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Thickness of CAD–CAM composite resin overlays influences fatigue resistance of endodontically treated premolars

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ABSTRACT

Objectives. Evaluate the influence of composite resin CAD–CAM restoration thickness on the in vitro fatigue resistance and failure mode of overlay-type restoration in endodontically treated premolars.

Methods. Thirty extracted premolars received root canal treatment followed by a standardized tooth preparation (1.5-, 2.5- or 3.5-mm cusp reduction, proximal gingival margins located 1.5 mm below the CEJ, glass-ionomer base and immediately sealed dentin with Optibond FL). Restorations were milled using Cerec3 and FiltekMZ100 composite blocks. The intaglio surfaces of the overlays were sandblasted and silanated. Tooth preparations were sandblasted and etched before insertion of the restoration. All restorations were luted with Optibond FL and preheated FiltekZ100. A closed-loop servohydraulic unit was used for simulating cyclic isometric chewing at 5 Hz, starting with a load of 200 N (5000 cycles), followed by stages of 400, 600, 800, 1000, 1200 and 1400 N at a maximum of 30,000 cycles each. All samples were loaded until fracture or to a maximum of 185,000 cycles. Groups were compared using the Kaplan–Meier survival curves.

Results. None of the restored premolars with the 1.5-mm cusp overlap restoration withstood all 185,000 loading cycles. With 2.5- and 3.5-mm cusp overlap, the survival rate was 30% and 40%, respectively. The rate of fracture below the CEJ was 60%, 60% and 30% for 1.5, 2.5 and 3.5 mm of cusp overlap, respectively. Survival of restored premolars with 2.5- and 3.5-mm cusp coverage was not significantly different ($p = .23$).

Significance. Thick FiltekMZ100 composite resin onlays showed higher fatigue resistance than thin ones and may be associated with fractures that are less subgingival.

1. Introduction

Endodontically treated posterior teeth present with specific challenges for the restorative dentist and the prosthodontist because of their more brittle behavior when compared to vital teeth. This difference is not explained by their moisture content but rather the structural defect generated during tooth preparation [1,2]. The clinical diagnosis generally requires extracoronal strengthening by cuspal coverage. Traditionally, full coverage cast restorations have been used, even though adhesively placed restorations with total cuspal coverage (overlays) have been proposed as a more conservative alternative [3]. The significant advantage of adhesive restorations is their ability to mimic the natural behavior

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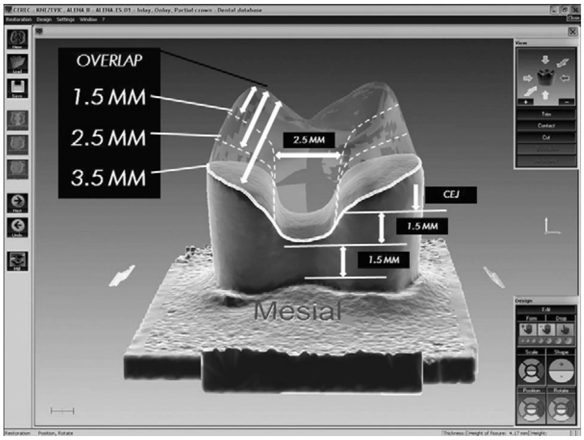

Fig. 1 – Preparation and restoration design for the three experimental groups.

of enamel and dentin (biomimetic principle) and simultaneously reduce the need for root canal treatment (RCT) and unreasonable destruction of remaining tooth substance [3–5]. As margins of adhesive restorations are not required to be placed subgingivally, they are associated with less gingival inflammation and secondary caries [6]. Teeth (with or without RCTs) restored with adhesive onlay restorations demonstrated superior fatigue resistance when composite resin restorations were used instead of porcelain [7–9]. Three-millimeter thick resin overlays [9], either generated by CAD/CAM or hand-layered, also demonstrated a reduced risk of subgingival catastrophic failure. An area which requires further investigation is whether the amount of cuspal coverage might influence the performance of the tooth-restoration complex. The usual cuspal reduction varies between 1.5 and 2.0 mm [10–12] but limited scientific evidence is available to support this recommendation.

Therefore, the aim of this study is to determine the influence of material thickness on the in vitro fatigue resistance and failure mode of overlay-type restoration of endodontically treated premolars. The null hypothesis is that there is no difference between thin and thick CAD/CAM composite resin overlays.

2. Materials and methods

Upon approval from the University of Southern California Institutional Review Board, 30 freshly extracted, sound human maxillary premolars were collected and stored in a solution saturated with thymol. Each tooth was mounted in a special positioning device using acrylic resin (Palapress, Haereus Kulzer, Armonk, NY, USA) embedding the root up to 3.0 mm below the cementoenamel junction (CEJ).

2.1. *Specimen preparation*

First, all specimens were prepared in a standardized way (Fig. 1), starting with occlusal reduction generating either 1.5-, 2.5- or 3.5-mm clearance for the overlay. This was followed by a 2.5-mm wide mesio-occluso-distal slot preparation with rounded internal line angles and proximal margins 1.5 mm below the cementoenamel junction. Second, a standard access opening was prepared to simulate root canal treatment. Following shaping with the stepback technique (maximum file size 35–40), the root canals were filled with a thermoplasticized gutta percha delivery system (ObturaII, Obtura/Spartan, Fenton, MO, USA). Third, a base was applied to the pulp chamber in the form of a 2.0–3.0-mm thick glass-ionomer barrier (Ketac Molar, 3M-ESPE, St. Paul, MN, USA). A coarse round diamond bur was used at 1500 rpm to refresh the dentin surface before the application of a 4th generation etch-and-rinse dentin bonding agent (Optibond FL, Kerr, Orange, CA, USA). This immediate dentin sealing was followed by the application of an air-blocking barrier (K-Y Jelly, Personal Products Company, Skillman, NJ, USA) and 10 s of additional light exposure (light unit Allegro, Den-Mat, Santa Maria, CA, USA) to polymerize the oxygen-inhibition layer. Excess adhesive resin was carefully removed from all enamel margins with a coarse round diamond at 1500 rpm.

2.2. *Restoration design and manufacturing*

Standardized overlays were generated with the Cerec3 CAD/CAM system (Cerec software v. 3.03, Sirona Dental Systems GmbH, Bensheim, Germany). All specimens were fitted with the anatomy of a first maxillary premolar (Lee Culp Youth database, Crown Master Mode) with cusp tips parallel to the preparation surface and the central groove aligned with the mesio-occluso-distal slot. All restorations were milled using the composite resin Paradigm MZ100 blocks (3M-ESPE, St. Paul, MN, USA) using the Endo mode with the sprue located at the distal surface, then polished mechanically using a commercial polishing kit (Dialite, Ultra Polishers; Brasseler, Savannah, GA, USA).

2.3. *Adhesive placement of restoration*

Surface conditioning of milled restorations included airborne-particle abrasion with 50-μm aluminum oxide at 30 psi, followed by cleaning using 37.5% phosphoric acid (Ultraetch, Ultradent, South Jordan, UT, USA) with a gentle brushing motion for 1 min and rinsing with water for 20 s. After final cleaning by immersion in distilled water kept in an ultrasonic bath for 2.5 min followed by oil-free air-drying, intaglio surfaces were silanated (Silane, Ultradent, South Jordan, UT, USA) and dried for 5 min.

Tooth preparations were treated by airborne-particle abrasion with 50-μm aluminum oxide at 30 psi and 30 s etching with 37.5% phosphoric acid. They were rinsed with water and dried. Both intaglio surfaces (restoration and tooth) were coated with adhesive resin (Optibond FL, bottle 2; Kerr, Orange CA, USA) left unpolymerized until the application of the luting material. The composite resin luting materials (Z100; 3M-ESPE, St. Paul, MN, USA) was preheated for 5 min (Calset; Addent, Danbury, CT, USA), applied onto the prepared tooth surface and the restoration was inserted. After careful removal of all excesses of uncured composite resin, each surface was light-polymerized for 60 s (Allegro; Den-Mat, Santa Maria, CA, USA). All margins were covered with an air-blocking barrier for the final polymerization cycle.

Fig. 2 – **Submerged specimen (2.5-mm overlap) in load chamber under isometric cyclic loading with stainless steel antagonist.**

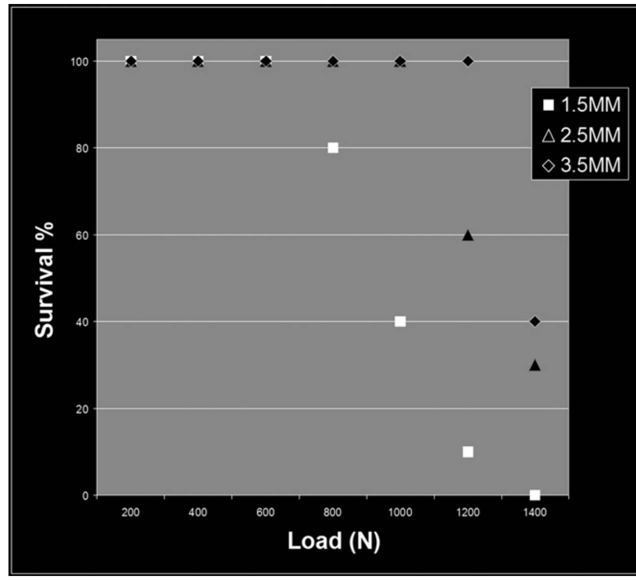

Fig. 3 – Survival scatter plot of specimens at each load stage ($n = 10$).

2.4. Fatigue testing

Prepared specimens were stored in distilled water at ambient temperature for at least 24 h following adhesive restoration placement. Restored teeth were tested according to a published fatigue loading protocol [8,9,15,16]. An artificial chewing device actuated by closed-loop servohydraulics (Mini Bionix II; MTS Systems, Eden Prairie, MN, USA) was used for simulating masticatory forces. The chewing cycle was replicated by an isometric contraction (load control) applied through a stainless steel cylinder with a diameter of 6 mm (Fig. 2). Cyclic load was applied at a frequency of 5 Hz, starting with a load of 200 N for 5000 cycles (preconditioning phase of the experiment), followed by stages of 400, 600, 800, 1000, 1200 and 1400 N at a maximum of 30,000 cycles each. All samples tested were loaded until fracture or to a maximum of 185,000 cycles. The number of endured cycles and failure mode were recorded. A distinction was made between fractures above or below the CEJ, with or without fragment, following a two-examiner agreement.

2.5. Statistical analysis

The fatigue resistance of the three 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 that interval were counted, allowing the calculation of survival probability at each interval. The influence of the restorative material thickness on the fracture strength (load step at which failure occurred) was analyzed using the Logrank 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 three comparisons).

3. Results

The restored premolars with 1.5-mm overlays fractured at an average load of 1060 N (114,478 cycles) and none of them withstood all 185,000 loading cycles (survival = 0%). With thicknesses of 2.5- and 3.5-mm thickness, the survival rate was 30% and 40% respectively. The Kaplan–Meier curves (Fig. 3) showed significant differences in survival between groups ($p < .01$). The failure modes are listed in Table 1. Post hoc tests revealed the higher fatigue resistance of 2.5- and 3.5-mm cuspal overlap compared to the 1.5 mm group ($p = .002$ and .001, respectively) but no differences between 2.5 and 3.5 mm was found ($p = .23$). Fractures with fragments below the CEJ (Fig. 4) were observed in 60% of all specimens in the groups with 1.5- and 2.5-mm occlusal coverage and 30% of all specimens in the group with 3.5-mm occlusal coverage. In all failed specimens, failures occurred cohesively through the restorative material and remained cohesive when cracks propagated into the tooth, leaving the interfacial bond intact.

4. Discussion

The null hypothesis which states that there would be no difference between thin and thick CAD/CAM composite resin overlays can be rejected. Within the limitations of this simulated-fatigue study, 2.5- and 3.5-mm thick restorations increased the fatigue resistance of endodontically treated premolars when compared to 1.5-mm overlays.

Table 1 – Failure types and numbers (crack implies fracture without isolated fragment).

Group	Intact specimen	Fracture above CEJ		Fracture below CEJ	
		Crack	Fragment	Crack	Fragment
1.5 mm ($n = 10$)	0	2	2	0	6
2.5 mm ($n = 10$)	3	1	0	2	4
3.5 mm ($n = 10$)	4	3	0	1	2

NB. No adhesive failure observed.

The present experimental set-up does not allow multiple sample testing and each specimen is loaded over the course of 1 day. This testing method is relatively time-consuming but has the advantage of minimizing confounding variables. Closed-loop servohydraulics is extremely accurate and versatile and can allow a physiologic representation of mastication [13]. The load cell provides constant feedback to the controller (the "brain" of the system). The signal is analyzed and used to correct loading parameters in order to maintain the ideal sine function of the load despite the differential wear at the surface of the material. Careful tooth selection, systematic loading because of standardized occlusal anatomy and predictable two-contact loading minimized the confounding variables. Other systems for in vitro simulation of mastication are more productive by allowing multiple sample testing. Instead of servohydraulics, they use springs, weights, electromechanical or electromagnetic actuators [14], which is usually at the cost of versatility and control of the load application profile. Fennis et al. found that adhesive restorations only failed after applying heavy loads or after more than 1,000,000 cycles under moderate loads [15,16]. Hence, the stepped load protocol applied in this study constitutes an adequate compromise between the classic load-to-failure test and the time-consuming low-load/high-cycle fatigue tests. While the clinical relevance of the load-to-failure approach is questionable, the time-consuming aspect of the true fatigue tests is a significant limitation.

In recent times, CAD/CAM systems have invaded the market. The Cerec system [17] is the oldest with more than 20 years of clinical service and numerous long-term clinical studies showing excellent longevity. The survival rate of Cerec restorations has been favorably compared to gold restorations [18–21]. This data is principally based on the use of early porcelain milling blocks. In vitro simulation demonstrated that more recent composite blocks [22] have an even greater potential and may fail in a safer way, limiting the risk of cuspal fracture below the CEJ when compared to porcelain onlays [8,9]. Composite resin blocks present the added advantage of conservation of tooth structure. Their ability to be processed in thin layers [23] allows substitution for indirect gold restorations.

Fig. 4 – Example of failed specimen (1.5-mm overlap) with fracture below CEJ (restoration and tooth).

The results of this study require careful interpretation. The earliest failures in this set-up occurred at a minimum load of 800 N with the 1.5-mm thin overlays. It can be hypothesized that those higher load ranges are achieved only during accidental biting of hard foreign bodies found in the bolus during fine food comminution or in case of trauma. All material thicknesses tested in this experiment withstood loads higher than is usually encountered in clinical situations [24,25], indicating that both thin and thick composite resin overlays can be used in cusp-replacing restorations of endodontically treated teeth. In other words, the data presented in this study are not contraindicating the use of 1.5-mm thick overlays, but rather confirming the possibility of using thicker overlays for severely destroyed/worn down teeth or in patients with high load requirements.

The absence of adhesive failure in the present study also confirms that a preheated light-polymerized composite resin restorative material can be used as a luting agent [3,26,27] even for thick onlays [8,9]. This type of luting should improve marginal integrity as well as fracture resistance of the tooth and restorative material.

5. Conclusion

Within the limitations of this in vitro fatigue study, it can be concluded that thick CAD–CAM composite resin overlays increased the fatigue resistance of endodontically treated premolars when compared to thin ones. None of the restored premolars with the thin 1.5-mm cusp overlap restoration withstood all 185,000 loading cycles and 60% of the fractures ended below the CEJ. With the thicker overlays, survival rates were 30% and 40%, respectively, and only 30% of all specimens fractured below the CEJ when using a 3.5-mm cusp overlap. Both thick and thin overlays withstood the normal range of bite forces simulated in the first part of the fatigue test.

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