Simulated fatigue resistance of composite resin versus porcelain CAD/CAM overlay restorations on endodontically treated molars

Pascal Magne, DMD, PhD[1]/Alena Knezevic, DDS, PhD[2]

Objective: To assess the influence of material selection (porcelain versus composite resin) for overlay-type restoration of endodontically treated molars and its effect on the in vitro fatigue resistance and failure mode. **Method and Materials:** A standardized tooth preparation was applied to 30 extracted molars, including root canal treatment, 3-mm coverage of all cusps, a mesial box 1.5 mm below the cementoenamel junction (CEJ), a distal box in enamel, a glass-ionomer base, and immediately sealed dentin. Using the Cerec machine (Sirona), all teeth were restored with an overlay of standardized thickness and occlusal anatomy. Fifteen restorations were milled in the ceramic Vita MKII block (Vident) and the other 15 using the composite resin Paradigm MZ100 block (3M ESPE). The intaglio surfaces of the ceramic restorations were etched and silanated. The intaglio surfaces of the composite resin overlays were airborne-particle abraded and silanated. Preparations were airborne-particle abraded and etched before restoration insertion. All restorations were adhesively luted with an adhesive resin (Optibond FL, Kerr) and a light-curing composite resin (Filtek Z100, 3M ESPE). Cyclic isometric chewing (5 Hz) was simulated, starting with a load of 200 N (5,000 cycles), followed by stages of 400, 600, 800, 1,000, 1,200, and 1,400 N at a maximum of 30,000 cycles each. Samples were loaded until fracture or to a maximum of 185,000 cycles. **Results:** MKII overlays fractured at a mean load of 1,147 N, and none of them withstood all 185,000 loading cycles (survival = 0%); with MZ100, the survival rate was 73%. With MKII, 40% of the fractures ended below the CEJ; with MZ100, only 25% did. **Conclusions:** Composite resin MZ100 increased the fatigue resistance of overlay-type restorations in endodontically treated molars when compared to porcelain MKII. The efficiency of the bond strategy (immediate dentin sealing) was demonstrated by the absence of adhesive failures. *(Quintessence Int 2009;40:125–133)*

Key words: Cerec, composite resin, endodontically treated molars, fatigue resistance, overlay restorations, porcelain

It is generally accepted that endodontically treated teeth are more likely to fracture than vital posterior teeth and that this difference is not explained by differences in biomechanical properties or moisture content of hard tissues,[1,2] but rather by the structural defect generated during tooth preparation. Following endodontic treatment, intracoronal adhesive restorations do not seem to have the ability to restore the fracture resistance to that of intact teeth.[3] Considering traditional principles of fixed prosthodontics, full-crown coverage would be recommended to strengthen the remaining tooth substance. When compared to bonded restorations, traditional full-crown coverages, however, require more sacrifice of hard tissue[4,5] and more subgingival margins and are associated with more gingival inflammation and secondary caries.[6] In view of the aforementioned, and knowing that cuspal

[1]Tenured Associate Professor, The Don and Sybil Harrington Foundation Chair of Esthetic Dentistry, Division of Primary Oral Health Care, School of Dentistry, University of Southern California, Los Angeles, California.

[2]Visiting Research Associate, Division of Primary Oral Health Care, School of Dentistry, University of Southern California, Los Angeles, California; Department of Endodontics and Restorative Dentistry, School of Dental Medicine, University of Zagreb, Zagreb, Croatia.

Correspondence: Dr Pascal Magne, University of Southern California, Division of Primary Oral Health Care, School of Dentistry, 3151 S. Hoover St., Suite E201, Los Angeles, CA 90089-7792. Fax: (213) 821-5324. E-mail: magne@usc.edu

coverage has the potential to increase the fatigue resistance of Class 2 resin restorations,[7] use of adhesive total-cuspal-coverage restorations (overlays instead of crowns) is recommended to reduce the risk of fracture and increase the coronal mechanical resistance in endodontically treated teeth.

There are still controversies, however, regarding the performance of ceramics versus composite resins in the posterior dentition. Most long-term data available today are related to ceramic materials, which seem to be preferred in cusp-replacing restorations.[8] Some clinical studies account for the excellent long-term behavior of porcelain inlays/onlays, either indirect[9] or computer-aided design/computer-assisted manufacture (CAD/CAM)–generated.[10,11] No such data are available for indirect composites, and it is extremely difficult to find clinical studies comparing ceramic and composite inlays/onlays.

Manhart et al[12] revealed the significantly better anatomic form and integrity of the ceramic restorations compared to composite resins. Accordingly, ceramic inlays seem to be able to perform well in the long term.[9,10] However, their higher cost and technique sensitivity (brittleness, abrasiveness) explain why clinicians restrict their use to specific clinical situations. As a result, there has been a growing interest for the “more convenient” or “easy-to-handle” composite inlays/onlays.[13]

Indirect composite materials are characterized by a filler content possibly exceeding 70% by volume, providing improved fracture toughness because they can be significantly reinforced by postcure treatment.[14,15] Composite resin overlays can also be fabricated using CAD/CAM technology and offer a considerable time advantage by being produced chairside. However, only limited data are available regarding the selection of the appropriate tooth-colored restorative material and its influence on the fatigue resistance of cusp-replacing restorations in endodontically treated posterior teeth.

This study assessed the influence of material selection (porcelain versus composite resin) for CAD/CAM overlay-type restoration of endodontically treated molars and its effect on the in vitro fatigue resistance and failure mode.

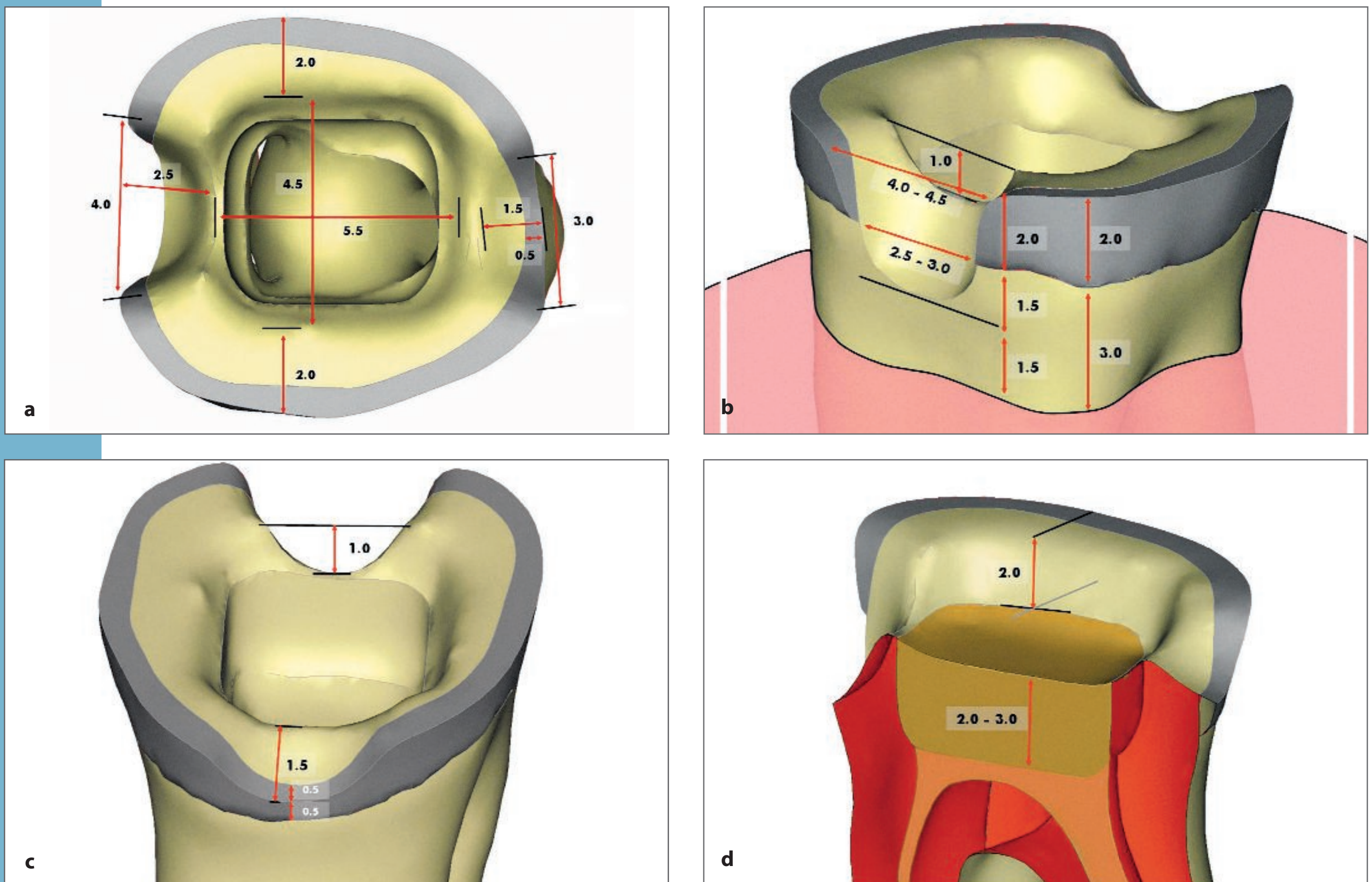
METHOD AND MATERIALS

Once approval was obtained from the University of Southern California Institutional Review Board, 30 freshly extracted, sound human molars stored in solution saturated with thymol were used. Teeth were mounted in a special positioning device with acrylic resin (Palapress, Heraeus Kulzer) embedding the root up to 3.0 mm below the cemento-enamel junction (CEJ).

Tooth preparation

A standardized tooth preparation was applied to all specimens. Detailed measurements and dimensions are shown in Figs 1a to 1d. First, the occlusal half of the crown was removed using a model trimmer. Second, a root canal treatment was simulated with a standard access opening. The root canals were shaped using the stepback technique (maximum file size 35 to 40) and filled with a thermoplasticized gutta-percha delivery system (Obturall, Obtura/Spartan). Third, using a coarse round diamond bur (801-023, Brasseler) mesial and distal rounded boxes were prepared 1.5 mm below and 0.5 mm above the CEJ, respectively. Four, a 2.0- to 3.0-mm-thick glass-ionomer barrier (Ketac Molar, 3M ESPE) was applied at the base of the pulp chamber. Special care was taken to obtain smooth and rounded internal line angles.

Immediate dentin sealing was then applied. For this purpose, the same coarse round diamond bur 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) according to the manufacturer’s instructions: 15-second dentin etching with 37.5% phosphoric acid, abundant rinsing, air drying for 5 seconds, application of primer (bottle 1) with a light brushing motion for 20 seconds, air drying for 5 seconds, and application of adhesive resin with a light brushing motion for 15 seconds. The adhesive was polymerized for 20 seconds at 1,000 mW/cm^2 (Allegro, Den-Mat) followed by the application of an air-blocking barrier (K-Y Jelly, Personal Products) and 10 seconds of additional light exposure with the same light unit



Figs 1a to 1d Standard tooth preparation and corresponding measurements and dimensions (mm). *(a)* Mesiobuccal view with embedding resin (pink). *(b)* Occlusal view with endodontic access channel. *(c)* Distal view. *(d)* Mesiodistal cross section following endodontic treatment and placement of the glass-ionomer base.

to polymerize the oxygen-inhibition layer. Finally, excess adhesive resin was carefully removed from all enamel margins with the same coarse round diamond at 1,500 rpm.

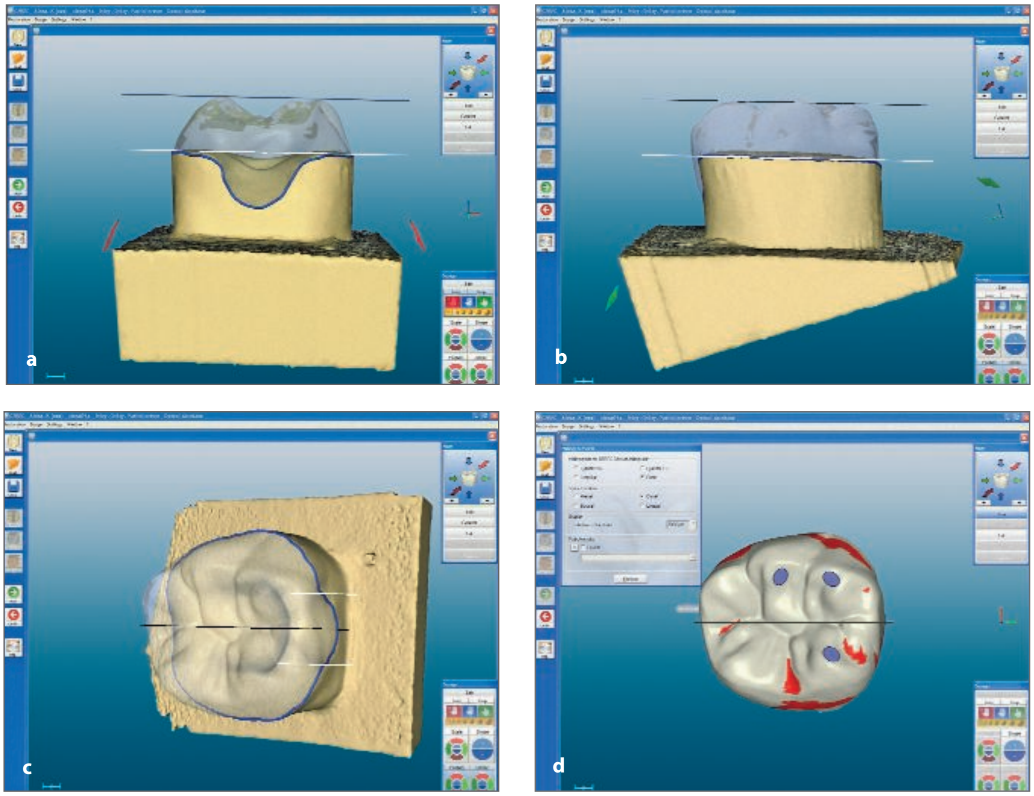
Design and manufacturing of restorations

The molars were restored using the Cerec 3 CAD/CAM system (Sirona Dental Systems). All specimens were fitted with an overlay of standardized thickness and occlusal anatomy (first mandibular molar, Lee Culp Youth database). Using the Crown Master Mode and the Design Tools of the Cerec software (version 3.03, Sirona Dental Systems), the occlusal surface was moved and rotated to make parallel the cusp tips and the preparation surface, as well as to align the central groove with the mesial and distal boxes (Fig 2). The restoration featured a maximum distance of 3.0 mm between the cusp tips and the preparation surface and a 2.5-mm thickness at the mesial isthmus.

For 15 specimens, restorations were milled in the ceramic Vita MKII blocks (Vident) (group MKII) and the other 15 using the composite resin Paradigm MZ100 blocks (3M ESPE) (group MZ100). All restorations were milled in Endo mode with the sprue at the distal surface and then polished mechanically using a commercial polishing kit (Dialite, Ultra Polishers, Brasseler).

Adhesive placement

Surface conditioning of the restorations for group MKII included airborne-particle abrasion with 50-µm aluminum oxide at 30 psi, followed by 9% hydrofluoric acid etching



Figs 2a to 2d Overlay-type restoration design steps in the Cerec software. *(a, b)* Cusp tips and preparation surface are made parallel and 3.0 mm apart. *(c)* Central groove is aligned with the center of the mesial and distal boxes. *(d)* Final occlusal view of the restoration ready for milling (occlusal load points marked in blue).

(Porcelain Etch, Ultradent) for 90 seconds and rinsing with water for 20 seconds. Specimens were then subjected to postetching cleaning using a microbrush and 37.5% phosphoric acid (Ultraetch, Ultradent) with a gentle brushing motion for 1 minute, followed by 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 212°F for 1 minute. The same surface conditioning was used for restorations of group MZ100 except for the hydrofluoric etching step, which was not used.

Tooth preparations (MKII and MZ100 groups) were treated by airborne-particle abrasion with 50-µm aluminum oxide at 30 psi and 30-second etching with 37.5% phosphoric acid, abundant rinsing, and 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 preheated luting material (Filtek Z100, 3M ESPE; preheated for 5 minutes in Calset, Addent) to the tooth and final insertion of the restoration. Following careful elimination of all uncured composite resin excesses, each surface was light-polymerized for 60 seconds (20 seconds per surface, for 3 times). All margins were covered with an air-blocking barrier (K-Y Jelly) for the last curing cycle.

Fatigue testing

Each specimen was stored in distilled water at ambient temperature for at least 24 hours following adhesive restoration placement. Masticatory forces were then simulated with an artificial mouth using closed-loop servo-hydraulics (Mini Bionix II, MTS Systems). Each specimen was placed into the load chamber (Fig 3) and situated with a positioning device (sliding table). The chewing cycle was simulated by an isometric contraction (load control) applied through a stainless

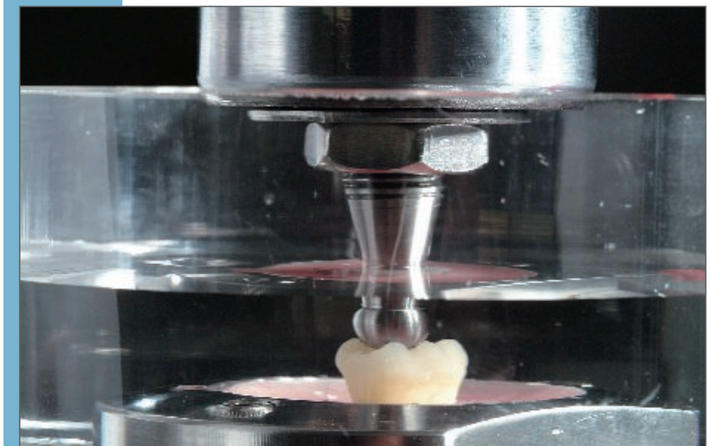


Fig 3 Load chamber with submerged specimen under isometric cyclic loading.

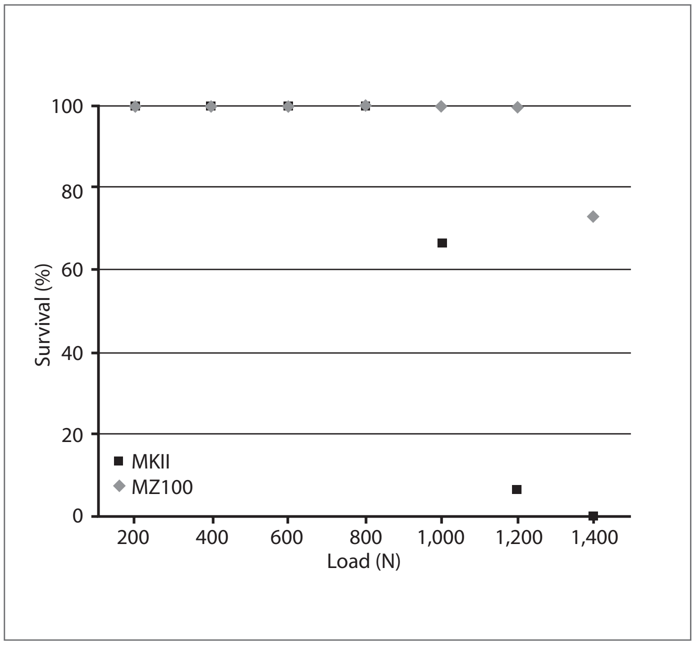


Fig 4 Survival scatter plot of specimens at each load stage (n = 15).

steel sphere with a diameter of 7 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, mesiolingual, and distobuccal cusps (tripod contact, see Fig 2d). The load chamber was filled with distilled water to submerge the sample during testing.

Cyclic load was applied at a frequency of 5 Hz, starting with a load of 200 N for 5,000 cycles (preconditioning phase of the experiment), followed by stages of 400, 600, 800, 1,000, 1,200, and 1,400 N at a maximum of 30,000 cycles each. Samples were loaded until fracture or to a maximum of 185,000 cycles. The number of endured cycles and failure mode were recorded. Following a 2-examiner agreement under optical microscope, a distinction was made between fractures above or below the CEJ and between cohesive fracture or fracture at the interface.

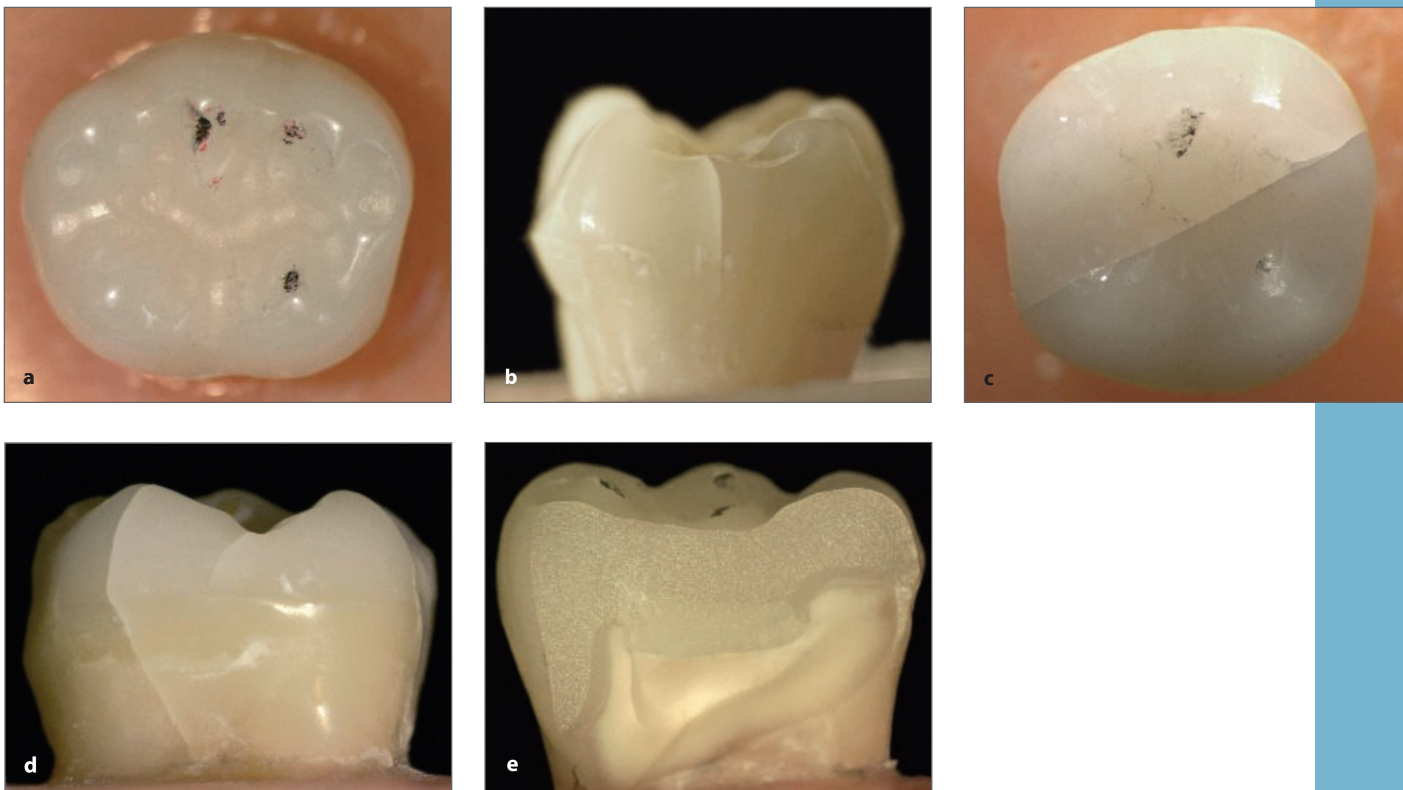
Statistical analysis

The fatigue resistance of the 2 groups was compared using the Kaplan-Meier survival curves. 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 using the log-rank test at a significance level of .05.

RESULTS

The restored molars of group MKII fractured at an average load of 1,147 N and 125,843 cycles, and none withstood all 185,000 loading cycles (survival = 0%). In group MZ100, the survival rate was 73% (Fig 4). Survival of group MZ100 was significantly higher than that of group MKII (P = .0001). The failure modes are presented in Figs 5a to 5e and Table 1. In group MKII, 40% of the fractures ended below the CEJ; in group MZ100, only 25% did.

In all failed specimens, except 1 specimen in group MZ100, failure was cohesive in the porcelain or composite resin restorative and remained cohesive when cracks propagated into the tooth, leaving the interfacial bond intact (see Fig 5).



Figs 5a to 5e Examples of specimens. *(a)* Intact specimen in group MZ100. *(b)* Fracture above CEJ in group MZ100, crack without fragment. *(c)* Fracture above CEJ in group MKII, crack without fragment. *(d)* Fracture below CEJ in group MKII, crack without fragment (*a* to *d*, original magnification × 1.4). *(e)* Fracture below CEJ with fragment in group MKII (original magnification × 1.6).

Table 1 Failure types and numbers

Group	Intact specimen	Fracture above CEJ		Fracture below CEJ	
		Crack*	Fragment	Crack	Fragment
MKII (n = 15)	0	9	0	1	5
MZ100 (n = 15)	11	2	1	0	1

* Implies fracture without isolated fragment.

DISCUSSION

Because of large natural anatomic variations of extracted teeth (age, size, and shape), experimental results may significantly vary. Using standardized specimens is of paramount importance and allows minimizing confounding variables and gaining sensitivity in testing. Because the same model of the Cerec database (mandibular first molar, Lee Culp Youth) was used in the Crown Master mode, all restored specimens featured the exact same anatomy and cuspal inclines and were loaded in the same configuration. This unique experimental setup was successful in discerning the performances of the restorative materials tested, yet using a reasonable number of specimens.

Another unique approach used in the present work is the stepped fatigue loading protocol. Based on original studies by Fennis et al[7] and Kuis et al,[16] this test strategy provides a better simulation of the clinical conditions than a static load test. Pilot tests showed that adhesive restorations are known to fail at high load range or when subjected to more than 1,000,000 cycles with moderate loads.[16] The present protocol appears to be the best compromise between available in vitro fatigue testing methods and clinical reality.

The clinical significance of the load range used in this study is further confirmed by studies on the maximal bite forces in human. In the molar region of healthy young adults, bite forces range between 597 N for women and 847 N for men and can reach over 900 N.[17,18] A higher load can be easily achieved when individuals bite on a hard foreign body accidentally found in the bolus during fine food comminution (eg, stone in salad, almond shell in cake) or in case of trauma. It is precisely in this upper range of forces that the present experimental setup was able to reveal the superior fatigue resistance of MZ100 overlays when compared to MKII. In a fatigue study using lower loads to compare the same materials (MKII versus MZ100 full cuspal coverage), Attia et al were not able to reveal such differences.[19] Therefore, it is not advisable, based on these combined results, to state that porcelain materials are contraindicated for overlay-type restorations in endodontically treated molars. On the other hand, it can be recommended to use CAD/CAM-generated composite resin onlays in patients with high bite forces and suspicion of parafunctional habits such as bruxism.

The results of the present study confirm the findings by Brunton et al, who demonstrated the greater compressive strength of composite onlays (1,500 N) compared to ceramic ones (990 N) in a simple load-to-failure test (premolars, no endodontic treatment, no fatigue).[20] It can be concluded that the choice of material might not be critical when considering low to average bite forces but could ultimately influence the outcome of a high-load catastrophic stress. Another characteristic of MZ100 compared to MKII is its higher material wear[21] and lower elastic modulus, which could have contributed to the absorption of intense stresses.

It is also relevant to consider the prognosis of a restored tooth in case of failure. The present study indicates that MZ100 yielded higher strength but also led to failures that were more likely to be repaired (only 25% of fractures below the CEJ) compared to MKII (40% of fractures below the CEJ). This is in agreement with other studies revealing higher rates of unrestorable failures with strong, stiff materials or onlay-type restorations.[7,20] Onlays also tend to exhibit a majority of compressive-type interfacial stresses, which can be assumed to prevent potential debonding. This behavior contrasts with that of inlays, which show a majority of tensile interfacial stresses challenging the adhesive bond.[22]

Another parameter that might influence the failure mode is the quality of the interfacial dentin bond. Low bond strength will favor cohesive failure (bulk fracture) of only the restoration (leaving the remaining tooth substance intact) but will not warrant the long-term success of the restoration.[23,24] Therefore, most clinicians expect to achieve the highest dentin bond strength possible, which will provide higher overall strength of the tooth-restoration system. In the case of indirect bonded restorations, such a goal is achieved through the use of a modified technique in the application of the dentin bonding agent. The so-called immediate dentin sealing used in this study, also referred to as resin coating,[25–27] consists of applying the dentin bonding agent to the freshly cut dentin before making the final impression. This is the first investigation using immediate dentin sealing in a fatigue loading protocol. The efficiency of this bond strategy was demonstrated by the absence of adhesive failures. Immediate dentin sealing generated a stable dentin bond, which did not allow the propagation of ceramic/composite onlay cohesive cracks along the adhesive interface despite the high load pattern. One may question, however, the fact that such strong adhesion also favors cohesive failures within the remaining tooth substance and problematic repairability. Therefore, further studies should investigate the so-called ideal bond strength—strong enough to assure the long-term clinical success of the tooth-restoration system but also weak enough to protect the remaining tooth substance from restoration bulk fracture when exposed to high load patterns.

CONCLUSIONS

Within the limitations of this in vitro fatigue study, it can be concluded that Cerec composite resin MZ100 increased the fatigue resistance of overlay-type restorations in endodontically treated molars when compared to Cerec porcelain Vita MKII. None of the molars restored with MKII withstood all 185,000 loading cycles, and 40% of the fractures ended below the CEJ. With MZ100 the survival rate was 73%, and only 25% of the fractures ended below the CEJ. The efficiency of the bond strategy (immediate dentin sealing) was demonstrated by the absence of adhesive failures. Since both materials withstood the normal range of bite forces simulated in the first part of the fatigue test, it would be premature to state that porcelain materials are contraindicated for overlay-type restorations in endodontically treated molars.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to Vident, Brea, California, for providing MKII blocks; 3M ESPE, St Paul, Minnesota, for MZ100 blocks and Filtek Z100 composite resin; Kerr, Orange, California, for Optibond FL; Patterson, El Segundo, California, for Cerec; Ultradent, South Jordan, Utah, for Ultraetch, Porcelain Etch, and Silane; and Heraeus Kulzer, Armonk, New York, for Palapress.

Special thanks to Don Wiggins and Ramon Delgadillo (University of Southern California machine shop) for the fabrication of the load chamber, Reyes Enciso (Assistant Professor, Craniofacial Sciences and Therapeutics, School of Dentistry, University of Southern California) for guidance with the statistical analysis presented in this study, and Dr Suzanne Wenzlaff (Clinical Assistant Professor, Primary Oral Health Care, School of Dentistry, University of Southern California) for help in revising the English draft.

REFERENCES

1. Papa J, Cain C, Messer HH. Moisture content of vital vs endodontically treated teeth. Endod Dent Traumatol 1994;10:91–93.
2. Sedgley CM, Messer HH. Are endodontically treated teeth more brittle? J Endod 1992;18:332–335.
3. de V Habekost L, Camacho GB, Azevedo EC, Demarco FF. Fracture resistance of thermal cycled and endodontically treated premolars with adhesive restorations. J Prosthet Dent 2007;98:186–192.
4. Edelhoff D, Sorensen JA. Tooth structure removal associated with various preparation designs for anterior teeth. J Prosthet Dent 2002;87:503–509.
5. Edelhoff D, Sorensen JA. Tooth structure removal associated with various preparation designs for posterior teeth. Int J Periodontics Restorative Dent 2002;22:241–249.
6. Pippin DJ, Mixson JM, Soldan-Els AP. Clinical evaluation of restored maxillary incisors: Veneers vs. PFM crowns. J Am Dent Assoc 1995;126:1523–1529.
7. Fennis WM, Kuijs RH, Kreulen CM, Verdonschot N, Creugers NH. Fatigue resistance of teeth restored with cuspal-coverage composite restorations. Int J Prosthodont 2004;17:313–317.
8. Magne P, Dietschi D, Holz J. Esthetic restorations for posterior teeth: Practical and clinical considerations. Int J Periodontics Restorative Dent 1996;16:104–119.
9. Fuzzi M, Rappelli G. Ceramic inlays: Clinical assessment and survival rate. J Adhes Dent 1999;1:71–79.
10. Otto T, De Nisco S. Computer-aided direct ceramic restorations: A 10-year prospective clinical study of Cerec CAD/CAM inlays and onlays. Int J Prosthodont 2002;15:122–128.
11. Sjögren G, Molin M, van Dijken JW. A 10-year prospective evaluation of CAD/CAM-manufactured (Cerec) ceramic inlays cemented with a chemically cured or dual-cured resin composite. Int J Prosthodont 2004;17:241–246.
12. Manhart J, Chen HY, Neuerer P, Scheibenbogen-Fuchsbrunner A, Hickel R. Three-year clinical evaluation of composite and ceramic inlays. Am J Dent 2001;14:95–99.
13. Dietschi D, Spreafico R. Adhesive Metal-Free Restorations. Berlin: Quintessence, 1997.
14. Leinfelder KF. Indirect posterior composite resins. Compend Contin Educ Dent 2005;26:495–503.
15. Peutzfeldt A, Asmussen E. The effect of postcuring on quantity of remaining double bonds, mechanical properties, and in vitro wear of two resin composites. J Dent 2000;28:447–452.
16. Kuijs RH, Fennis WM, Kreulen CM, Roeters FJ, Verdonschot N, Creugers NH. A comparison of fatigue resistance of three materials for cusp-replacing adhesive restorations. J Dent 2006;34:19–25.

17. Waltimo A, Könönen M. A novel bite force recorder and maximal isometric bite force values for healthy young adults. Scand J Dent Res 1993;101:171–175.

18. Waltimo A, Könönen M. Maximal bite force and its association with signs and symptoms of craniomandibular disorders in young Finnish non-patients. Acta Odontol Scand 1995;53:254–258.

19. Attia A, Abdelaziz KM, Freitag S, Kern M. Fracture load of composite resin and feldspathic all-ceramic CAD/CAM crowns. J Prosthet Dent 2006;95:117–123.

20. Brunton PA, Cattell P, Burke FJ, Wilson NH. Fracture resistance of teeth restored with onlays of three contemporary tooth-colored resin-bonded restorative materials. J Prosthet Dent 1999;82:167–171.

21. Kunzelmann KH, Jelen B, Mehl A, Hickel R. Wear evaluation of MZ100 compared to ceramic CAD/CAM materials. Int J Comput Dent 2001;4:171–184.

22. Magne P, Belser UC. Porcelain versus composite inlays/onlays: Effects of mechanical loads on stress distribution, adhesion, and crown flexure. Int J Periodontics Restorative Dent 2003;23:543–555.

23. Aberg CH, van Dijken JW, Olofsson AL. Three-year comparison of fired ceramic inlays cemented with composite resin or glass ionomer cement. Acta Odontol Scand 1994;52:140–149.

24. Gemalmaz D, Ozcan M, Alkumru HN. A clinical evaluation of ceramic inlays bonded with different luting agents. J Adhes Dent 2001;3:273–283.

25. Magne P, Douglas WH. Porcelain veneers: Dentin bonding optimization and biomimetic recovery of the crown. Int J Prosthodont 1999;12:111–121.

26. Magne P, Kim TH, Cascione D, Donovan TE. Immediate dentin sealing improves bond strength of indirect restorations. J Prosthet Dent 2005;94:511–519.

27. Sultana S, Nikaido T, Matin K, Ogata M, Foxton RM, Tagami J. Effect of resin coating on dentin bonding of resin cement in Class II cavities. Dent Mater J 2007;26:506–513.