IN VITRO FATIGUE RESISTANCE OF CAD/CAM COMPOSITE RESIN AND CERAMIC POSTERIOR OCCLUSAL VENEERS

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Statement of problem. Thin, bonded, posterior occlusal veneers constitute a conservative alternative to traditional complete coverage crowns. Information regarding selection of the appropriate material and its influence on fatigue resistance, which may affect the longevity of the restoration, is missing.

Purpose. The purpose of this study was to assess and compare the fatigue resistance of composite resin and ceramic posterior occlusal veneers.

Material and methods. Thirty extracted molars received a standardized nonretentive tooth preparation (simulating advanced occlusal erosion), including removal of occlusal enamel, exposure of dentin, and immediate dentin sealing (Optibond FL). All teeth were restored with a 1.2-mm-thick occlusal veneer (Cerec 3 chairside CAD/CAM system). The restorations ($n=10$) were milled from leucite-reinforced and lithium disilicate ceramics (IPS Empress CAD and IPS e.max CAD, respectively) and a composite resin (Paradigm MZ100). The intaglio surfaces of the ceramic restorations were conditioned by hydrofluoric acid etching and silane. Airborne-particle abrasion and silane were used to condition the composite resin restorations. Preparations were airborne-particle abraded and etched. All restorations were bonded with preheated luting material and submitted to cyclic isometric loading at 5 Hz, starting with a load of 200 N (×5000 cycles), followed by stepwise loading of 400, 600, 800, 1000, 1200, and 1400 N at a maximum of 30,000 cycles each. The number of cycles at initial failure (first cracks) was recorded. Specimens were loaded for a maximum of 185,000 cycles. Groups were compared using the life table survival analysis ($\alpha=.016$, Bonferroni method).

Results. IPS Empress CAD failed at an average load of 900 N, with no specimen withstanding all 185,000 load cycles (survival 0%), while IPS e.max CAD and Paradigm MZ100 demonstrated survival rates of 30% and 100%, respectively. None of the specimens exhibited catastrophic failure, but only cracks limited to the restorative material.

Conclusions. Posterior occlusal veneers made of composite resin (Paradigm MZ100) had significantly higher fatigue resistance ($P<.002$) compared to IPS Empress CAD and IPS e.max CAD. (J Prosthet Dent 2010;104:149-157)

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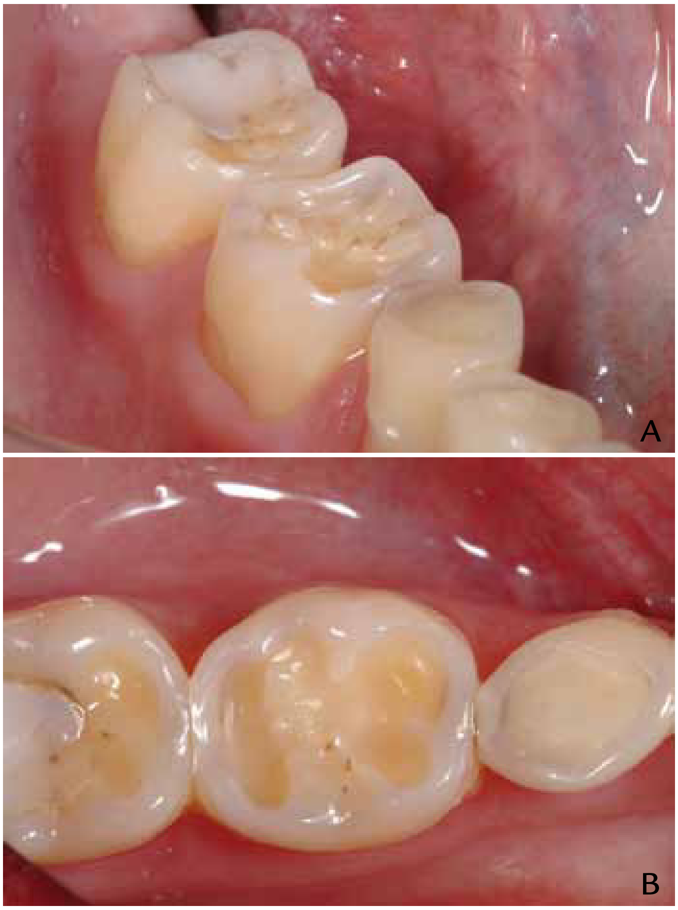
Clinical Implications

CAD/CAM composite resins may provide better fracture resistance for nonretentive occlusal veneers in posterior teeth with high load requirements. When porcelain is required, IPS e.max CAD may perform better than IPS Empress CAD.



1 Severe erosion caused by gastroesophageal reflux disease (35-year-old woman). A, Note significant loss of occlusal anatomy. B, Occlusal view with severe dentin exposure. Such situations call for noninvasive approaches using indirect bonded restorations.

Preservation of tooth structure is a major driving force in restorative dentistry.[1,2] From a biomimetic perspective, the conservation of tooth structure is paramount in maintaining the subtle equilibrium between biologic, mechanical, functional, and esthetic parameters.[3] It is clearly beneficial to keep the pulp alive and prevent endodontic treatment and the need for posts and cores, because these more invasive approaches violate the biomechanical balance and compromise the performance of restored teeth over time.[3,4] As quantified by Edelhoff,[1] preparations with deep shoulders and chamfers, as required for complete coverage crowns in the 1970s and 1980s, have been strongly associated with an increase in microleakage and pulpal complications.[5-7] When compared to bonded restorations, metal ceramic complete coverage crowns are also associated with more gingival inflammation and secondary caries.[8] Partial coverage preparations with reduced macroretentive geometry, such as onlays and partial coverage ceramic crowns, have been reported to remove half the amount of tooth structure compared to a complete coverage metal ceramic crown.[1] With survival rates of 88.7% after 17 years[9] and 84% after 12 years,[10] porcelain adhesive inlays and onlays have demonstrated long-term reliability. As a result, their range of indications has been increased, including treatment of advanced erosion[11-14] (Fig. 1) and stabilization of teeth with cracked-tooth syndrome.[15,16]

The benefits of decreasing retentive features of tooth preparations could be increased by the translational application of principles used in treatment with anterior porcelain laminate veneers, hence the proposal for posterior "occlusal veneers" (thin onlay/overlay with nonretentive design). Such restorations could potentially compete with gold onlays/overlays. Occlusal veneers are extracoronal restorations requiring a simpler and more intuitive preparation driven by interocclusal clearance and anatomical considerations. The usual recommendation for porcelain restoration thickness is 1.5 to 2.0 mm.[17-20] However, given the development of stronger materials in combination with CAD/CAM techniques and innovative adhesive technology such as immediate dentin sealing,[21-27] more conservative approaches should be considered. Yet, there is a significant lack of data regarding the selection of the appropriate material and its influence on the fatigue resistance of such thin, nonretentive occlusal veneers.

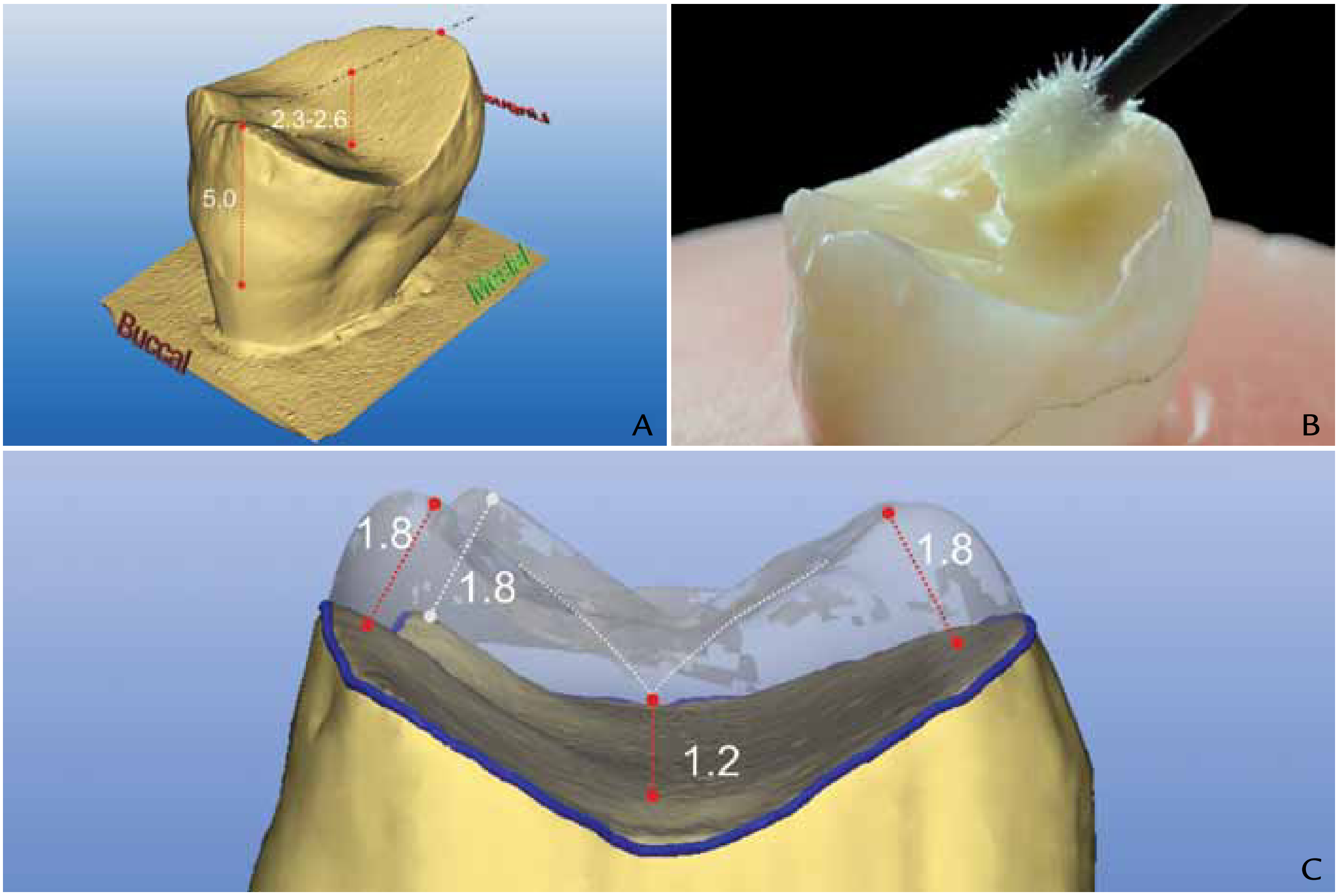
The purpose of this study was to assess and compare the fatigue resistance of composite resin and ceramic posterior occlusal veneers. The null hypothesis was that no significant difference would be found with respect to fatigue resistance among the 3 materials used in this study for posterior occlusal veneers.

MATERIAL AND METHODS

Thirty freshly extracted, sound human maxillary molars were collected (stored in a solution saturated with thymol) upon approval from both the Ethical Committee of the Federal University of Santa Catarina and the University of Southern California Review Board. Teeth were inserted in a special positioning device filled with acrylic resin (Palapress; Heraeus Kulzer GmbH, Hanau, Germany), embedding the root up to 3 mm below the cemento-enamel junction (CEJ).

Tooth preparation

A standardized tooth preparation was applied to all specimens to simulate advanced erosion of the occlusal surfaces. First, complete occlusal dentin exposure was obtained through selective removal of occlusal enamel with a round-ended, tapered diamond rotary cutting instrument (6850-023; Brasseler USA, Savannah, Ga). The buccal and palatal margins were maintained at approximately 5.0 mm from the CEJ and 2.3 to 2.6 mm above the central groove (Fig. 2, A), keeping the cuspal inclination as constant as possible. In an effort to standardize tooth preparation and match the anatomy of the Cerec database (see next section), a "virtual indexing technique" was used: a preliminary optical impression (Cerec 3; Sirona Dental Systems GmbH, Bensheim, Germany) was made, the restoration was designed, and the preparation was adjusted as needed. Immediate dentin sealing was then applied according to a previously published protocol,[21,23,25-27] using a fourth generation etch-and-rinse dentin bonding agent (OptiBond FL; Kerr Corp, Orange, Calif), following the manufacturer's instructions: dentin etching for 15 seconds with a 37.5% phosphoric acid (Ultra-Etch; Ultradent Products, Inc, South Jordan, Utah), abundant rinsing, careful air drying with no desiccating for 3 to 5 seconds, application of the primer with a light brushing motion for 15 seconds, air drying for 3 to 5 seconds, and application of adhesive resin, only on dentin, for 20 seconds (no air thinning) (Fig. 2, B). The adhesive was light polymerized for 20 seconds at 1000 mW/cm^2 (Allegro; Den-Mat, Santa Maria, Calif), and then an air barrier (K-Y Jelly; Johnson & Johnson, Montreal, Canada) was applied to reduce the oxygen-inhibited layer, and additional light exposure was applied for 10 seconds with the same light unit. Excess adhesive resin was carefully removed from the enamel margins with a round diamond rotary cutting instrument (801-023; Brasseler USA) at 1500 rpm. Finally, each specimen was stored in distilled water for 24 hours before the



2 A, Tooth preparation (standard cuspal inclination) and corresponding measurements and dimensions (in mm). B, Immediate dentin sealing. C, Thin occlusal-type restoration with desired clearances (in mm).

optical impression, designing, and adhesive placement of the CAD/CAM restorations.

Design of restorations and manufacturing

Standardized overlays from the Cerec database (third maxillary molar, Lee Culp Youth database; Sirona Dental Systems GmbH) were generated with the Cerec 3 CAD/CAM system (Sirona Dental Systems GmbH). The occlusal surface was created using the software's design tools (Cerec v. 3.03; Sirona Dental Systems GmbH) set in Master Mode, with an average thickness of 1.2 mm at the central groove, a maximum of 1.8 mm at the cusp tip, and 1.6 mm at the internal cusp slope (measured with a caliper after milling and polishing) (Fig. 2, C). To standardize form and anatomy, the design of the restoration was obtained by the sole use of the "position" tools (translation and rotation), with no editing of the original shape produced by the software.

Twenty restorations were milled with reinforced glass ceramics, 10 from leucite-reinforced ceramic blocks (IPS Empress CAD; Ivoclar Vivadent AG, Schaan, Liechtenstein) (group ECAD), and another group of 10 from lithium disilicate blocks (IPS e.max CAD; Ivoclar Vivadent AG) (group EMAX). Finally, 10 restorations were milled with composite resin (Paradigm MZ100 blocks; 3M ESPE, St. Paul, Minn) (group MZ100).

All restorations were milled in Endo Mode with the sprue at the lingual surface and inspected to detect possible milling cracks. The restorations milled with lithium disilicate blocks were crystallized in a ceramic furnace (Austromat D4; DEKEMA Dental-Keramiköfen GmbH, Freilassing, Germany) following the manufacturer's instructions (Ivoclar Vivadent AG). The surface polishing of the ECAD and EMAX restorations was performed mechanically using diamond ceramic polishers (CeramiPro Dialite; Brasseler USA), while the MZ100 specimens were finished with brushes (Jiffy Composite Polishing Brushes; Ultradent Products, Inc).

Adhesive placement

Milled ceramic restorations were etched with 9% hydrofluoric acid (Porcelain Etch; Ultradent Products, Inc) for 60 seconds (ECAD) or 20 seconds (EMAX). After rinsing for 20 seconds, the specimens were subjected to postetching cleaning using phosphoric acid (Ultra-Etch; Ultradent Products, Inc) with a brushing motion for 1 minute, followed by rinsing for 20 seconds, and then immersion in distilled water in an ultrasonic bath for 3 minutes. After thorough air drying, intaglio surfaces were silanated (Silane; Ultradent Products, Inc) and heat dried at 100°C for 5 minutes (DI-500 oven; Coltène/Whaledent AG, Alstätten, Switzerland). Specimens in group MZ100 received the same intaglio surface conditioning, except the hydrofluoric etching step, which was replaced by airborne-particle abrasion with 27-µm aluminum oxide at 30 psi (RONDOflex plus 360; KaVo Dental, Charlotte, NC).

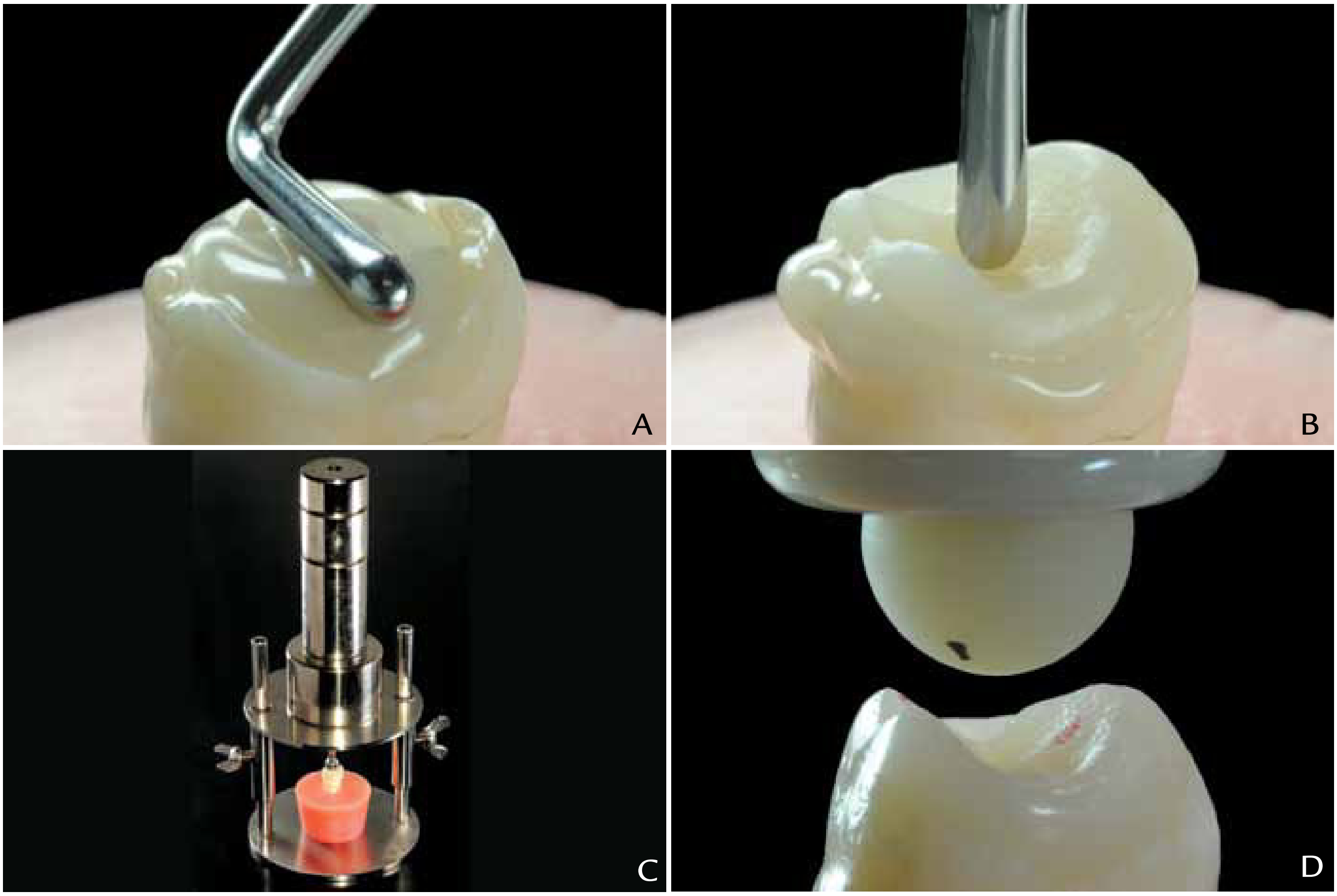
Tooth preparations were all treated with airborne-particle abrasion (RONDOflex plus 360; KaVo Dental), etched for 30 seconds with 37.5% phosphoric acid (Ultra-Etch; Ultradent Products, Inc), rinsed, and dried. Both fitting surfaces, restoration and tooth, were coated with adhesive resin (Optibond FL, Bottle no. 2; Kerr Corp) and left unpolymerized until the luting material (Z100; 3M ESPE), preheated to 68°C (Calset; AdDent, Inc, Danbury, Conn), was applied to the tooth (Fig. 3, A) and the restoration was definitively inserted (Fig. 3, B). After careful insertion, the restorations were subjected to a standardized load of 6 N (Fig. 3, C), followed by elimination of excess composite resin and initial light polymerization.[28] Each surface was exposed at 1000 mW/cm^2 (Allegro; Den-Mat) for 60 seconds (20 s/surface, repeated 3 times). All margins were covered with an air-blocking barrier (KY Jelly; Johnson & Johnson) for the final 20-second polymerization cycle. The margins were finished and polished with diamond ceramic polishers (CeramiPro Dialite W16DG, W16DM, W16D; Brasseler USA) (all groups) and silicon bristle brushes (Jiffy Composite Polishing Brush; Ultradent Products, Inc) (MZ100 group only), then each specimen was stored in distilled water at ambient temperature for 24 hours before testing.

Fatigue testing

Masticatory forces were simulated using closed-loop servohydraulics (Mini Bionix II; MTS Systems Corp, Eden Prairie, Minn) with a 7-mm-diameter composite resin sphere (Z100; 3M ESPE) postpolymerized at 100°C for 5 minutes (Fig. 3, D). Due to the standardized occlusal anatomy, each specimen was placed in the load chamber in the same reproducible position with the load sphere contacting the mesiobuccal, distobuccal, and lingual cusps equally (tripod contact). The load chamber was filled with distilled water to submerge the specimen during testing. Cyclic load (isometric mastication using load control) was applied at a frequency of 5 Hz, starting with a load of 200 N for 5000 cycles (preconditioning phase to guarantee predictable positioning of the sphere with the specimen),[29] followed by stages of 400, 600, 800, 1000, 1200, and 1400 N at a maximum of 30,000 cycles each. If the material did not fail, the experiment continued with the same load level until 30,000 cycles was reached. The number of cycles at initial failure was recorded (explained below in crack detection and tracking). The specimens were loaded until catastrophic failure (lost restoration fragments) or to a maximum of 185,000 cycles.

Crack detection and tracking

Specimens were evaluated at baseline and at the end of each load step using transillumination (Microlux; AdDent, Inc) and optical microscopy



3 A, Application of preheated composite resin material (Z100 at 68°C). B, Placement of restoration. C, Device for application of standardized load during luting procedures. D, Positioning of specimen for fatigue testing (7-mm-diameter resin sphere).

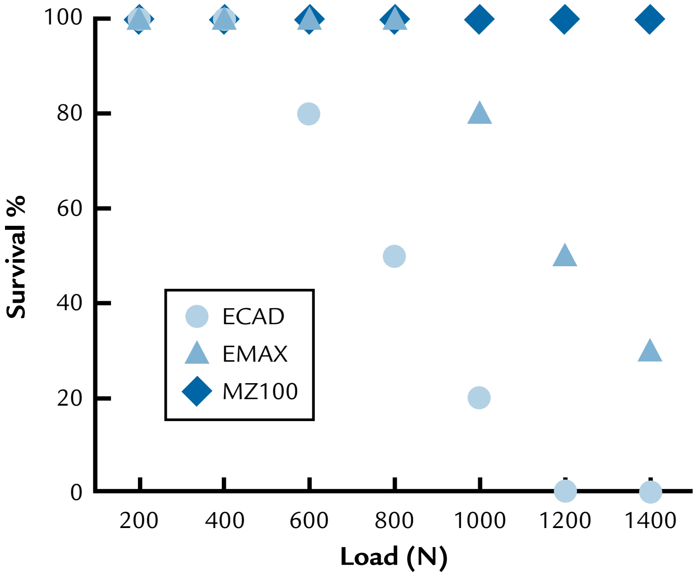
(Leica MZ 125; Leica Microsystems GmbH, Wetzlar, Germany) at ×10 magnification, in a 2-examiner agreement. Each specimen was also photographed under standardized conditions at ×1.5 magnification (Nikon D70 and Medical-Nikkor 120-mm lens and close-up lens; Nikon, Tokyo, Japan). Cracks smaller than 2 mm in length or subsurface cracks are difficult to diagnose under normal clinical conditions. Therefore, to meet the criteria for "failure," a specimen had to exhibit 1 or more surface cracks greater than or equal to 2 mm in length. This crack tracking procedure was performed until catastrophic failure (fragment loss) or until completion of the 185,000 cycles.

The fatigue resistance of the 3 groups was compared using the life table survival analysis. At each time interval (defined by each load step), the number of specimens beginning the interval intact and the number of specimens cracking during the interval were counted. This allowed the calculation of survival probability (%) at each load step. The influence of the restorative material on the cracking propensity was analyzed using the log-rank test at a significance level of .05. Differences were localized using pairwise post hoc comparisons with the same test at a significance level of .016 (Bonferroni correction for 3 comparisons). The data were analyzed with statistical software (MedCalc, v. 11.0.1; MedCalc Software, Mariakerke, Belgium).

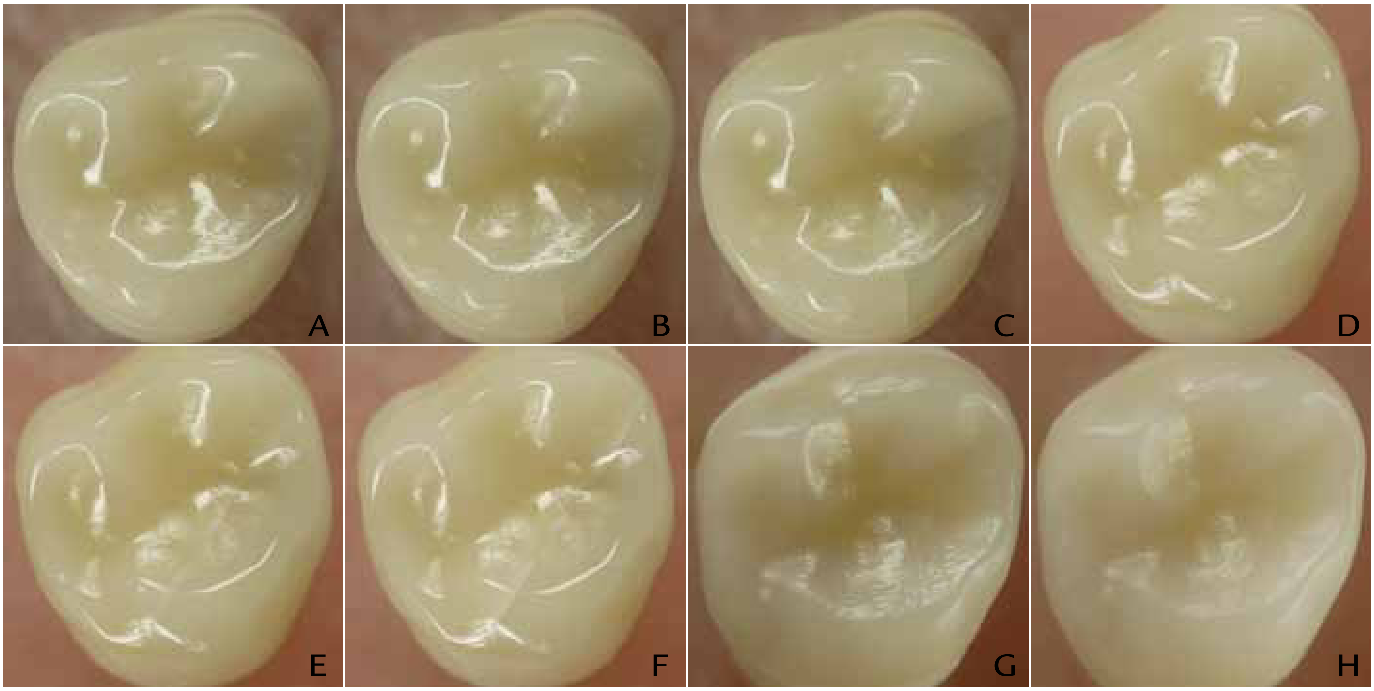
RESULTS

For group ECAD, restorations demonstrated failure at an average load of 900 N (110,918 cycles), and all specimens exhibited ceramic cracks by the completion of the 185,000 cycles (survival=0%). For groups EMAX and MZ100, the survival rates (no cracking) were 30% and 100%, respectively. Life table survival analysis (Fig. 4) revealed significant differences among groups (*P*<.001). Post hoc tests showed higher fatigue resistance of MZ100 compared to ECAD and EMAX (*P*<.001 and *P*=.002, respectively), and higher fatigue resistance of EMAX compared to ECAD (*P*=.001).

Among the 30 specimens, none demonstrated catastrophic failure with loss of a restoration fragment. None of the specimens experienced loss of or significant damage to intact tooth structure (Fig. 5).



4 Life table survival distributions by materials at each load step (n=10).



5 A-C, Specimen from group ECAD. A, Before testing. B, Initial failure (1000 N). C, After 185,000 cycles. D-F, Specimen from group EMAX. D, Before testing. E, At initial failure (1000 N). F, After 185.000 cycles. G, H, Specimen from group MZ100. G, Before testing. H, After 185,000 cycles.

DISCUSSION

The null hypothesis, namely, that there would be no difference in terms of fatigue resistance among the 3 materials evaluated in this study for posterior occlusal veneers, was rejected. Composite resin MZ100 had a significantly increased fatigue resistance with thin posterior occlusal veneers as compared to the ceramics IPS Empress CAD and IPS e.max CAD. The study also revealed the in vitro feasibility of a less invasive approach using CAD/CAM ceramics and composite resins to fabricate thin occlusal veneers.

Restorative materials are often tested by subjecting standardized beams to a 3- or 4-point flexural cyclic load. Only 2 modes of fatigue can be simulated by this process: contact and flexure.[30] However, loading a restored tooth through a submerged cusp in a 3-point/facet contact can generate a large variety of stresses (compressive, tensile, shear), as well as water sorption and aging in wet conditions.[27] In the present study, a fully functional restored natural tooth could be simulated, which constitutes the uniqueness of this protocol. Simulation of the periodontal ligament was omitted because elastomers or silicone films usually used for this purpose show accelerated degradation; this would allow for excessive displacement of the tooth

6 Specimen after testing in group ECAD. Note "mosaiclike" cracks.

and would destabilize the servohydraulic control system.

The experimental design did not allow testing of multiple specimens, and each specimen was loaded over the course of 1 day. This testing method is relatively time consuming. However, confounding variables were minimized by the combined use of the Cerec technology (Sirona Dental Systems GmbH) and complete occlusal restoration, generating standardized restoration size, shape, and cuspal inclines.

The decision to use a resin sphere rather than stainless steel is also unique to this study, but was previously suggested by Magne and Knezevic.[27] According to Kelly,[31] steel indenters tend to generate localized and intense point loads, which are more likely to generate surface damage and powderlike debris by crushing (Hertzian cone cracks). The lower stiffness and higher wear of the composite resin sphere allowed more realistic simulation of tooth contacts through wear facets, distributing the load without reaching the compressive limit of the tissues or restorative materials. At the beginning of the test (200-N load step), the intact ball generated contact pressure of approximately 200 MPa (3 contacts for approximately 1 mm^2), while at the end of the fatigue test (1400 N), the worn ball produced contact pressures of only 350 MPa (approximately 4 mm^2). The intrinsic wear of the antagonistic load sphere prevented the contact pressure from decreasing as fast as the increasing load. This is an essential aspect of this test, as mentioned by Kelly,[31] who suggested using large radii spheres or indenting the specimen to reduce the increase in contact pressure. It was also important to ensure that the composite resin used for the fabrication of the load sphere would be strong enough to undergo the entire fatigue test and maintain contact regardless of the load step. Therefore, the load cusps were carefully inspected at each load step. However, none of the spheres were damaged or had to be replaced.

The luting procedure constituted another strong element of the protocol. It included the so-called "immediate dentin sealing" (sealing the freshly cut dentin with a dentin bonding agent directly following tooth preparation, before making an impression) associated with application of a preheated light-polymerized composite resin restorative material as a luting agent,[23-27] which might be considered the state of the art in bonding indirect restorations.[21,22,25] Despite the high loads used in the present study and the "mosaiclike" cracking observed (Fig. 6), none of the fractured fragments separated from the tooth, which demonstrated the fatigue resistance of the dentin bond. Cracks were restricted to the restorations and remaining enamel in all tested groups. This constitutes a demonstration of the "biomimetic" behavior of the restoration and underlying tissue, simulating to some degree the enamel cracks stopped at the dento-enamel junction (DEJ).[32]

From the present data, it appears that higher flexural strength does not necessarily result in a restoration with a higher load tolerance.[33] The uniaxial flexural strength of ceramic blocks (256 and 127 MPa for EMAX and ECAD, respectively) compared to that of the composite resin blocks (150 MPa for MZ100) did not correlate with their respective survival rates. In fact, structural integrity of complex structures made from multilayered materials, such as restored teeth, cannot be predicted using strength data alone.[33] The intrinsic strength, as well as the thickness of the material, has limited influence on the failure triggered by the development of tensile stresses, which is much more sensitive to the ratios of elastic moduli between the restorative material and the luting material and dentin.[31] As demonstrated by the behavior of the resin groups, the relative similarity of elasticity moduli of the composite tested (16-20 MPa) and dentin (18.5 GPa)[34] may have a key role in the tooth-restoration performance.

With a restoration thickness ranging from 1.2 mm (at the central groove) to 1.8 mm (at the cusp tips), the present study explored the lower limits of the usual thickness recommendation for the "safe" restoration of posterior teeth.[18-20] The results of the present study are in agreement with similar previous experiments, which confirmed the robustness of compromised endodontically treated molars restored with MZ100 overlays[26,27] when compared to porcelain (VITABLOCS Mark II; Vident, Brea, Calif). Patients with high load requirements may benefit from the design of thin occlusal veneers made using MZ100 or EMAX. In the latter, the first cracks appeared only at high loads. The results show that ECAD is not likely to survive under high load requirements, since none of the specimens withstood the second half of the test

(1000-1400 N). This would correspond to extreme situations with high extrinsic loads (trauma)[26,27] or intrinsic masticatory accidents (under masticatory loads but delivered to a small area due to a hard foreign body such as a pit or seed, for example).

This in vitro experimental design can be used to generate and explore the performance of occlusal veneers with even thinner designs (less than 1-mm thickness), which could be an additional step towards ultraconservative approaches for patients with moderate erosion or complete mouth rehabilitation requiring moderate changes of the vertical dimension of occlusion. While composite resin restorations are expected to wear more than ceramic, they also tend to preserve more of the antagonistic enamel.[35] This differential wear of CAD/CAM composite resin and ceramic thin occlusal veneers requires additional investigation. This in vitro research does not fully simulate the oral environment; thus, it is difficult to draw direct correlations to the clinical performance of these restorations. The present study is therefore limited, and further research should include clinical trials.

CONCLUSIONS

Within the limitations of this in vitro fatigue study, it was concluded that:

1. CAD/CAM composite resin posterior occlusal veneers had significantly higher fatigue resistance when compared to ceramic occlusal veneers.

2. None of the IPS Empress CAD occlusal veneers withstood all 185,000 load cycles (survival=0%), whereas IPS e.max CAD and MZ100 demonstrated survival rates of 30% and 100%, respectively.

3. Despite the simulation of loads of a higher magnitude than is usually encountered in clinical situations, there were no catastrophic failures, but only cracks limited to the restorative material.

REFERENCES

1. Edelhoff D, Sorensen JA. Tooth structure removal associated with various preparation designs for posterior teeth. Int J Periodontics Restorative Dent 2002;22:241-9.
2. Edelhoff D, Sorensen JA. Tooth structure removal associated with various preparation designs for anterior teeth. J Prosthet Dent 2002;87:503-9.
3. Magne P, Belser U. Bonded porcelain restorations in the anterior dentition: a biomimetic approach. Chicago: Quintessence; 2002. p. 23-55.
4. Torbjörner A, Fransson B. Biomechanical aspects of prosthetic treatment of structurally compromised teeth. Int J Prosthodont 2004;17:135-41.
5. Ericson S, Hedegård B, Wennström A. Roentgenographic study of vital abutment teeth. J Prosthet Dent 1966;16:981-7.
6. Schwartz NL, Whitsett LD, Berry TG, Stewart JL. Unserviceable crowns and fixed partial dentures: life-span and causes for loss of serviceability. J Am Dent Assoc 1970;81:1395-401.
7. Goldman M, Laosonthorn P, White RR. Microleakage--full crowns and the dental pulp. J Endod 1992;18:473-5.
8. Pippin DJ, Mixson JM, Soldan-Els AP. Clinical evaluation of restored maxillary incisors: veneers vs. PFM crowns. J Am Dent Assoc 1995;126:1523-9.
9. Otto T, Schneider D. Long-term clinical results of chairside Cerec CAD/CAM inlays and onlays: a case series. Int J Prosthodont 2008;21:53-9.
10. Frankenberger R, Taschner M, Garcia-Godoy F, Petschelt A, Krämer N. Leucite-reinforced glass ceramic inlays and onlays after 12 years. J Adhes Dent 2008;10:393-8.
11. Vailati F, Belser UC. Full-mouth adhesive rehabilitation of a severely eroded dentition: the three-step technique. Part 1. Eur J Esthet Dent 2008;3:30-44.
12. Vailati F, Belser UC. Full-mouth adhesive rehabilitation of a severely eroded dentition: the three-step technique. Part 2. Eur J Esthet Dent 2008;3:128-46.
13. Vailati F, Belser UC. Full-mouth adhesive rehabilitation of a severely eroded dentition: the three-step technique. Part 3. Eur J Esthet Dent 2008;3:236-57.
14. Lussi A, Hellwig E, Ganss C, Jaeggi T. Buonocore Memorial Lecture. Dental erosion. Oper Dent 2009;34:251-62.
15. Signore A, Benedicenti S, Covani U, Ravera G. A 4- to 6-year retrospective clinical study of cracked teeth restored with bonded indirect resin composite onlays. Int J Prosthodont 2007;20:609-16.
16. Geurtsen W, Schwarze T, Günay H. Diagnosis, therapy, and prevention of the cracked tooth syndrome. Quintessence Int 2003;34:409-17.
17. Roulet JF. Longevity of glass ceramic inlays and amalgam--results up to 6 years. Clin Oral Investig 1997;1:40-6.
18. Dietschi D, Spreafico R. Adhesive metal-free restorations: current concepts for the esthetic treatment of posterior teeth. Berlin: Quintessence; 1997. p. 96.
19. Federlin M, Krifka S, Herpich M, Hiller KA, Schmalz G. Partial ceramic crowns: influence of ceramic thickness, preparation design and luting material on fracture resistance and marginal integrity in vitro. Oper Dent 2007;32:251-60.
20. Stappert CF, Chitmongkolsuk S, Silva NR, Att W, Strub JR. Effect of mouth-motion fatigue and thermal cycling on the marginal accuracy of partial coverage restorations made of various dental materials. Dent Mater 2008;24:1248-57.
21. Magne P, Douglas WH. Porcelain veneers: dentin bonding optimization and biomimetic recovery of the crown. Int J Prosthodont 1999;12:111-21.
22. Dietschi D, Monasevic M, Krejci I, Davidson C. Marginal and internal adaptation of class II restorations after immediate or delayed composite placement. J Dent 2002;30:259-69.
23. Magne P. Immediate dentin sealing: a fundamental procedure for indirect bonded restorations. J Esthet Restor Dent 2005;17:144-54.
24. Magne P. Composite resins and bonded porcelain: the postamalgam era? J Calif Dent Assoc 2006;34:135-47.
25. Magne P, So WS, Cascione D. Immediate dentin sealing supports delayed restoration placement. J Prosthet Dent 2007;98:166-74.
26. Magne P, Knezevic A. Simulated fatigue resistance of composite resin versus porcelain CAD/CAM overlay restorations on endodontically treated molars. Quintessence Int 2009;40:125-33.
27. Magne P, Knezevic A. Influence of overlay restorative materials and load cusps on the fatigue resistance of endodontically treated molars. Quintessence Int 2009;40:729-37.
28. Wilson PR. Low force cementation. J Dent 1996;24:269-73.
29. Fennis WM, Kuijs RH, Kreulen CM, Verdonschot N, Creugers NH. Fatigue resistance of teeth restored with cuspal-coverage composite restorations. Int J Prosthodont 2004;17:313-7.
30. Al-Turki LI, Drummond JL, Agojci M, Gosz M, Tyrus JM, Lin L. Contact versus flexure fatigue of a fiber-filled composite. Dent Mater 2007;23:648-53.
31. Kelly JR. Clinically relevant approach to failure testing of all-ceramic restorations. J Prosthet Dent 1999;81:652-61.
32. Lin CP, Douglas WH. Structure-property relations and crack resistance at the bovine dentin-enamel junction. J Dent Res 1994;73:1072-8.
33. Kelly JR. Perspectives on strength. Dent Mater 1995;11:103-10.
34. Craig RG. Selected properties of dental composites. J Dent Res 1979;58:1544-50.
35. Kunzelmann KH, Jelen B, Mehl A, Hickel R. Wear evaluation of MZ100 compared to ceramic CAD/CAM materials. Int J Comput Dent 2001;4:171-84.

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