Computer-Aided-Design/Computer-Assisted-Manufactured Adhesive Restoration of Molars with a Compromised Cusp: Effect of Fiber-Reinforced Immediate Dentin Sealing and Cusp Overlap on Fatigue Strength

PASCAL MAGNE, DMD, PhD[*†], **LUÍS L. BOFF,** DDS, MDS[‡], **ELISA ODERICH,** DDS, MDS[§],
ANTÔNIO C. CARDOSO, MDS, PhD[‖]

ABSTRACT

Statement of Problem: Cracked teeth may traditionally require the use of complete coverage crowns. Alternative conservative treatments involve the use of adhesive inlays/onlays with the possibility of including a fiber patch to reinforce the cracked cusp.

Purpose: The purpose of this study was to evaluate the fatigue strength of compromised molars restored with computer-aided-design/computer-assisted-manufactured (CAD/CAM) composite resin inlays/onlays with and without fiber-reinforced immediate dentin sealing (IDS).

Methods and Materials: Large mesio-occluso-distal preparations with cracked/undermined palatal cusps were simulated on 40 extracted maxillary molars. All teeth received IDS (Optibond FL, Kerr, Orange, CA, USA), and composite resin (Paradigm MZ100, 3M-ESPE, St. Paul, MN, USA) inlays ($N = 20$) and onlays ($N = 20$). A fiber patch (Ribbond, Ribbond Inc., Seattle, WA, USA) was applied in half of the preparations. Restorations were adhesively luted with pre-heated composite resin (Z100, 3-M ESPE) and submitted to cyclic isometric loading at 5 Hz, starting with a load of 50 N (5,000 cycles), followed by stages of 150, 300, 450, 600, 750, 900, and 1,050 N at a maximum of 25,000 cycles each. Specimens were loaded until fracture or to a maximum of 180,000 cycles. Groups were compared using the life table survival analysis.

Results: Differences in survival probability were found ($p = 0.04$). The inlay group with fiber patch failed at an average load of 870 N, and none of the specimens withstood all 180,000 load cycles; survival rates of inlays and onlays without fibers, and onlays with fibers were 10, 30, and 50%, respectively.

Conclusions: Onlays (with or without fibers) increased the fatigue resistance of compromised molars in this in vitro study.

CLINICAL SIGNIFICANCE

The results of this in vitro study suggest that molars with a compromised cusp may be best reinforced by a cusp-protecting composite resin onlay. There was no benefit of using fiber reinforcement under those indirect restorations.

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*Associate Professor, Division of Restorative Sciences, Herman Ostrow School of Dentistry of University of Southern California, Los Angeles, CA, USA
†Don and Sybil Harrington Foundation Professor of Esthetic Dentistry, the Herman Ostrow School of Dentistry of University of Southern California, Los Angeles, CA, USA
‡Assistant Professor of Prosthodontics and Researcher, Health Science Center—Dentistry, Federal University of Santa Catarina—UFSC, Florianópolis, SC, Brazil
§Researcher, Department of Dentistry, Health Science Center—Dentistry, Federal University of Santa Catarina—UFSC, Florianópolis, SC, Brazil
‖Titular Professor, Health Science Center—Dentistry, University of Santa Catarina—UFSC, Florianópolis, SC, Brazil

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INTRODUCTION

The cracked-tooth syndrome is a painful condition found in teeth and failing restorations.[1,2] In vital restored teeth microcracks develop at the base of weakened cusps, primarily due to increased cuspal movement under repeated functional occlusal loading.[3,4] It is known that intact teeth demonstrate cuspal flexure under occlusal load[4–6] and that restorative procedures can result in increased cuspal movement[5,7] compromising fatigue strength, inducing fracture leading to cracked tooth syndrome.[1,8] Amalgam restorations are the most typical example of this phenomenon.[7]

Challenging situations such as laterotrusive and mediotrusive movements that generate harmful concentrations of stress can cause cuspal flexure predisposing a tooth to fracture.[9] A finite element analysis simulating those interferences[10] has shown inverted stress patterns (laterotrusive versus mediotrusive interferences). Although nonsupporting cusps were submitted to tensile stresses, supporting cusps were generally well protected (compressive stresses). In the same study high stress levels were found in the central groove during mediotrusive contact. The knowledge of bite forces and stress distribution is of paramount importance in understanding the biomechanical behavior (cuspal flexure and plastic yielding) of compromised tooth structure and ultimately in understanding why restorations fail.[10–15] The therapeutic decision-making process and the biomimetic approach to restoring posterior teeth[16] will be influenced by these biomechanical factors.

Traditionally cracked teeth have been restored with complete coverage crowns, which promote extracoronal strengthening and protection against fracture,[2,17–20] but require substantial sacrifice of tooth structure.[21,22] Alternative conservative techniques involve the use of adhesive inlays/onlays[23–25] and have the potential to “reassemble” weakened cusps through reinforcement using adhesive materials and techniques.[3,6,26,27] During the last decade, indirect and computer-aided-design/computer-assisted-manufactured (CAD/CAM) composite materials have gained popularity.[28–30] They are characterized by a filler content possibly exceeding 70% by volume, providing improved fracture toughness because they can be significantly reinforced by post-cure treatment.[29,30] Another strengthening approach consists of including fiber reinforcements, which has been explored in several load-to-failure experiments,[31–34] with controversial results of their ability to reinforce teeth. Different fiber systems can be used. Although some authors favor woven (mostly isotropic) polyethylene fibers,[35,36] others recommend the use of unidirectional (orthotropic) glass fibers.[37–39] A well-designed fiber system should influence the stress distribution mechanism and, depending on its location and orientation, be effective in stopping, reducing, or redirecting the propagation of cracks.[35,36] Whereas woven fibers reinforce the polymer in more than one direction, continuous unidirectional fibers give strength and stiffness to the composite only in the direction of the fibers (anisotropic mechanical strength).[37] Practically, the most challenging aspect is the ability to apply all these engineering concepts in the small biological structure of a tooth. Currently, the most practical and conservative method of using fiber reinforcement is the application of woven fiber patches, because of their ease of manipulation and positioning in an intracoronal defect, like a deep mesio-occluso-distal preparation. However, in view of the current data[32–34] the claim that including fiber reinforcement would ensure a better stress distribution to the tooth and reduce harmful tensile stresses requires validation. In fact, the existing literature focuses on direct composite resin restorations but there is no data published about the use of fiber reinforcement beneath indirect adhesive inlays or onlays.

The purpose of this study was to evaluate the fatigue strength of compromised molars (wide mesio-occluso-distal defects and undermined cusps) restored using CAD/CAM composite resin inlays and onlays with and without fiber reinforcement and immediate dentin sealing (IDS). The null hypothesis tested was that there is no influence of preparation design and presence of fiber reinforcement on the fatigue resistance of such restorations.

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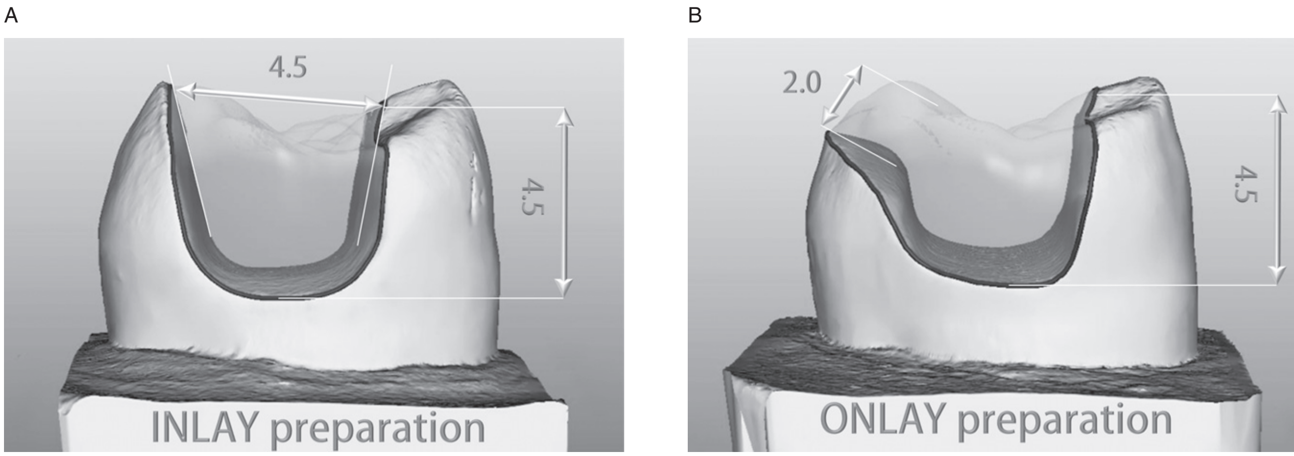

FIGURE 1. A, Inlay and B, onlay preparation measurements (in mm).

METHODS AND MATERIALS

Two hundred freshly extracted, sound human maxillary third molars were collected upon approval from both the Ethical Review Committees of the Federal University of Santa Catarina and the University of Southern California (No. 632/10). Standardization is a goal in research to reduce bias, but it is challenging, especially when using extracted teeth with a wide range of shapes and sizes. The objective of the present work was not to investigate how the various treatments compare with the intact tooth. Nevertheless, to limit the confounding variables, 40 maxillary molars were selected from the pool of 200 maxillary third molars according to their occlusal anatomy (three cusps only) and size (medium size buccolingual and mesiodistal measurements), and distributed in four groups. A single experienced operator performed all the procedures. Teeth were mounted in a special positioning jig with acrylic resin (Palapress, Heraeus Kulzer, Armonk, NY, USA) embedding the root up to 3.0 mm below the cementoenamel junction (CEJ).

For standardization purposes, all specimens received a large standardized mesio-occluso-distal defect without boxes (slot shape 4.5 mm in depth and 4.5 mm in buccolingual width), which were prepared with tapered diamond rotary cutting instruments (313.029 and 314.021, Brasseler USA, Savannah, GA, USA). The interproximal gingival finish lines were maintained 1 mm above the CEJ. A digital caliper (no. 1436, General Tools, Montreal, Canada) was used to verify those measurements. The palatal cusps of all specimens were undermined (dentin removed) with a coarse round diamond rotary cutting instrument (801-023, Brasseler USA) to simulate secondary caries removal. To further weaken the cusp a 1-mm deep crack at the cusp base was simulated with a 0.1-mm-thick disc (Vision Flex Disc, Brasseler USA) at an angle of 20 degrees. In half of the specimens ($N = 20$) the weakened cusp was maintained (groups IN and INF) and in the other 20 teeth the palatal cusp was reduced 1.5 to 2.0 mm parallel to the cusp incline (groups ON and ONF). Special care was taken to obtain smooth and rounded internal line angles (Figures 1 and 2).

IDS was applied to all specimens as suggested by several authors to obtain a secure bond.[16,26,40,41] For this purpose, the coarse round diamond rotary cutting instrument (801-023, Brasseler USA) was used at 1,500 rpm to refresh the dentin surface before the application of a fourth generation etch-and-rinse dentin bonding agent (Optibond FL, Kerr, Orange, CA, USA) according to the manufacturer's instructions: 15 seconds of dentin etching with 37.5% phosphoric acid, abundant rinsing for 20 seconds, air drying for 5 seconds, application of primer (Optibond FL, bottle 1) with a light brushing motion for 20 seconds, gentle air drying for 5 seconds (moist dentin), application of adhesive resin (Optibond FL, bottle 2) with a light brushing motion for 15 seconds. The adhesive was

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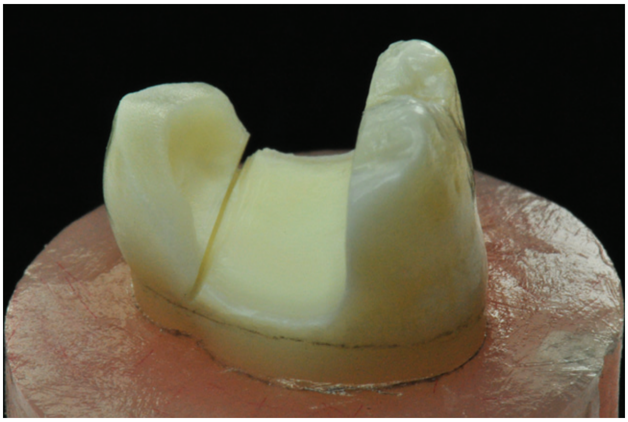

FIGURE 2. Specimen with onlay preparation, undermined enamel and simulated crack at base of palatal cusp.

polymerized for 20 seconds (1,000 mW/cm^2—Allegro, Den-Mat, Santa Maria, CA, USA) followed by the application of a composite resin base (Z100, 3M-ESPE, St. Paul, MN, USA) to block the undercut in the palatal cusp (Figure 3A). In groups IN and ON, an air-barrier coating (K-Y Jelly, Personal Products Company, Skillman, NJ, USA) was applied followed by 10 seconds of additional curing light exposure to polymerize the oxygen-inhibition layer. In groups INF and ONF, the composite resin base was left unpolymerized. Meanwhile, a U-shaped polyethylene fiber patch (7 × 4 mm, Ribbond-THM, Ribbond Inc., Seattle, WA, USA) was pre-impregnated with Optibond FL adhesive resin (Optibond FL, bottle 2) for 5 minutes at 65°C. The patch was applied to the occlusal one-third of the buccal wall, across the occlusal floor to the occlusal one-third of the lingual wall (Figure 3B). The impregnated fiber patch on the composite resin base was polymerized for 20 seconds followed by the application of an air barrier coating (K-Y Jelly) and 10 seconds of additional light exposure to polymerize the oxygen-inhibition layer. The air barrier coating was easily removed by abundant rinsing, as it is totally water soluble. Finally, excess adhesive resin was carefully removed from the enamel margins of all specimens with a round diamond rotary cutting instrument at 1,500 rpm (801-023, Brasseler USA) (Figure 3C).

The specimens were restored using a CAD/CAM system (Cerec 3, Sirona Dental Systems GmbH, Bensheim, Germany). All preparations were fitted with an inlay or onlay of standardized thickness, using the Inlay/Onlay/Partial Crown Master Mode and the Design Tools of the Cerec software (v. 3.03, Sirona Dental Systems GmbH). The restorations featured a standardized thickness of ca. 2.5 mm at the central groove (all groups) and 2.0 mm at the palatal cusp tip (groups ON and ONF). For all specimens, restorations were milled in composite resin (Paradigm MZ100 blocks, 3M-ESPE) with the sprue located at the distal surface.

Surface conditioning of all restorations included airborne particle abrasion with 27 μm of aluminum oxide at 30 psi, followed by cleaning with a microbrush and 37.5% phosphoric acid (Ultraetch, Ultradent, Salt Lake City, UT, USA) with a gentle brushing motion for 1 minute and rinsing with water for 20 seconds. Cleaning was completed by immersion in distilled water in an ultrasonic bath for 2.5 minutes. Following thorough oil-free air drying, intaglio surfaces were then silanated (Silane, Ultradent) and dried at 100°C/212°F for 1 minute.

Tooth preparations were conditioned by airborne-particle abrasion with 27 μm of aluminum oxide at 30 psi and 30 seconds etching with 37.5% phosphoric acid, abundant rinsing for 20 seconds, and thorough drying. One coat of adhesive resin (Optibond FL, bottle 2) was then applied to both intaglio surfaces (restoration and tooth) and left unpolymerized until the application of the pre-heated luting material (Z100, 3M-ESPE; preheated for 5 minutes in Calset, Addent, Danbury, CT, USA) to the tooth and final insertion of the restoration. Following careful elimination of excess unpolymerized composite resin, each surface was polymerized for 60 seconds (20 seconds per surface, three times). All margins were covered with an air-blocking barrier (K-Y Jelly) for the last polymerization cycle. Restorations were then polished mechanically using a composite resin polishing system (Kit 4477 Q-Polishing System, Komet of America Inc., Rock Hills, SC, USA) and a silicon bristle brush (Occlubrush, KerrHave, Orange, CA, USA).

Each specimen was stored in distilled water at ambient temperature for at least 24 hours following adhesive

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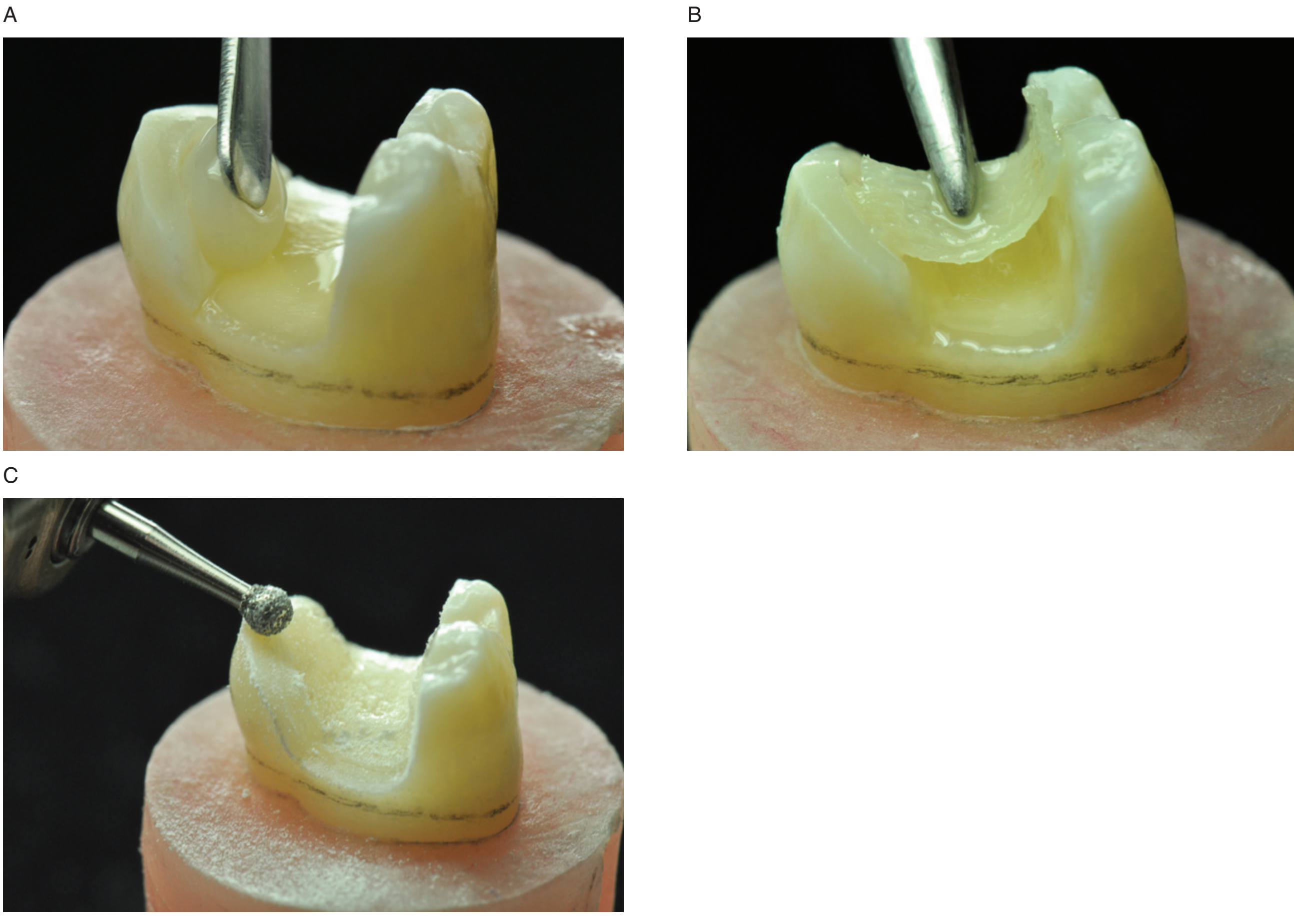

FIGURE 3. A, Composite resin base to block undercut in palatal cusp. B, Positioning of pre-impregnated "U-shape" polyethylene fiber. C, Refining of enamel margins with round diamond rotary cutting instrument.

restoration placement. Because the stability of the bond using this specific adhesive technique appears to be stable (no statistical differences up to 12 weeks after its application)[42] there was no reason to delay testing for more than 24 hours. Masticatory forces were then simulated using closed-loop servohydraulics (Mini Bionix II, MTS Systems, Eden Prairie, MN, USA). Each specimen was placed in the load chamber at a 30-degree angulation and situated with a positioning device (sliding table). The masticatory cycle was simulated by an isometric contraction (load control) applied through an artificial composite resin cusp (Z100, 3M-ESPE) shaped like a cylinder (2.15-mm radius). Steel indenters tend to generate a localized and intense point load, which are more likely to generate surface damage and powder-like debris by crushing (Hertzian cone cracks).[43] Instead, the lower stiffness and higher wear of the composite resin cylinder allowed more realistic simulation of tooth contacts, through wear facets distributing the load without reaching the compressive limit of the tissues or restorative materials. All specimens were adjusted (with the positioning device) in the same position with single contact between the cylinder and the palatal cusp (Figure 4). This load point was 2.0 mm equidistant from the cusp tip and central groove. The load chamber was filled with distilled water to submerge the specimens during testing. Cyclic load was applied at a frequency of 5 Hz, starting with a warm-up load of 50 N for 5,000 cycles (preconditioning stage), followed by stages of 150, 300, 450, 600, 750, 900, and 1,050 N at a maximum of 25,000 cycles each (staircase loading). Specimens were loaded until fracture or to a maximum of 180,000 cycles (loading protocol modified from Fennis and colleagues,

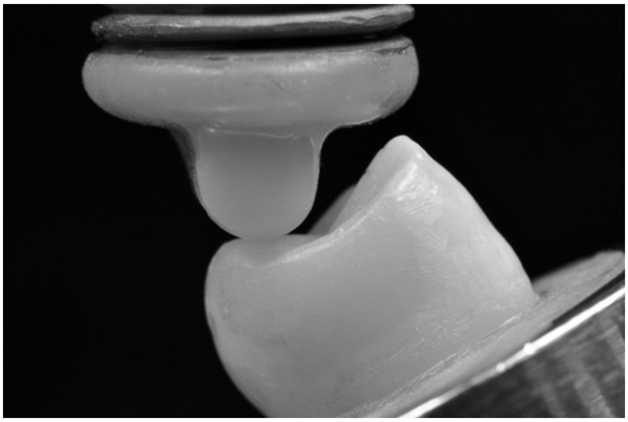

FIGURE 4. Specimen (onlay) positioned in testing machine at a 30-degree angle. Load is applied through single contact between composite resin cylinder and palatal cusp.

and Kuijs and colleagues).[19,20] The fracture load was determined by the load step at which the machine stopped (triggered by displacement-based, failure-detect module of the testing software). The number of endured cycles and failure mode were recorded. Following a two-examiner agreement under optical microscopy (Leica MZ 125, Leica Microsystems, Wetzlar, Germany), a distinction was made between fractures above or below the CEJ or for cohesive fracture (within the restoration) or fracture at the interface.

The fatigue resistance of the four groups was compared using the life table survival analysis. At each time interval (defined by each load stage), 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 stage at which failure occurred) was analyzed by using the logrank test at a significance level of .05. Post hoc comparisons were performed using the logrank test and were made without adjusting for multiple comparisons, thus increasing the potential for a type one error (indicating that a difference exists, when in fact there is no difference). Adjusting for multiple comparisons using the Bonferroni correction, however, would have increased the chance of a type two error (no effect or difference declared, although in fact there is an effect).

TABLE 1. Post hoc comparisons using logrank test ($p < 0.05$ indicates significant difference)

	IN	INF	ON	ONF
IN	—	0.76	0.11	0.06
INF		—	0.03	0.02
ON			—	0.55
ONF				—

RESULTS

Inlay-restored molars fractured at an average load of 844.74 N and an average of 118.393 cycles (IN and INF data pooled). One specimen in the IN group withstood all 180,000 cycles (survival = 10%) but none (0%) in the INF group. For onlay-restored molars, the survival rate for ON and ONF groups was 30 and 50%, respectively (Figure 5A). Significant differences in survival were found ($p = 0.036$). Detailed post hoc tests are presented in Table 1 and reveal significantly higher survival rates for groups ON and ONF compared with group INF.

Additional comparisons were performed by pooling the data by restoration design (Figure 5B, inlays versus onlays) and by presence/absence of fiber reinforcement (Figure 5C). Survival of onlays (Figure 6A) was significantly higher than inlays (pooled data, $p = 0.005$) but the presence of fiber reinforcement was not significant (pooled data, $p = 0.91$). Consequently, the presence of the U-shape polyethylene fiber patch did not increase the fracture strength. It appears that it did not prevent failure below the CEJ either. In group INF 70% of the specimens fractured below the CEJ (Figure 6B), in group IN 40%, whereas in group ONF, 40% had failure below the CEJ, and in group ON 50%. The percentage of fractures above the CEJ (Figure 6C) in groups IN, INF, ON, and ONF was 56, 30, 29, and 20%, respectively (Table 2). In all specimens of this study, failure was cohesive in the composite resin restoration and remained cohesive when cracks propagated into the tooth, leaving the interfacial bond intact. Only one load cusp had to be changed due to delamination.

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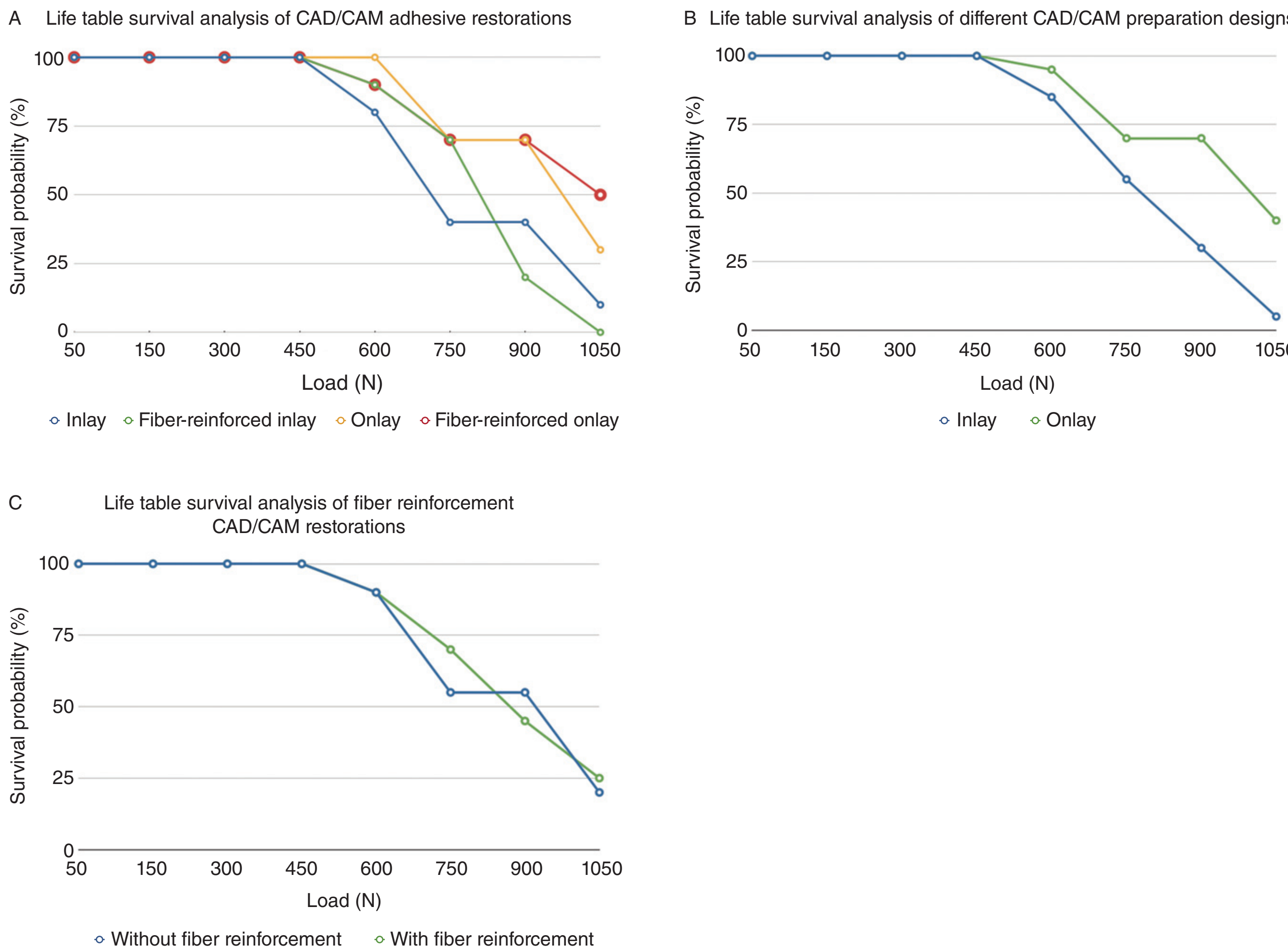

FIGURE 5. Survival analysis of computer-aided-design/computer-assisted-manufactured (CAD/CAM) inlays and onlays with and without fiber reinforcement. A, All groups. B, Pooled data for inlays (with and without fibers) and onlays (with and without fibers). C, Pooled data for restoration without fiber reinforcement (inlays and onlays) and with fiber reinforcement (inlays and onlays).

DISCUSSION

The null hypothesis that there was no influence of preparation design and presence of fiber reinforcement on the fatigue resistance of such restorations was rejected in part because onlays increased fatigue resistance of compromised molars (wide mesio-occluso-distal defects and cracked compromised cusp) when compared with inlays (pooled data). However, the presence of fiber reinforcement did not have a significant effect on the fatigue resistance of such restorations.

The clinical diagnosis of "cracked tooth syndrome" is often made by the patient's symptoms alone, and the location and severity of the crack is undetermined at the time of restoration. The current study only simulated one type of defect (due to the need for standardization) and therefore is limited in its clinical implications. Another limitation is that the experimental design did not allow multiple specimens testing and each specimen was loaded over the course of 1 day. This method is relatively time-consuming because each specimen requires over 1 day of testing time (fabrication time not included). However, normalization of restoration anatomy and cuspal inclination was obtained using the Cerec system, in this case the Inlay/Onlay/Partial Crown Master Mode was used. The occlusal surface was designed based on the reminiscent occlusal enamel contours. Post-milling "fine

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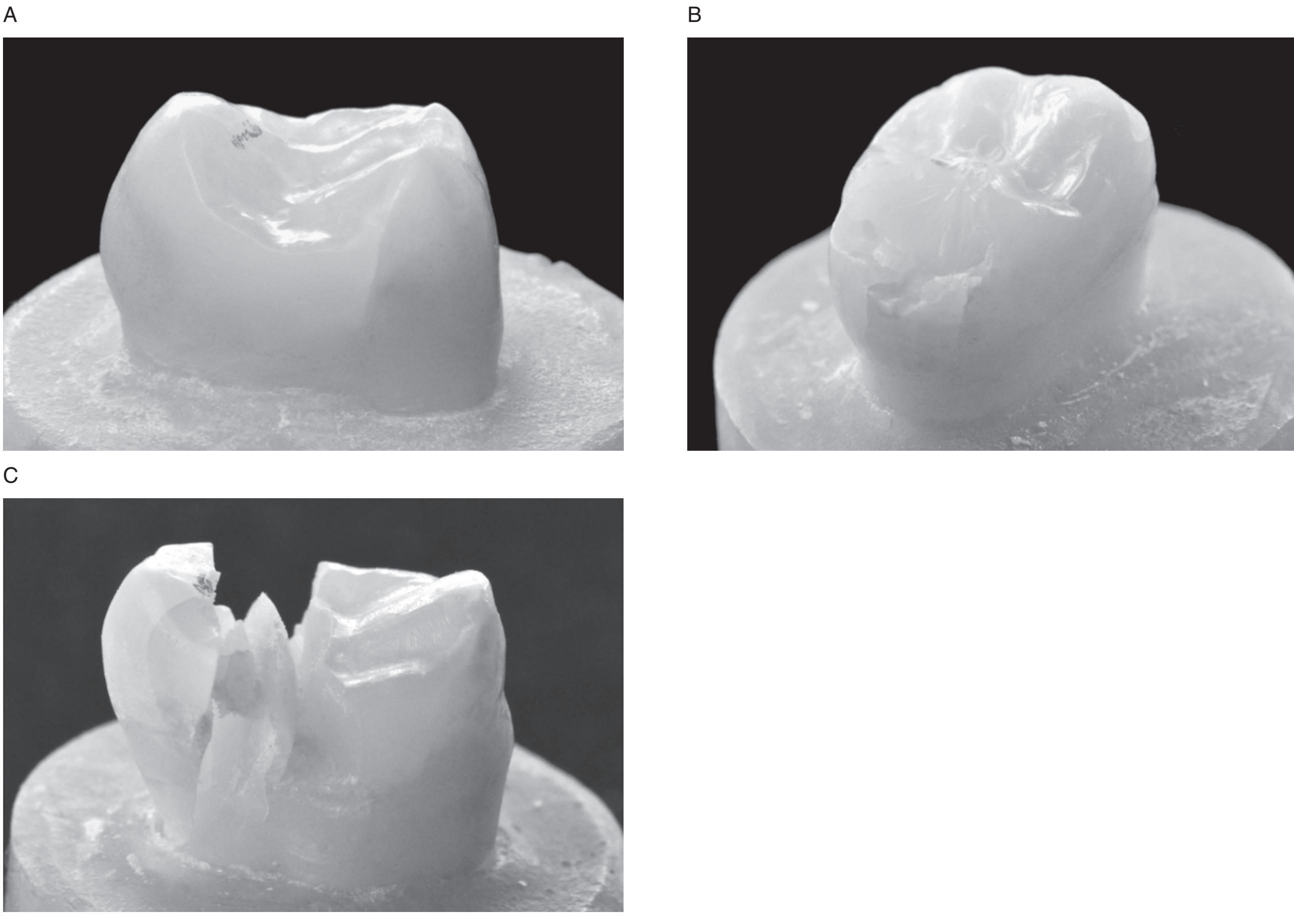

FIGURE 6. A, Onlay with fiber reinforcement that survived (total 180,000 cycles, no failure). B, Non-destructive fracture of inlay at 1,050 N. C, Catastrophic failure of onlay with fiber reinforcement at 750 N.

TABLE 2. Distribution of failure modes (%) as observed by optical microscopy

Group	Survival	Above CEJ	Below CEJ
IN	10	50	40
INF	—	30	70
ON	30	20	50
ONF	50	10	40

CEJ = cementoenamel junction.

tuning" of the restoration thickness, anatomy, and cuspal inclination were accomplished by adjusting with a diamond rotary cutting instrument. All those optimization steps allowed specimens to be loaded in a consistent and reproducible fashion.

The fatigue load protocol of the present study provides closer simulation of the clinical conditions than a simple static load-to-failure test.[26] The fatigue design was based on previous studies.[19,26] According to studies on the maximal occlusal forces in humans in the molar region, the occlusal forces range between 597 and 847 N for women and men, respectively, and can be as high as 900 N.[13,14] A higher load can be easily achieved when individuals masticate a hard foreign body accidentally found in the bolus during fine food comminuting (such as a stone in salad, almond shell in cake) or in case of trauma. The current study presents a unique design to subject compromised molars restored with CAD/CAM inlays/onlays to an extreme loading scenario with the fatigue load applied at 30 degrees to the weakened palatal cusp, simulating a single nonworking contact. Instead of a metal sphere and a

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contact distributed on a tripod, the specimens were loaded, at only one point, with a composite resin cylinder. In an observational study, Ratcliff and colleagues[9] observed that the shear stress generated during laterotrusive interferences increased the risk of cracking. The cause of cracks in teeth is complex and multifactorial.[9] Inadequate preparation, restorative materials, age and occlusal forces misdirected over the occlusal surface that generate harmful concentrations of stress can influence the cuspal flexure, violate the elastic limits of teeth and predispose a tooth to cracking or fracturing.[9]

As there were no adhesive failure and all specimens survived the first half of the test (normal range of occlusal forces), it would be premature to state that cusp overlap is absolutely indicated for the adhesive restoration of molars with a compromised cusp. It is traditionally recommended that there be overlap of an undermined cusp in case of cracked-tooth syndrome,[2] to promote extracoronal strengthening and protect against further crack propagation. However, adhesive restorations have shown the potential to "reassemble" weakened cusps through reinforcement by the use of adhesive techniques, with or without cusp overlap as demonstrated by Opdam and Roeters.[3] The authors treated 40 symptomatic cracked teeth with direct composite resin restorations, and found no influence of cusp overlap in reducing the symptoms. Fennis and colleagues,[19] however, emphasized the strengthening effect of cuspal overlap, which is in agreement with the results of the present study (pooled data), even though there seem to be no differences in the performance of cusp replacing direct composite restorations compared with indirect ones (either composite resin or ceramic).[20] Due to residual polymerization shrinkage stress, direct resin composite restorations, are often contraindicated for large preparations[23–25] and tend to generate more adhesive failures.[20] In these situations indirect porcelain or polymer restorations may be a better choice because they are more conservative than complete veneer crowns. Whenever indirect or semi-direct inlays and onlays are used, IDS is recommended to optimize the ultimate bond strength, desensitize and protect the preparations, as well as facilitate try-in and insertion procedures.[16,26,40,41] Therefore, IDS was applied in the present study regardless of the use of fiber reinforcement. The performance of the IDS-optimized dentin bond was demonstrated by the absence of adhesive failures and may also have contributed to the survival of all specimens within the maximum range of normal occlusal forces (up to 600 N).

In this study, the inclusion of fiber reinforcement did not result in a significantly better outcome when compared with the groups with no fiber reinforcement. Recently, several load-to-failure studies,[31–34,39] have explored the use of fiber-reinforcement to obtain strengthening of weakened teeth, with controversial results of their ability to reinforce teeth. Belli and colleagues[31–33] used U-shaped polyethylene fibers under direct composite restorations in root-filled molar teeth with wide mesio-occluso-distal preparations and observed significantly increased fracture strength. The same approach in the present study (U-shape polyethylene fiber patch) did not increase the fatigue strength for inlays or onlays, which is in agreement with the findings of Fennis and colleagues[34] and Beltrão and colleagues.[39] The present study is unique in that a fatigue load was applied at 30 degrees instead of the traditional axial static load-to-failure test. The specimens were restored by means of inlays/onlays following IDS as opposed to the direct composite resin restorations used in the previously mentioned studies. Resin pre-impregnation is required for bonding of fibers to the polymer matrix.[37] According to the manufacturer of Ribbond, the fibers should be infused with an unfilled, low viscosity bonding resin. Optibond FL (50% filled in weight) was used instead, the viscosity of which could have compromised the wetting of the Ribbond fabric. However, in a pilot study, some specimens were analyzed under a scanning electron microscope, it was concluded that there was no differences in infusing polyethylene fibers with filled Optibond FL or the manufacturer's unfilled adhesive (Figure 7).

From a practical standpoint, it is important to consider the difficulty of handling the fibers, for cutting and for placement. This was reported by Vallittu[37] when trying to incorporate glass and polyethylene fibers accurately in the base of dental prostheses. The authors emphasized the importance of the accurately placing

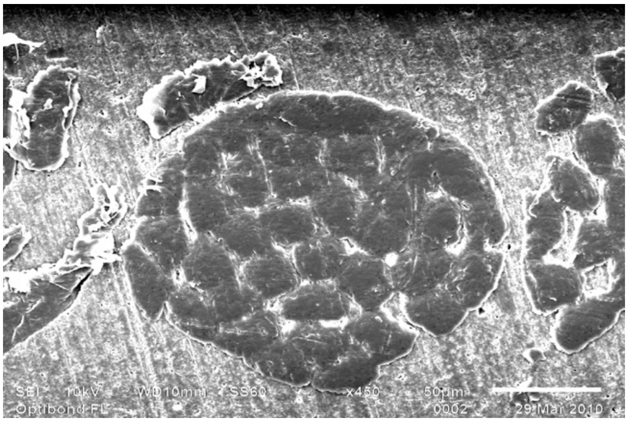

FIGURE 7. Scanning electron microscope micrograph of polyethylene fibers pre-impregnated with Optibond FL adhesive resin (section view, original magnification ×450).

and orienting of the fibers to obtain the so-called "total fiber reinforcement," which best uses the fiber properties. Polyethylene woven fibers present the advantage of a lower elastic modulus (compared with e-glass fibers) and the ability to better conform to a variety of defect shapes. It is known that a well-designed fiber system should influence the stress distribution and, depending on its orientation and alignment, be effective in altering, stopping, and redirecting the propagation of cracks.[35,36] Per the manufacturer's recommendations and previously published studies,[31–33] the fiber patch was applied from the occlusal one-third of the buccal wall, across the occlusal floor, to the occlusal one-third of the lingual wall. This U-shape was intentional to place the fibers as close as possible to the defect. Knowing that fibers best perform in tension, not in compression, it might be questioned whether better positioning would be possible. The highest tensile stresses in molars under misdirected loads are found at the central groove,[10,15] therefore placing Ribbond closer to the occlusal surface might prove beneficial in stopping or redirecting cracks. According to studies, such an approach proved unsuccessful unless additional tooth reduction (such as for an intracoronal defect) is made to anchor the fibers within the remaining cusps.[31–33,39] In addition to its practical difficulty, subsurface placement of Ribbond increases the risk of exposing the fibers if postoperative occlusal adjustments are necessary.

Another important finding in this research was that the presence of the U-shape polyethylene fiber patch did not influence the failure mode of the indirect restorations in contrast to the findings of other studies on direct restorations.[31–34] A limitation of the present study is that the overall occlusal thickness of the restorations in groups INF and ONF may have been different than that in groups IN and ON. Uniformity of restoration thickness would have required additional preparation of intact tooth substance in group INF and ONF in order to create the space for the fiber patch. In addition, the presence of the fiber reinforcement might have been "masked" by the stability of the bond provided by IDS[42] (possible only with indirect restorations) because the latter generates a high cohesiveness of the tooth-restoration complex (witnessed by the absence of adhesive failures). Fennis and colleagues[34] observed that teeth fractured in a less catastrophic manner when fibers were applied under direct composite resin restorations. This beneficial effect on the failure mode was more consistent with woven (isotropic) fibers than unidirectional fibers (orthotropic). The design and application of the fiber system used in this study may require further optimization as it is suggested that the best results may be obtained when the cusps are overlapped[32] or transfixed[39] by the fibers. Further studies are also needed to explore different possibilities like the use of unidirectional fibers, other positioning methods, or use of pretensioned fibers.[38] Regardless of the system used, special attention should be given to the maximum preservation of tooth structure, which is the first goal of modern restorative dentistry.

CONCLUSIONS

Within the limitations of this in vitro fatigue study, it is concluded that CAD/CAM composite resin onlays (with or without fiber reinforcement) increased the fatigue resistance of restored compromised molars. CAD/CAM composite resin inlays without fibers had the most favorable failure mode (restorable). As there were no adhesive failures and all specimens survived the first half of the test (normal range of occlusal forces), it would be premature to state that cusp overlap

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is absolutely indicated for adhesive restoration of molars with a compromised cusp. The inclusion of fiber reinforcement is not necessary. The efficiency of the bonding strategy (IDS, indirect technique) was demonstrated in part by the absence of adhesive failures.

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Reprint requests: Pascal Magne, DMD, PhD, University of Southern California, Los Angeles, Oral Health Center, 3151 S. Hoover Street, Los Angeles, CA 90089-7792, USA; Tel.: 213-740-4239; email: magne@usc.edu

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