F-2.0) (PAN), and eight were cemented using self-adhesive resin cement (RelyX-Unicem-Clicker) (RXU). Following storage for 1 week in water, specimens were subjected to uniaxial compressive cyclic loading in an Instron testing machine at 12 Hz for 1,000,000 cycles. Load was applied at the central fossa, and the cycle range was 60–600 N. Specimens were then subjected to microleakage testing. Data were statistically analyzed using factorial ANOVA and Post Hoc (Tukey HSD) tests.
Results: All composite crowns survived compressive cyclic loading without fracture, while three ceramic crowns from the subgroup cemented with RXU developed surface cracks at the center of occlusal surfaces, extending laterally. Microleakage scores of ceramic crowns cemented with PAN were significantly lower than those of the other three subgroups ($p < 0.05$).
Conclusions: After 1,000,000 cycles of compressive cyclic loading, PMZ composite molar crowns were more fatigue-resistant than VMII ceramic crowns. Cement type had a significant effect on fatigue resistance of the ceramic crowns but not the composite ones. Microleakage scores of ceramic crowns cemented with PAN were significantly lower than those of the other subgroups ($p < 0.05$).

The increasing demand for esthetics in the posterior region of the mouth and environmental concerns about restorations containing metal were behind the evolution of new techniques for fabrication of posterior inlays, onlays, and crowns.[1] Such restorations have several advantages, including lifelike appearance, biocompatibility,[2] wear resistance, and color stability.[3] However, their drawbacks include brittleness, especially glass or feldspathic ceramics,[4,5] susceptibility to fracture, causing excessive wear to opposing dentition, requiring more involved tooth reduction, and being technique-sensitive.[6] When nonmetallic crowns undergo fracture, the fracture typically originates from flaws or defects in the intaglio surfaces. Subcritical crack growth follows,[7,8] which is enhanced in the aqueous environment.[9]

Nonetheless, there has been an increase in the use of ceramics and composites in the last two decades in posterior teeth due to significant improvements in their mechanical properties, as well as the development of improved adhesive cements.[10,11] Such cements bond to tooth enamel and dentin as well as to the restoration. This produces reinforcement and reduces microleakage, postoperative sensitivity, marginal staining, and recurrent caries.[12]

The introduction of computer-aided design/computer-aided manufacturing (CAD/CAM) technology in dentistry enabled dentists to use new treatment modalities.[13] CAD/CAM machines are gaining popularity and are clinically proven.[14] They were further developed to enable fabrication of monolithic posterior crowns.[15] The aim of this study was to determine the

Figure 1 The parallelometer device used to control the handpiece orientation during tooth preparation to ensure the same angle of convergence for all preparations.

effect of compressive cyclic loading on fatigue resistance and microleakage of monolithic molar ceramic and composite crowns fabricated using CEREC-3D and cemented with two adhesive resin cements.

Materials and methods

Thirty-two caries-free extracted molars were selected from a collection of recently extracted teeth. Teeth were first sterilized with gamma irradiation (2.5 mRad) for 20.5 hours (Gamma cell 220, Atomic Energy Ltd, Mississauga, Canada).[16] They were then assigned to four groups (n = 8) according to their type (upper vs. lower) and size (small, medium, large). Each tooth was prepared to receive a crown as recommended for the CEREC-3D system (1.2-mm axial reduction, cuspal reduction of 2 and 1.5 mm for functional and nonfunctional cusps, respectively). The central fissure area was reduced by 1.5 mm, and the gingival margin was a circumferential shoulder positioned just occlusal to the cementoenamel junction. All line angles were prepared rounded, and the angle of convergence was maintained at 6^o to 8^o with the aid of a parallelometer (Parallel-A-Prep, Dentatus-USA, New York, NY). A high-speed handpiece with copious water cooling along with diamond burs was used for this purpose (Fig 1). The CEREC-3D system (Sirona Dental Systems GmbH, Bensheim, Germany) was used to design and mill crowns from two materials: ceramic, VITABLOCS Mark II (VMII) for CEREC, size I14 and shade A3.5 (Vita Zahnfabrik, Bad Sackingen, Germany); and resin composite, Paradigm MZ-100 Block (PMZ) for CEREC, size 14 and shade A3.5 (3M/ESPE, St Paul, MN). Milled crowns were finished and polished following manufacturer's instructions. Crown thicknesses were verified with a digital caliper to ensure consistent dimensions. All specimens were mounted in round resin bases (SR Ivolen, Ivoclar Vivadent, Schaan, Liechtenstein) to facilitate their attachment to the Instron universal testing machine.

Internal surfaces of VMII crowns were etched with 9.6% hydrofluoric acid-etching gel (Pulpdent Corp., Watertown, MA), while internal surfaces of PMZ crowns were grit-etched for 5 seconds with 50 μm Al_2O_3 powder at 80 psi. A silane-coupling agent (Clearfil Ceramic Primer, Kuraray America Inc., New York, NY) was then applied to the intaglio surfaces of ceramic crowns to be cemented with a self-etching resin cement (Panavia-F-2.0 [PAN], Kuraray America Inc.) while a silane-coupling agent (RelyX Ceramic Primer, 3M/ESPE AG, Seefeld, Germany) was applied to crowns to be cemented with a self-adhesive resin cement (RelyX-Unicem-Clicker [RXU], 3M/ESPE AG)).

One subgroup of eight composite crowns and one of eight ceramic crowns were cemented with PAN according to manufacturer's instructions. Crowns of the remaining two subgroups were cemented with RXU also following manufacturer's instructions. The crowns were seated on their respective teeth using finger pressure for 2 minutes. They were then maintained under 2.2-kg static pressure for 5 minutes. Excess cement was removed, and light polymerization with an LED light (Demi Plus, Kerr Corporation, Orange, CA) followed for 20 seconds per surface.

One hour after cementation, specimens were stored in water at 37°C for 1 week. Crowns were then subjected to compressive cyclic loading along the long axis with a 3.0-mm-diameter hardened steel ball centered at the central fossa of the occlusal surface. Crowns were subjected to 1,000,000 load cycles of 60 to 600 N each at 12 Hz. The Instron machine was adjusted to stop if specimen deformation increased beyond 0.15 mm. Crowns were maintained under distilled water at room temperature throughout the duration of cyclic loading. After test completion, each crown was examined under magnification (10×) for presence of cracks.

Crowns were then subjected to microleakage testing by immersion in 0.5% aqueous solution of red basic fuscin dye for 24 hours after sealing root surfaces with nail polish. Specimens were then thoroughly rinsed in water and sectioned mesiodistally using a low-speed saw with a diamond blade (Isomet 1000, Buehler Ltd., Lake Bluff, IL). Images of tooth sections were captured with a digital camera, and a five-point scale was used to score microleakage at both mesial and distal aspects of each section as follows:

0 = no leakage.
1 = microleakage up to one third of axial wall.
2 = microleakage up to two-thirds of axial wall.
3 = microleakage along full length of axial wall.
4 = microleakage extending onto occlusal surface.

The microleakage score for each specimen was calculated as the average of the two scores at the mesial and distal aspects of both sections. Microleakage scores were statistically analyzed using SPSS v13.0 (SPSS Inc., Chicago, IL). Factorial ANOVA test, one-way ANOVA test, and Tukey's HSD post hoc test were used. All tests were performed at an alpha level of 0.05 where $p \leq 0.05$ is considered significant.

Results

At the culmination of cyclic loading all PMZ crowns (16) survived without any fractures or cracks, while 3/16 VMII crowns developed crack lines that extended from the central fossa, the loading point, to the axial walls of the crowns (Fig 2). These were all cemented with RXU.

ANOVA indicated significant differences in mean microleakage scores among the four subgroups ($p < 0.05$). Tukey's test

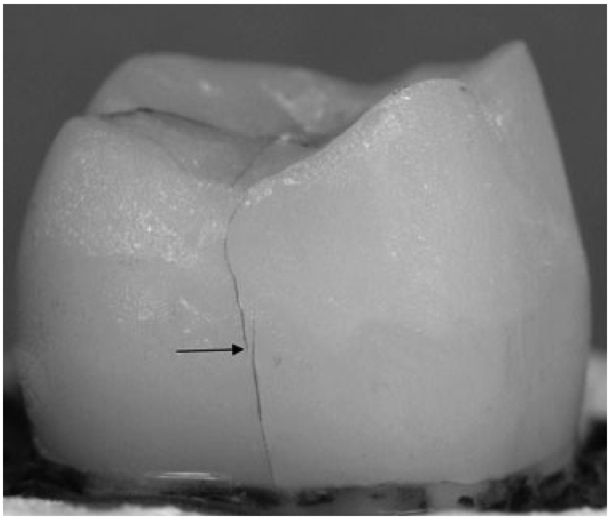

Figure 2 Ceramic crown cemented with RelyX-Unicem-Clicker after 1,000,000 load cycles. A crack line that developed at the central fossa and extended to the proximal surface can be seen. Arrow points to a vertical crack line on the proximal surface of crown.

revealed that mean microleakge scores of crowns cemented with PAN were significantly lower than those of crowns cemented with RXU, irrespective of the type of crown material ($p < 0.05$). Also, mean microleakge scores of ceramic crowns were significantly lower than those of composite ones, irrespective of the type of cement used ($p < 0.05$).

Further analysis with Tukey's test revealed that mean microleakage scores of ceramic crowns cemented with PAN were significantly lower than those of ceramic crowns cemented with RXU and those of the two composite crowns groups. Means, standard deviations, minimum, maximum, lower bound, and upper bound of microleakage scores are shown in Table 1. Figure 3 shows representative images of tooth sections from the four subgroups after die immersion.

Discussion

Using natural teeth might have some inherent disadvantages, including variations in shape/size and difference in mechanical properties.[17] However, teeth were assigned to groups so as to keep effects of such variability to a minimum. Typically, steel or epoxy resin dies are used for fatigue testing of crowns.[18] However, using natural teeth has been recommended due to modulus of elasticity, bonding characteristics, thermal conductivity, and strength characteristics that better match the clinical situation.[19] Cementation of crowns followed standard techniques, and load applied during cementation was similar to that reported in a previous investigation.[20]

Humans perform an average of 250,000 chewing cycles per year.[21,22] In this study, 1,000,000 load cycles were preformed, estimated to equate to 5 to 10 years of normal function.[23] Normal masticatory loads range from 50 to 250 N, while in parafunctional behavior such as clenching and bruxism, loads between 500 to 800 N may be generated.[24,25] In this study, all

Table 1 Microleakage scores of ceramic and composite crowns

Group	N	Mean	SD	Minimum	Maximum	Lower bound	Upper bound
PA/CO	8	3.5	0.9	2	4	2.7	4.3
RX/CO	8	3.4	0.9	2	4	2.6	4.1
PA/CE	8	0.5	0.5	0	1	.1	1
RX/CE	8	3.4	1.1	1	4	2.5	4.3

PA/CO = composite crown cemented with PAN; RX/CO = composite crown cemented with RXU; PA/CE = ceramic crown cemented with PAN; RX/CE = ceramic crown cemented with RXU.

specimens were subjected to 60 to 600 N load cycles, which fall well within the above ranges.

High-frequency (20 Hz) cyclic loading was previously used with leucite-reinforced all-ceramic crowns with a range of

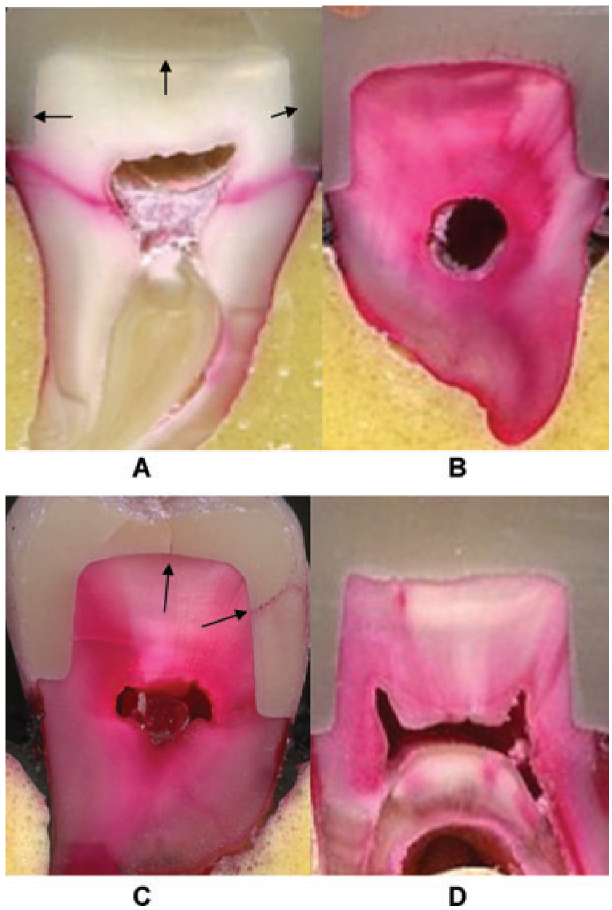

Figure 3 Representative tooth sections made after die immersion. (A) Ceramic crown cemented with Panavia-F-2.0 (PAN). Notice minimal leakage limited to gingival shoulder. Arrows point to a die-free crown/dentin interface. (B) Composite crown cemented with RelyX-Unicem-Clicker (RXU). Notice massive leakage that included the whole dentin. (C) Ceramic crown cemented with RXU. Notice massive leakage that included the whole dentin. This was one of three ceramic crowns that developed cracks during fatigue test. Arrows point to two crack lines. (D) Composite crown cemented with PAN. Notice massive leakage that included the whole dentin.

100 to 600 N in water.[26] This frequency is higher than what was used in this study (12 Hz); however, a smaller ball was used in this study to simulate the contact pressure of the crown by opposing cusp. The contact pressure is influenced by the ratio of the elastic modulus of the porcelain or composite to the elastic modulus of the loading ball, and also by the radius of the loading ball.[27]

Myers et al reported that ceramic crowns showed a liability to stress-corrosion fatigue when tested in water.[28] Cyclic loading, especially when performed under wet conditions, leads to propagation of small cracks that start from porosities within the crown surfaces.[29] The small cracks combine to form larger ones that weaken the crown and lead to failure.[29,30] A stress-dependent chemical reaction occurs between water and surface flaws in crowns, resulting in their growing to a critical size, causing crack propagation with subsequent fracture.[31] In this study, all eight ceramic crowns cemented with PAN survived the 1,000,000 load cycles while three of the eight crowns cemented with RXU developed surface cracks. This suggests a significant effect of cement type on the fatigue resistance of the ceramic crowns. This is in agreement with the findings of Zahran et al, although they used only 500,000 load cycles. They also reported a 100% survival of all VMII CEREC crowns cemented with PAN without any crack formation.[32]

An in vitro microleakage test carried out with a dye gives reliable results that can be correlated to the clinical conditions. Therefore, if a restoration responds positively (resists microleakage well) to in vitro testing, it would be expected to perform even better clinically.[33] Also, while one may anticipate a difference in microleakage between vital and nonvital teeth, which lack the so-called "pulpal pressure," Schneider et al stated that microleakage did not differ significantly between vital and nonvital dentin.[34]

Crowns cemented with PAN had significantly lower mean microleakage scores than those cemented with RXU. This difference might be related to the mechanism of adhesion of each cement. The etch-prime agent of PAN has a 2.4 pH and has monomers with low molecular weight that diffuse selectively into dentin,[35] forming a hybridized complex.[36,37]

Therefore, these monomers produce a small degree of dentin demineralization that results in bonding between cement and dentin. This is not the case with RXU, which has multifunctional phosphonic acid methacrylates that react with the dentin hydroxyapatite.[38] In a recent study, RXU showed no evidence of decalcification/infiltration into dentin despite an initial acidic pH.[39] The nature of interface between cement and dentin was reported to resemble that of some conventional cements.[40] This might explain the significantly higher microleakage scores reported in this study for crowns cemented with RXU as compared to ones cemented with PAN.

It is intriguing to find crowns made of a resin composite to be highly resistant to failure under conditions of mechanical fatigue. Unlike direct composite restorations, the CEREC composite blocks are manufactured under optimum conditions. These enhance the degree of polymerization of the monomers and eliminate incorporation of voids, thus optimizing their mechanical properties. Crowns made out of these blocks would be expected to be less abrasive to the opposing dentition than ceramic ones would be; however, in the clinical situation, crowns are subjected to a multitude of challenges that may act collectively to cause them to undergo failure. These include temperature changes when different foods/drinks are consumed, variable pH, enzymatic challenges, and loading in multiple directions, not just vertical, that occur over a prolonged period of time. This study did not replicate all of the above challenges and, therefore, its findings must be interpreted with caution, as crowns may react differently under conditions of the oral cavity.

Conclusions

Within the limitations of this study the following was concluded:

1. Molar crowns made of CEREC resin composite blocks (PMZ) sustained 1,000,000 load cycles each of 60 to 600 N without any fractures or cracks, irrespective of the resin cement used.
2. Molar crowns made of CEREC ceramic blocks (VMII) sustained 1,000,000 load cycles each of 60 to 600 N without any fractures or cracks when PAN was used for their cementation.
3. Crowns made with PMZ showed significantly higher mean microleakage scores than those made with VMII.
4. Crowns cemented with PAN had mean microleakage scores significantly lower than those obtained with ones cemented with RXU.

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