Influence of overlay restorative materials and load cusps on the fatigue resistance of endodontically treated molars

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

Objectives: To assess the influence of restorative materials and load cusps on the fatigue resistance of endodontically treated molars. **Method and Materials:** Thirty extracted molars received root canal treatment followed by a standardized tooth preparation (3-mm cuspal reduction and immediate dentin sealing). Twenty Cerec 3 overlays (Sirona Dental Systems) were milled in the ceramic Vita MKII block (Vident; groups MKIIGL and MKIIGL-Z, oven-glazed), and 10 restorations were duplicated with a composite resin (Miris 2, Coltène/Whaledent; group M2). The fitting surfaces of the restorations were hydrofluoric acid etched (porcelain only) and silanated. Preparations were airborne-particle abraded and etched. All restorations were luted with preheated Filtek Z100 (3M ESPE) and subjected to cyclic isometric chewing (5 Hz) starting at 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. A stainless steel load sphere was used for groups MKIIGL and M2, while a composite resin load sphere was used in group MKIIGL-Z. All samples were loaded until fracture or to a maximum of 185,000 cycles. Groups were compared using the Kaplan-Meier survival curves (P = .05). **Results:** None of the molars restored with porcelain withstood all 185,000 loading cycles (survival = 0%). The mean fracture load for MKIIGL was 1,060 N and for MKIIGL-Z, 1,280 N. In group M2, the survival rate was 50%. The rate of fracture below the CEJ was 40%, 30%, and 20% for MKIIGL, MKIIGL-Z, and M2, respectively. **Conclusion:** Miris 2 overlays showed higher fatigue resistance than MKII porcelain (P = .01) when loaded with a stainless steel antagonist. *(Quintessence Int 2009;40:729–737)*

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

Reconstruction of endodontically treated teeth has long been a topic for discussion in the dental literature.[1] Endodontically treated posterior teeth do not differ by their moisture content[2,3] but are more brittle than vital posterior teeth because of the structural defect generated during tooth preparation. Adhesively placed restorations with total cuspal coverage (overlays) have been proposed as an alternative to the more traditional and invasive full-coverage crown.[4]

An area that merits further investigation is whether porcelain or composite resin is better as a restorative material for adhesive onlays/ overlays. While porcelain is credited for its esthetics, durability, and biocompatibility, it also presents significant drawbacks. Brittle catastrophic fracture due to accumulation of microstructure damage during mastication and abrasive wear of the antagonistic natural teeth are documented disadvantages of these materials.[5–8] In clinical studies, quantitative fractography has identified crack initiation as the main cause of crown failure.[9,10]

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

[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. Email: magne@usc.edu

These cracks originate at the internal surface of the occlusal region, where the greatest tensile stress concentration accumulates. Therefore, fatigue plays a critical role when considering the clinical performance of these restorations.[9–16]

Indirect bonded porcelain restorations were the material of choice for restoring heavily deteriorated posterior teeth.[17,18] In recent times, composite resins have improved in terms of their mechanical properties.[19,20] New polymerization techniques have also led to their rise in popularity. Modern composite resins are characterized by a filler content exceeding 65% by volume, providing improved fracture toughness.[21] They can also be significantly reinforced by postcure treatment.[20,22] One key property of composite onlays is their low elastic modulus, allowing more absorption of functional stresses through deformation.[5] More recently, dental laboratories have been able to fabricate composite resin overlays using computer-aided design/computer-assisted manufacture (CAD/CAM) technology or through the classic layering technique. It is not known whether the choice of milled versus layered composite resins could influence the longevity of the overlay restoration.

Another parameter that could influence the in vitro fatigue resistance of porcelain restorations is the material used to simulate the antagonistic cusp. In a former study[8] using a stainless steel antagonist, CAD/CAM composite resins showed higher fracture resistance than CAD/CAM porcelain. One reason for that particular finding may have been the high elastic modulus of the load sphere.

The aim of this study was to determine the influence of material selection (oven-glazed porcelain versus layered composite resin), as well as the influence of the material used for the antagonistic cusp (stainless steel versus composite resin) on the in vitro fatigue resistance and failure mode of overlay-type restoration of endodontically treated molars. The null hypothesis stated that there is no difference between glazed porcelain overlays loaded with either steel or composite resin antagonists and layered composite resin overlays loaded with a steel antagonist. Previous data about mechanically polished CAD/CAM overlays loaded with a steel antagonist[8] by the same research group were included for comparison.

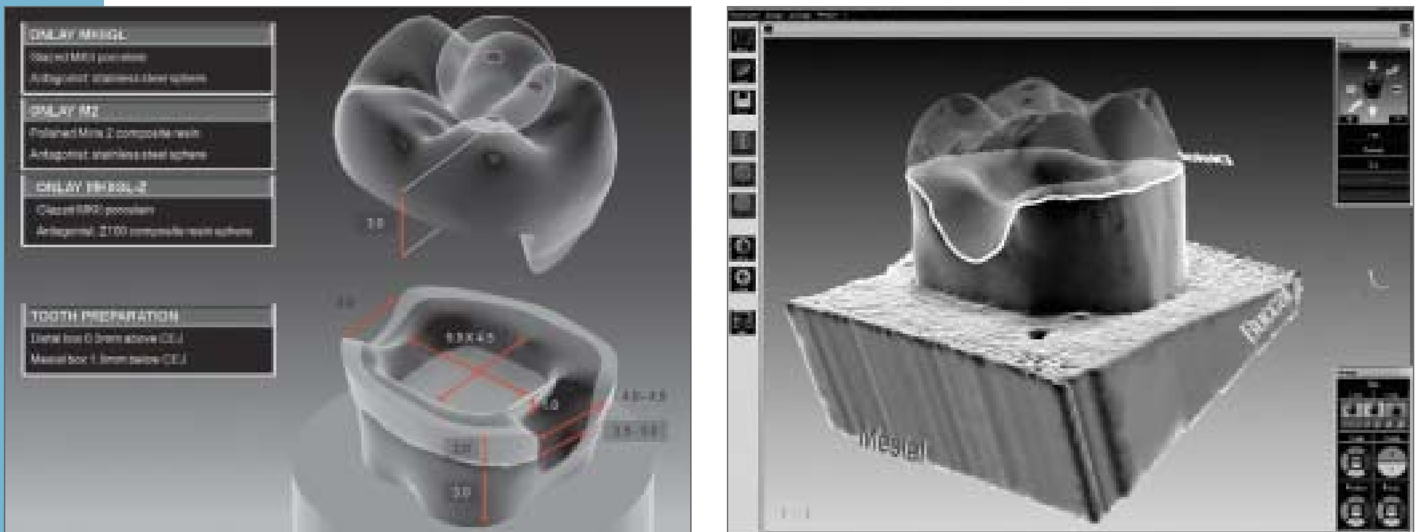
METHOD AND MATERIALS

Thirty freshly extracted, sound human molars stored in a solution saturated with thymol were collected upon approval from the University of Southern California Institutional Review Board. Acrylic resin (Palapress, Heraeus Kulzer) was used to mount each tooth in a special positioning device. The root was embedded up to 3.0 mm below the cementoenamel junction (CEJ).

Specimen preparation

All specimens were prepared in a standardized way (Fig 1a). First, flat midcoronal dentin surfaces were created with a model trimmer. Upon completion of the previous step, the surfaces were evaluated for the presence of any remaining occlusal enamel, which was removed by additional trimming. Second, a standard access opening was prepared to simulate root canal treatment in each tooth. Following shaping with the stepback technique (maximum file size 35 to 40), the root canals were filled with a thermoplasticized gutta-percha delivery system (Obtura II, Obtura/Spartan). Third, mesial and distal rounded box forms were prepared to a depth of 1.5 mm below and 0.5 mm above the CEJ, respectively, with the aid of a coarse round diamond bur (801-023, Brasseler). Finally, a 2.0- to 3.0-mm–thick glass-ionomer barrier (Ketac Molar, 3M ESPE) was applied to the pulp chamber.

A 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). This immediate dentin sealing was followed by the application of an air-blocking barrier (K-Y Jelly, Personal Products) and 10 seconds of additional light exposure (light unit Allegro, Den-Mat) to polymerize the oxygen-inhibition layer. Excess adhesive resin was carefully removed from all enamel margins with the same coarse round diamond at 1,500 rpm.



Figs 1a and 1b Preparation and restoration design. *(a)* Standard onlay and tooth preparation and corresponding measurements and dimensions (mm). Mesiolingual view with embedding resin base and restored endodontic access channel (glass-ionomer base). *(b)* Final design steps in the Cerec software.

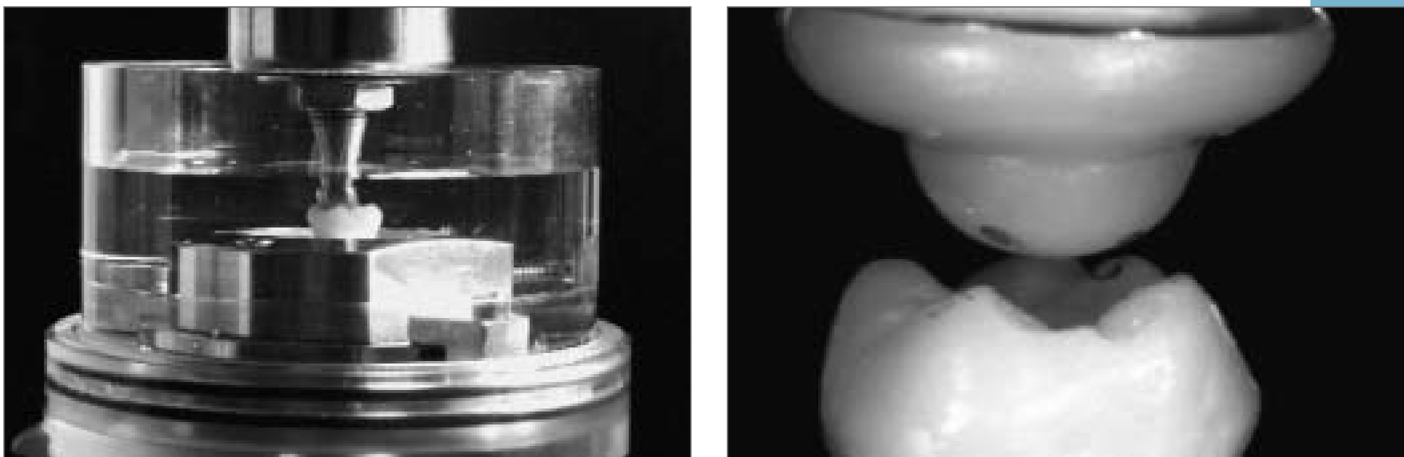
Restoration design and manufacturing

Thirty standardized overlays were generated with the Cerec 3 CAD/CAM system (Cerec software version 3.03., Sirona Dental Systems) (Fig 1b). All specimens were made with similar occlusal anatomy (mandibular first molar, Lee Culp Youth database, Crown Master Mode) with cusp tips parallel to the preparation surfaces (3.0-mm distance) and central grooves aligned with the mesial and distal boxes. All restorations were milled in the ceramic Vita MKII blocks (Vident) using the Endo mode with the sprue at the distal surface and then polished mechanically using a commercial polishing kit (Dialite, Ultra Polishers, Brasseler). For groups MKIIGL and MKIIGL-Z (n = 10 each), the surface polishing was completed by oven glazing without vacuum with 1 minute holding at 950°C with Akzent Spray Glaze (Vident) according to the manufacturer's instructions. For group M2 (n = 10), the original Cerec overlays were positioned on the tooth and duplicated using a translucent silicone index (Elite Transparent, Zhermack) and a light-polymerized restorative composite resin (Miris 2, Coltène/Whaledent). For the latter process, the composite was placed in the index and pressed over the isolated tooth preparation (isolation medium Rubbersep, Kerr) and then polymerized for 20 seconds per surface. The M2 onlay was then separated from the tooth and immediately placed in a photothermal postcure oven for 5 minutes at 100°C (D.I. 500, Coltène/Whaledent).

Adhesive placement of restoration

Surface conditioning of milled restorations (groups MKIIGL/MKIIGL-Z) included airborne-particle abrasion with 50-µm aluminum oxide at 30 psi, followed by etching with 9% hydrofluoric acid (Porcelain Etch, Ultradent) for 90 seconds and rinsing with water for 20 seconds. Postetching cleaning was performed using 37.5% phosphoric acid (Ultraetch, Ultradent) with a gentle brushing motion for 1 minute, followed by rinsing with water for 20 seconds. After final cleaning by immersion in distilled water in an ultrasonic bath for 2.5 minutes and oil-free air drying, fitting surfaces were silanated (Silane, Ultradent) and dried at 100°C for 1 minute. The surface conditioning used for restorations in group M2 differed in only 1 of the steps—etching with hydrofluoric acid was omitted.

For all groups tested, tooth preparations were abraded with 50-µm aluminum oxide airborne particles at 30 psi and etched for 30 seconds with 37.5% phosphoric acid, rinsed with water, and dried. Both fitting surfaces



Figs 2a and 2b Load apparatus. *(a)* Submerged specimen in load chamber under isometric cylic loading with stainless steel antagonist. *(b)* Detailed view of specimen with composite resin load sphere during control of occlusal contact before testing.

(restoration and tooth) were coated with adhesive resin (OptiBond FL, bottle 2; Kerr). The resin was not polymerized until the application of the luting material (Z100 [3M ESPE], preheated at 54°C for 5 minutes in Calset [Addent]) to the tooth and final insertion of the restoration. After careful removal of all uncured excess composite resin, each surface was light polymerized for 60 seconds (20 seconds per surface, for 3 times with Allegro [Den-Mat]). All margins were covered with an air-blocking barrier (K-Y Jelly) for the final polymerization cycle.

Fatigue testing

Prepared specimens were stored in distilled water at ambient temperature for at least 24 hours following adhesive restoration placement. An artificial mouth using closed-loop servohydraulics (Mini Bionix II, MTS Systems) was used for simulating masticatory forces. The chewing cycle was replicated by isometric contraction (load control) applied through a stainless steel sphere with a diameter of 7 mm for MKIIGL and M2 groups (Fig 2a), while for MKIIGL-Z group a composite resin sphere of the same diameter (fabricated with Filtek Z100) was used (Fig 2b). As all specimens had standardized occlusal anatomy, they could be reproducibly positioned in the same location with the sphere contacting the mesiobuccal, mesiolingual, and distobuccal cusps (tripod contact).

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. All tested samples were loaded until fracture or to a maximum of 185,000 cycles. The number of endured cycles and failure modes were recorded. An agreement between 2 examiners allowed distinction between fractures above and below the CEJ and between cohesive and adhesive fractures.

Statistical analysis

The fatigue resistance of the 3 groups was compared using Kaplan-Meier survival curves (MedCalc, MedCalc Software). 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. This allowed the calculation of survival probability at each interval. The influence of the restorative material on the fracture strength (load step at which failure occurred) was analyzed by 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).

Additional computations were made by including experimental groups of a former

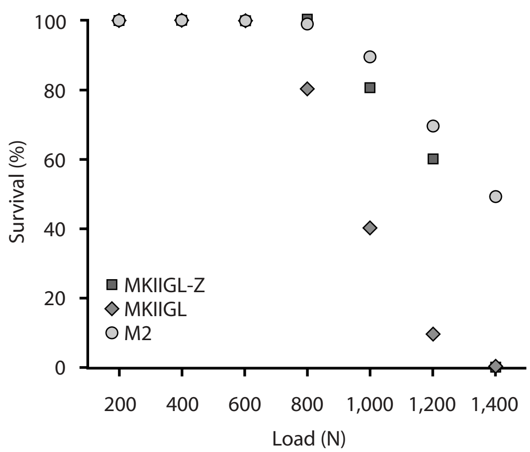


Table 1	Pairwise post hoc comparisons with the log-rank test				
	MKII	MZ100	MKIIGL	M2	MKIIGL-Z
MKII		.0001*	.2615	.0011*	.0168
MZ100			.0001*	.1343	.0001*
MKIIGL				.0016*†	.0140†
M2					.0542
MKIIGL-Z					

*Indicates significant differences between all materials, including groups from previous study[8] (MKII: polished MKII porcelain with stainless steel antagonist; MZ100: polished MZ100 composite resin with stainless steel antagonist) with a *P* value of .005 (Bonferroni-corrected for 10 comparisons).
†Indicates significant differences between materials tested in this study (MKIIGL, M2, and MKIIGL-Z) with a *P* value of .016 (Bonferroni-corrected for 3 comparisons).

Fig 3 Survival scatter plot of specimens at each load stage (n = 10). (M2) Polished Miris 2 composite resin with stainless steel antagonist; (MKIIGL) glazed MKII porcelain with stainless steel antagonist; (MKIIGL-Z) glazed MKII porcelain with composite resin antagonist.

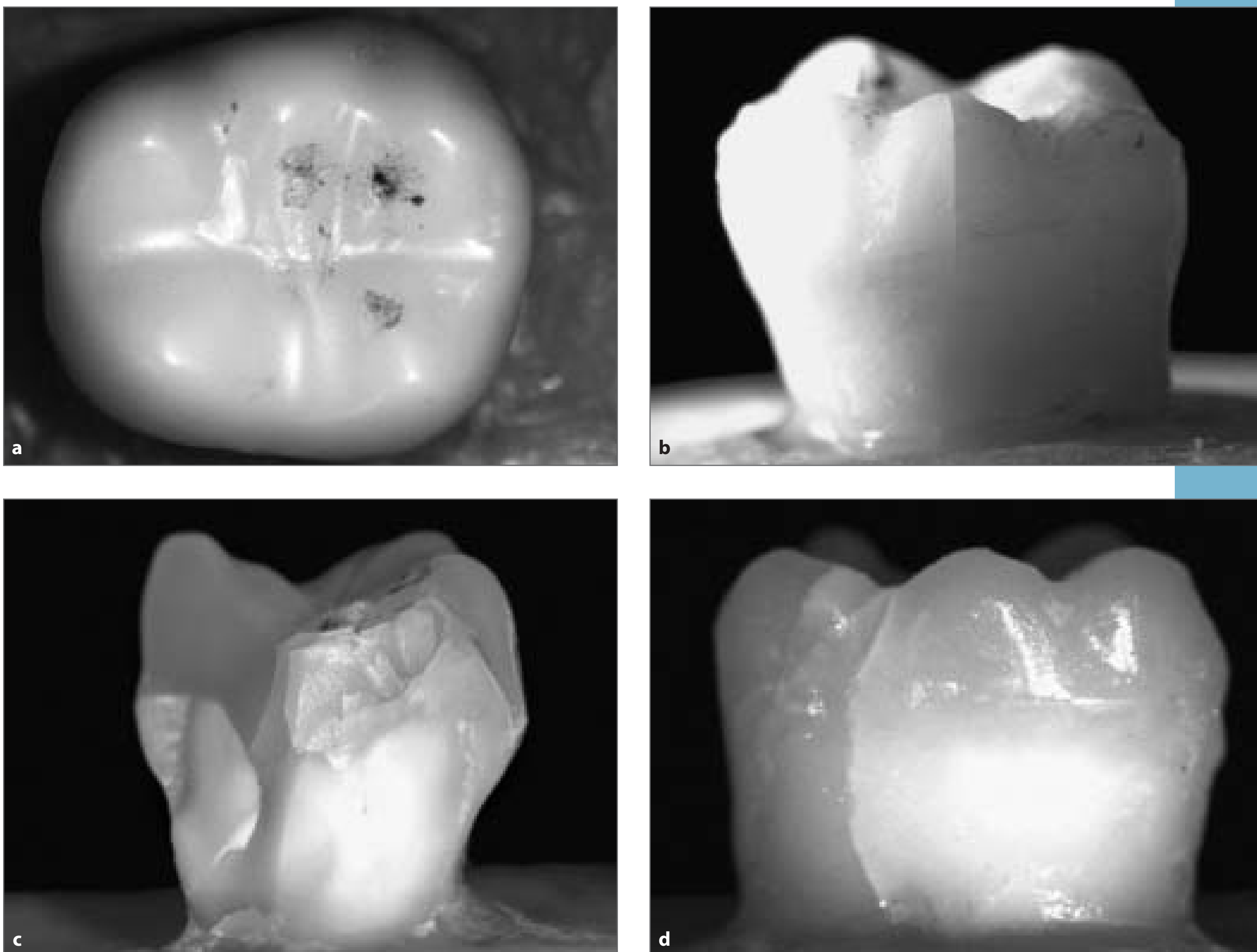
study about mechanically polished CAD/CAM overlays loaded with a steel antagonist.[8] The study was conducted by the same research group and generated in strictly identical conditions (operators, specimen preparation, and experimental setup). MZ100 designates milled composite resin overlays (Paradigm MZ100, 3M ESPE), and MKII designates milled porcelain overlays (Vita MKII, Vident). Kaplan-Meier survival curves were used to compare the fatigue resistance of the 5 groups (differences in fracture strength analyzed by the log-rank test at a significance level of .05). Pairwise post hoc comparisons at a significance level of (Bonferroni correction for 10 comparisons) were used to localize the differences at a significance level of .005.

RESULTS

The restored molars of group MKIIGL fractured at a mean load of 1,060 N (100,616 cycles), and none of them withstood all 185,000 loading cycles (survival = 0%). In group MKIIGL-Z, the mean fracture load was 1,280 N (151,109 cycles) and survival rate 0%. In group M2, the survival rate was 50%. Kaplan-Meier curves (Fig 3) showed significant differences in survival between the groups (P = .01). Post hoc tests (Table 1) revealed the higher fatigue resistance of MKII loaded with the composite resin antagonist compared to stainless steel (P = .014) and the superiority of M2 compared to MKIIGL (P < .002). In group MKIIGL, 40% (4/10) of the specimens fractured below the CEJ; in group MKIIGL-Z 30% did (3/10) and in group M2 only 20% (2/10).

Different failure modes are presented in Figs 4a to 4d and Table 2. In all failed specimens, failure was cohesive in the porcelain or composite resin restorative and remained cohesive when cracks propagated into the tooth, leaving the interfacial bond intact.

Previous results about mechanically polished overlays are presented in Fig 5. From the comparisons in Table 1, it appears that oven glazing does not improve the overall fatigue strength of porcelain onlays (MKII and MKIIGL not different; P = .26); neither does loading with a composite resin antagonist (MKII and MKIIGL-Z not different; P = .017). The milled composite resin performed similarly to the layered composite resin restorations (MZ100 and M2 not different; P = .13), and both materials were more fatigue resistant than porcelain, either mechanically polished or glazed (stainless steel antagonist). In the MKII group, 40% of the fractures terminated below the CEJ. However, in the MZ100 group, only 25% of the fractures terminated below the CEJ.



Figs 4a to 4d Examples of specimens. *(a)* Intact specimen in group M2. *(b)* Fracture above the CEJ in group M2; crack without fragment. *(c)* Fracture below the CEJ in group MKIIGL (*a to c,* original magnification × 1.4). *(d)* Fracture below the CEJ without fragment in group MKIIGL-Z (original magnification × 1.6).

Table 2 Failure types and numbers (n = 10 for each group)

Group	Intact specimen	Fracture above CEJ		Fracture below CEJ	
		Crack*	Fragment	Crack*	Fragment
MKIIGL (n = 10)	0	5	1	1	3
MKIIGL-Z (n = 10)	0	7	0	2	1
M2 (n = 10)	5	2	1	1	1

*Implies fracture without isolated fragment.

DISCUSSION

The null hypothesis, which states that there would be no difference between glazed porcelain overlays loaded with either steel or composite resin antagonists and layered composite resin overlays loaded with a steel antagonist, can be rejected. Within the limitations of this simulated-fatigue study, Miris 2 composite resin increased the fatigue resistance of overlay-type restorations in endodontically treated molars when compared to oven-glazed Cerec porcelain Vita MKII. The simulated cusp in composite resin also increased the fatigue resistance of MKII restorations compared to the stainless steel cusp.

In vitro fatigue characteristics of dental restoratives are usually evaluated by subjecting a beam of material to cyclic 3- or 4-point flexural loading, in which contact and flexure represent 2 modes of fatigue.[16] The main limitation of testing an isolated beam of restorative material is its lack of clinical relevance. In the present study, because of the standard occlusal anatomy, 3-point contact was achieved in a highly reproducible position and facilitated subjecting the specimen to a variety of fatigue modes including contact, flexure, water sorption, and aging (wet conditions). The strength of this protocol is in the ability to simulate a fully functional restored natural tooth. This experimental setup had additional advantages, which include the minimization of confounding variables and gain of sensitivity in testing. The application of a standardized occlusal surface, cuspal inclines, and load configuration eliminated anatomic variations present in natural teeth. Using a reasonable number of specimens, this study successfully identified the different performance of the restorative materials tested. The stepped load protocol is another unique element in this approach. Compared to a static load test, this test strategy provides a better simulation of the clinical conditions. It also appears to be the best compromise between available in vitro fatigue testing methods and clinical reality, because adhesive restorations are known to fail at high load ranges or when subjected to more than 1 million cycles with moderate loads.[13,15]

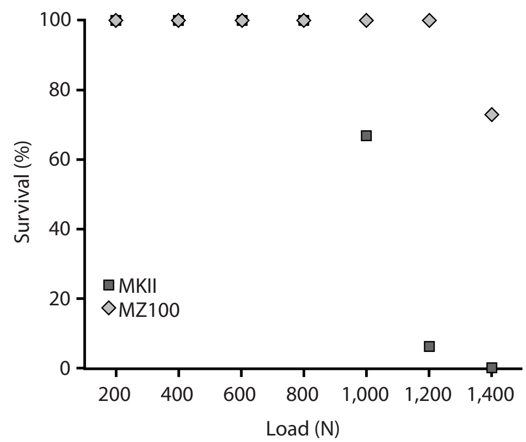


Fig 5 Survival scatter plot of specimens at each load stage (Magne and Knezevic[8]). (MKII) Polished MKII porcelain with stainless steel antagonist; (MZ100) polished MZ100 composite resin with stainless steel antagonist.

In a previous study by the same operators in strictly identical conditions,[8] stainless steel was used as a loading material for both milled composite resin (MZ100) and porcelain (MKII) onlays. All specimens in the previous study were mechanically polished. The results clearly revealed the superior performance of machined composite resin onlays (see Fig 5). Additional computations that included experimental groups in the current study allowed exploration of the possible effects of material selection (porcelain versus milled composite resin versus layered composite resin) and surface finishing (mechanical polishing versus oven glazing). It appeared that oven glazing did not improve the overall strength of porcelain onlays, nor did loading with a composite resin antagonist. Surface glazing, however, is still recommended for Cerec all-ceramic crowns[12] because the glazed surface is considered to be stronger and more cleansable. The glaze material has a different coefficient of thermal expansion than the ceramic. It covers the ceramic surface with an overall tensile stress during the cooling process and probably inhibits crack initiation. It may be postulated that the slightly thicker surface that results from glazing may also increase the fracture resistance of crowns and lead to better mechanical properties.

The prognosis of the restored tooth in case of clinical failure is also a relevant parameter to consider. Both composite resin restorations (MZ100[8] and M2) yielded higher fatigue strengths, but also led to more failures that were repairable (only 20% of fractures below the CEJ) compared to porcelain restorations. MKII, either mechanically polished[8] or glazed, led to more catastrophic failures (40% of fractures below the CEJ), leaving an unrestorable tooth. Porcelain is a brittle material that cannot absorb a large amount of deformation energy and shows only moderate resistance to localized shear and tensile stresses. With a high modulus of elasticity, brittle fractures can be observed after fatigue loading, which is also confirmed in this study (see Fig 4c). Higher elastic modulus does not necessarily result in a restoration with a higher load resistance.[15] Brunton et al[5] suggested that structural failure of teeth restored with more rigid material is more likely to generate significant fractures of the underlying remaining tooth structure and the restoration. Composite resin materials are more elastic and therefore able to absorb more stress by deformation during mastication.[6] Dental composite resins' fatigue behavior is also characterized by a well-defined fatigue limit, above which the composite material fails quickly, and below which there is long-term survival.[11]

The additional data presented in Table 1 confirms the superior fatigue strength of composite resin materials (either milled or layered) over porcelain (MZ100 and M2 not different and superior to MKII and MKIIGL). It is remarkable that 73% of MZ100 overlays[8] and 50% of M2 overlays survived the same test, with a maximum load of 1,400 N and 185,000 cycles. This also reveals that a composite similar to M2, which is marketed for direct applications, is also an ideal material for indirect use. The latter takes advantage of the photothermal postpolymerization to improve its degree of conversion, mechanical properties, and wear resistance.[20,22] While composite resin restorations are still expected to wear more than porcelain, they also tend to preserve more of the antagonistic enamel.[6] This differential wear of composite resin and porcelain overlays was clearly observed during the present fatigue test. Understanding the wear process would require additional investigation, which is beyond the scope of this study.

The results of this study require careful clinical interpretation. The differences between composite resins and porcelain were revealed at a minimum load of 800 N. The clinical relevance of the load protocol may be justified considering that higher load could be achieved during accidental biting of a hard foreign body found in the bolus during fine food comminution or in case of trauma. However, all materials tested in this experiment withstood loads higher than is usually encountered in clinical situations,[23,24] therefore indicating that both materials tested can be used in cusp-replacing restorations of endodontically treated teeth. Furthermore, a new concept of adhesively luted restoration using immediate dentin sealing and a preheated composite resin restorative as a luting agent should improve marginal integrity as well as fracture resistance of the restored tooth and material used for restoration.[25–27]

CONCLUSION

Within the limitations of this in vitro fatigue study, Miris 2 composite resin increased the fatigue resistance of overlay-type restorations in endodontically treated molars when compared to oven-glazed Cerec porcelain Vita MKII. None of the molars restored with MKII withstood all 185,000 loading cycles (loaded with either a stainless steel or composite resin antagonist), and 30% to 40% of the fractures terminated below the CEJ. With Miris 2, the survival rate was 50%, and only 20% of the specimens fractured below the CEJ. It could be premature to conclude that porcelain materials are contraindicated for overlay-type restorations in endodontically treated molars because both materials withstood the normal range of bite forces simulated in the first part of the fatigue test.

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