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Risk of onlay fracture during pre-cementation functional occlusal tapping☆

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ABSTRACT

Objective. To evaluate *in vitro* the pre-cementation resistance of CAD/CAM onlays subjected to functional occlusal tapping.

Methods. An extracted tooth model (molar and premolar) with simulated bone and periodontal ligament was used to make a mesio-occlusal onlay preparation (two mesial cusps covered). Immediate dentin sealing was applied to the prepared tooth. The corresponding onlays were fabricated with Cerec either using composite resin (Paradigm MZ100) or ceramic (e.max CAD and Mark II) ($n = 14$). An elevated marginal ridge was designed with the intention of generating hyper-occlusion. Pre-cementation occlusal tapping was simulated using closed-loop servo-hydraulics at 2 Hz, starting with a load of 40 N, followed by 80, 120, 160, 200, 240 and 280 N (10 cycles each). All samples were loaded until fracture or to a maximum of 70 cycles. Groups were compared using the life table survival analysis ($p = .016$, Bonferroni method).

Results. Survival probability was MZ100 > e.max CAD > Mark II. The restorations made from e.max CAD and Mark II failed at an average load of 157 N and 123 N, respectively with no specimen withstanding all 70 load cycles (survival 0%); with MZ100 the survival rate was 36%.

Significance. Material selection has a significant effect on the risk of CAD/CAM onlay fracture during pre-cementation functional occlusal tapping with composite resin onlays showing the minimum risk compared to ceramic ones.

1. Introduction

Bonded restorations are undoubtedly the most conservative and biomimetic option allowing the minimum loss of sound structure when compared to conventional procedures, namely amalgam and crowns [1]. Standard fixed prosthodontics procedures include testing the occlusion of the restoration before cementation. Such a step is usually not recommended for partial indirect bonded restorations (inlays, onlays and veneers)[2]. The main reason is the vulnerability of these brittle restorations prior to cementation. They require meticulous tooth preparation (due to the more complex geometry with multiple inner angles and walls) and delivery sessions, requir-

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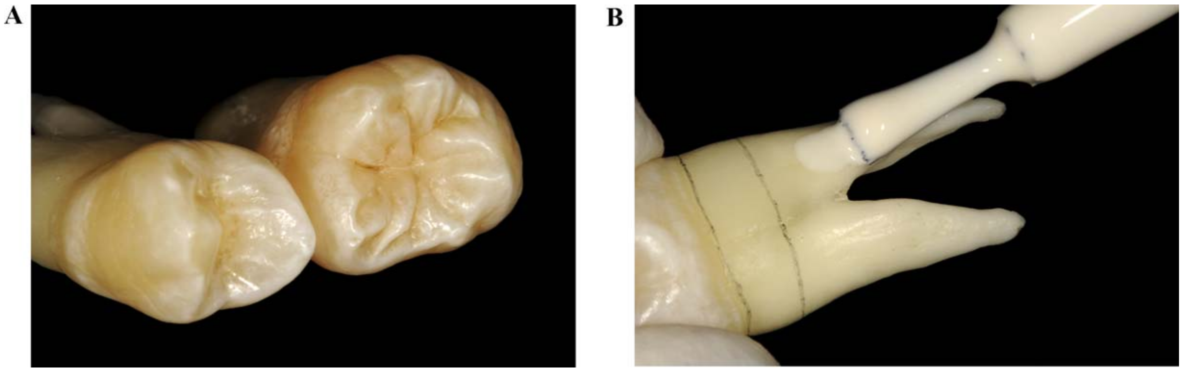

Fig. 1 – (A) Extracted maxillary teeth (third molar and first premolar). (B) Application of Rubber-Sep (Kerr) to simulate the periodontal ligament up to 3 mm below the cement–enamel junction.

ing special attention to interproximal contacts, marginal fit, and occlusal contacts [3]. There are significant drawbacks for not being able to carry out pre-cementation occlusal adjustments. Even in the presence of optimal clinical conditions and dental laboratory support, it is very likely that minor adjustments of the restoration will be needed. While minor changes can easily be carried out after cementation, other more significant adjustments such as major hyperocclusion call for substantial work, which cannot be ideally performed intraorally. Onlays present additional challenges compared to inlays because of their increased occlusal participation. Both the patient's and clinician's discomfort at the end of the cementation appointment can be amplified when major occlusion discrepancies are detected. This will require prolonged corrective procedures, possibly resulting in flawed anatomy, surface roughness and color discrepancy.

Maximum bite force varies considerably and is in the range of 234–597 N for women and 306–847 N for men [4–6]. However it has been demonstrated that the controlled bite force during tapping is much lower, approximately 22 N [7] somewhat similar to the maximum cementation force, approximately 25 N [8]. Given the development of stronger materials in combination with CAD/CAM techniques, it calls into question whether those new CAD/CAM restorations actually require special handling during try-in and cementation. It can be speculated that most modern materials used to fabricate bonded restorations have flexural strength and toughness that will sustain tapping/cementation forces. This issue, however, has not been addressed in the literature.

The aim of the present study was to evaluate *in vitro* the pre-cementation resistance of CAD/CAM onlays subjected to functional occlusal tapping. The influence of different machinable materials was assessed: high-strength ceramic, composite resin, and feldspathic porcelain. The null hypothesis stated that (1) there is no influence of material selection on the try-in resistance of the onlays and (2) restoration design (onlays versus inlays) has no influence of the try-in resistance of the indirect partial restorations. Part 2 of the null-hypothesis was formulated by including previous data concerning the pre-cementation resistance of CAD/CAM inlays subjected to occlusal tapping by the same research group in strictly identical conditions [9].

2. Materials and methods

2.1. *Specimen preparation*

Two freshly extracted maxillary teeth – one molar and one premolar – stored in solution saturated with 0.1% thymol, were used upon approval from the University of Southern California Institutional Review Board (Fig. 1A). Two layers of water-based liquid latex (Rubber-Sep; Kerr Corporation, Orange, CA) were applied on the roots in order to simulate the periodontal ligament (Fig. 1B) [10]. Teeth were positioned in proximal contact and the roots were embedded in acrylic resin (Palapress; Haereus Kulzer, Armonk, NY) up to 3.0 mm below the cement–enamel junction (CEJ).

The molar received a mesio-occlusal onlay preparation derived from a preexisting inlay preparation used in a previous study [9] by reducing the two mesial cusps 1.5-mm with a round-ended tapered diamond bur (6856-027; Brasseler, Savannah, GA) (detailed dimensions in Fig. 2). The dentin was sealed with 3-step etch-and-rinse dentin bonding agent (Optibond FL; Kerr, Orange, CA) immediately following tooth preparation. After the standard light curing time of 20 s, an air-blocking barrier (K-Y Jelly; Personal Products Company, Skillman, NJ) was then applied and followed by 10 s of additional light exposure (Allegro; Den-Mat, Santa Maria,

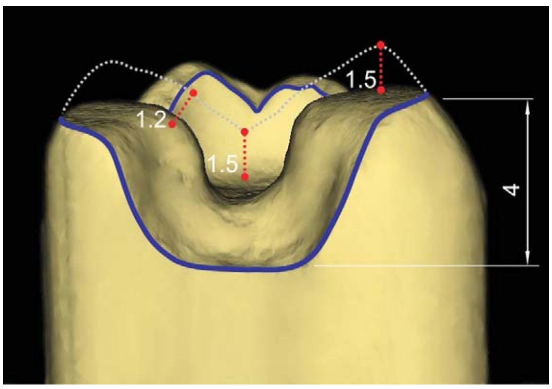

Fig. 2 – Dimensions of the mesio-occlusal onlay preparation (mm).

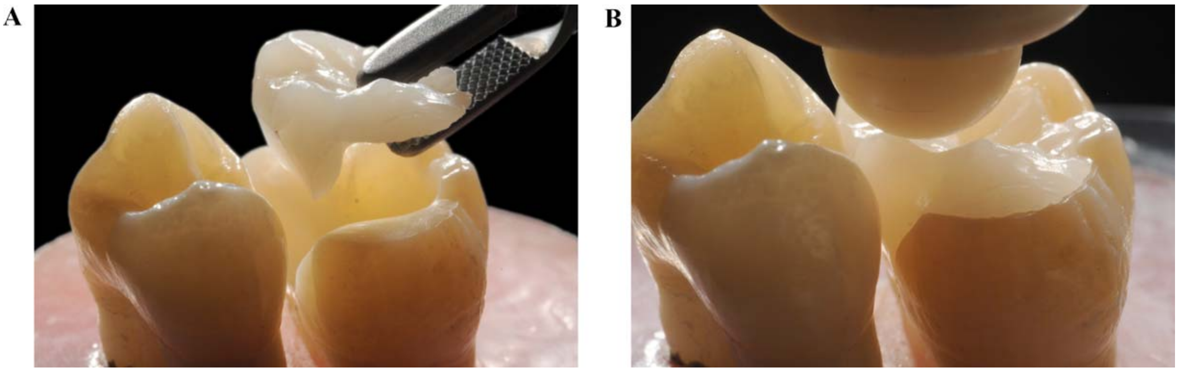

Fig. 3 – (A) Standardized onlay generated with the Cerec 3 CAD/CAM system in its insertion path on the preparation. (B) Simulated load cusp contacting the inner slope of the mesial marginal ridge.

CA) to optimize the polymerization of the oxygen-inhibition layer. The use of "immediate dentin sealing" technique (IDS) is supported by the prerogative of using limited anesthesia to allow the patient to better control tapping forces and improve their ability to detect minor occlusal discrepancies. Studies have reported an increase in bite force development induced by anesthetization [11–13]. By utilizing IDS technique [14], in which all the exposed dentin is etched, primed and resin-coated immediately after tooth preparation, before impression making, the patient does not require anesthesia during delivery of the restorations.

2.2. *Restoration design and manufacturing*

Standardized onlays were generated with the Cerec 3 CAD/CAM system (Cerec software v. 3.03., Sirona Dental Systems GmbH, Bensheim, Germany) (Fig. 3A). All restorations were identical in size and anatomy (by means of the correlation mode the original shape of the intact molar was scanned before preparation and replicated on the restorations) because they were produced by the multiple milling of the same design. The latter included a marginal ridge slightly higher than the neighboring premolar marginal ridge. This anatomical flaw was included to simulate hyperocclusion. Fourteen inlays were milled for each restorative material: e.max CAD (Ivoclar; Schaan, Liechtenstein), Paradigm MZ100 (3 M/ESPE; Saint Paul, MN), and Vita MarK II Blocks (Vident; Brea, CA). Detailed description of the materials is presented in Table 1. All the restorations were milled in Endo mode (optimized fit for smooth preparations) with the sprue at the distal edge. The restorations milled with lithium disilicate blocks were cerammed 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 ceramic onlays was performed mechanically using diamond ceramic polishers (Dialite, Brasseler), while the composite resin onlays were finished with brushes (Jiffy Composite Polishing Brushes, Ultradent, South Jordan, UT). A stone replica of the preparation was used for holding the onlays during finishing procedures.

2.3. *Occlusal tapping test*

The onlay was placed inside the wet prepared tooth. An artificial mouth using closed-loop servohydraulics [17] (Mini Bionix II; MTS Systems, Eden Prairie, MN) was used to simulate occlusal tapping forces. The try-in cycle was simulated by an isometric contraction (load control) applied through a 7-mm-diameter composite resin sphere (Filtek Z100, 3M/ESPE). Due to their identical occlusal anatomy, all specimens could be positioned in the same reproducible location with the sphere contacting the inner slope of the mesial marginal ridge (Fig. 3B). Cyclic occlusal tapping was applied at a frequency of 2 Hz, starting with a load of 40 N for 10 cycles followed by stages of 80, 120, 160, 200, 240, and 280 N at a maximum of 10

Table 1 – Properties of the materials used in this study.

Material	Content	Particle size
e.max (lithium disilicate glassceramic)	≈58% in volume of needle-like lithium disilicate homogeneously dispersed in the glassy matrix[a]	Lengths and thicknesses of elongated crystals: ∼10 and ∼1 μm, respectively[a]
MZ100 (composite resin)	85 wt% zirconia–silica particles bisGMA/TEGDMA polymer matrix[c]	0.6 μm[c]
MK II (feldspathic porcelain)	≈30% in volume of feldspar uniformly embedded in the glassy matrix[c]	1–7 μm[b]

[a] Data from Gonzaga et al. [15].
[b] Data from He and Swain [16].
[c] Manufacture's data.

Fig. 4 – Onlay cusp overlap fracture.

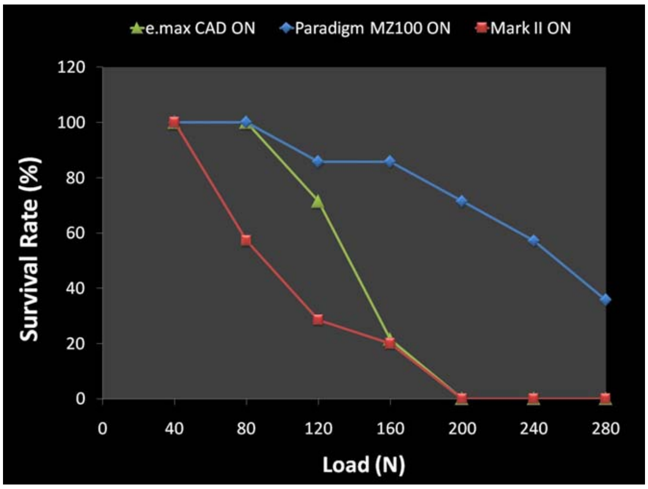

Fig. 5 – Life table survival analysis of CAD/CAM onlays at each load step of pre-cementation occlusal tapping.

cycles each. The specimens were loaded until fracture or to a maximum of 70 cycles. The failure load was recorded.

2.4. Statistical analysis

The fracture resistance of the three groups was compared using the life table survival analysis (MedCalc, v. 11.0.1; MedCalc Software, Mariakerke, Belgium). At each time interval (defined by each load step), the number of onlays starting the interval intact and the number of onlays that fractured during the interval were counted, allowing the calculation of survival probability at each interval. The influence of the restorative material on the fracture resistance was determined by comparing the survival curves using the log rank test at a significance level of 0.05. Differences were identified using pairwise post hoc comparisons with the same test at a significance level of 0.016 (Bonferroni correction for 3 comparisons). Additional computations were made by including three experimental groups of a previous study about the pre-cementation resistance of CAD/CAM inlays subjected to occlusal tapping [9]. The study was carried out by the same authors and produced in rigorously identical conditions (operators, same teeth, and experimental setup). The life table survival analysis was used to compare the fatigue resistance of the six groups (differences in fracture strength detected by the log-rank test at a significant level of .05). Pairwise post hoc comparisons were used to locate the differences at a significant level of 0.003 (Bonferroni correction for 15 comparisons).

3. Results

Onlays fractured consistently at the same cavo-occlusal line angle in the restoration (Fig. 4) and did not generate any damage to the teeth. For e.max CAD and Mark II, onlays demonstrated fracture at an average load of 157 N and 123 N, respectively, and none of them withstood all 70 load cycles (survival = 0%). In group Paradigm MZ100 the survival rate was 36%. The life table survival analysis (Fig. 5) revealed significant differences among groups ($p = .0006$). Post hoc tests showed higher fracture resistance of Paradigm MZ100 compared to both e.max CAD ($p = 0.0001$) and Mark II ($p < 0.0001$). However e.max CAD was not different when compared to Mark II ($p = 0.1174$).

Previous results regarding pre-cementation resistance of CAD/CAM inlays subjected to occlusal tapping are presented in Fig. 6. Additional computations and corresponding comparisons are presented in Table 2. It appears that the design of the preparation influenced the pre-cementation resistance of CAD/CAM restorations with feldspathic porcelain and composite resin (MK II ON > MK II IN and Paradigm MZ100 ON > Paradigm MZ100 IN; $p < 0.0001$), but not with lithium disilicate glass ceramic ($p = 0.03$).

4. Discussion

The present study assessed the pre-cementation resistance of CAD/CAM onlays subjected to functional occlusal tapping. A comparison to previously published data about the resistance of CAD/CAM inlays (strictly identical experimental condi-

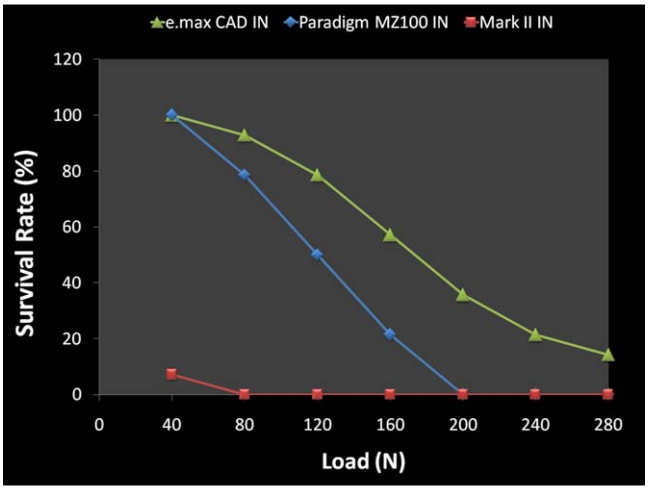

Fig. 6 – Life table survival analysis of CAD/CAM inlays at each load step of pre-cementation occlusal tapping from previous study [9].

Table 2 – Pairwise post hoc comparisons with the log-rank test including previous data.

	MKII IN	Paradigm MZ100 IN	e.max CAD IN	Paradigm MZ100 ON	MKII ON	e.max CAD ON
MKII IN		<0.0001[*]	$p<0.0001$[*]	<0.0001[*]	<0.0001[*]	<0.0001
Paradigm MZ100 IN			.011	<0.0001	0.4807	0.4092
e.max CAD IN				0.064	0.004	0.03
Paradigm MZ100 ON					<0.0001[*,a]	0.0001[*,a]
MKII ON						0.1174
e.max CAD ON						

[*] Significant differences between all materials, including groups from previous study [14] (e.max CAD IN and Mark II: pre-cementation resistance of CAD/CAM inlays subjected to occlusal tapping) with a p value of 0.003 (Bonferroni-corrected for 15 comparisons).
[a] Significant differences between materials tested in this study with a p value of 0.016 (Bonferroni-corrected for 3 comparisons).

tions and operators) was included. The null hypothesis can be rejected because (1) the different materials showed significantly different fracture resistance (with composite resin superior to lithium disilicate glass ceramic and feldspathic porcelain) and (2) the design of the restoration (inlay vs. onlay) influenced the pre-cementation resistance for two of the three materials tested.

A latex liner was applied to the roots in order to simulate the periodontal ligament and therefore its resilience [10]. It is quite likely that the deformation of this elastic material allowed sufficient absorption of forces during load application, modifying not only the load of fracture of the restorations but also their failure mode [10]. Replication of the intra-oral environment also included the use of an isometric cyclic load protocol with a staircase design based on previously published data by Fennis et al. [18]. It was modified to adapt to the load and number of cycles of a try-in procedure. The first load step (40 N) lies inside the range of controlled bite force during occlusal functional tapping (and cementation), approximately 22 N [7,8]. The next steps (80–280 N) cover the range of loads that could be reached in function of the patients' individual response to the command "gently tap your teeth", as well as the effect of anesthesia [6]. Therefore, loads higher than the tapping force (22 N) [7] and lower than the voluntary bite forces (234–306 N) [4] were achieved. Closed-loop servo-hydraulics was used in this study due to its accuracy and reliability in testing dental materials under simulated mastication. The load cell acts as sensors located in the periodontal ligament [17]. It monitors the force being applied by means of a constant feedback and the information is analyzed by the controller, which acts as "the brain" of the system [17]. Any changes in the seating of the onlay during the test is taken into account and compensated for.

The onlay preparation was designed to generate a classic partial restoration with a relatively thin conservative overlap so that the integrity of the remaining tooth structure could be preserved after each test and allow for the re-use of the specimen. The tooth was not only checked regarding loss of structure but also to detect any development of cracks. No enamel or dentin cracks were detected during the entire experiment, which may also be attributed to the use of immediate dentin sealing (IDS). IDS consists of applying the dentin bonding agent to the freshly cut dentin prior to the final impression [14]. In addition to the comfort experienced by the patients during all the provisional phase and other practical and technical advantages of this technique, the sealed dentin also allows a controlled bite force during try-in since only limited or even no anesthesia is needed. In addition, IDS is used to systematically block undercuts with light curing composite, an approach that contributes for the preservation of sound dental tissue and also prevent the remaining tooth substance from fracturing during provisionalization and try-in procedures [14].

In a previous study conducted by the same research group [9], inlays were tested in rigorously identical conditions. The results showed a better performance of lithium disilicate glass ceramic during try-in, followed by composite resin and feldspathic porcelain. Those results were aligned with the physical properties (flexural test or fracture toughness) of the respective materials (manufacturer's data): e.max CAD (257 MPa, 2–2.5 MPa m$^{1/2}$) > Paradigm MZ100 (150 MPa, 1.6 MPa m$^{1/2}$) > Mark II (103 MPa, 1.3 MPa-m1/2). The inclusion of the previous data about inlays in the present study allowed investigating the influence of the design (inlays versus onlays). For feldspathic porcelain and composite resin, CAD/CAM onlays presented a significantly higher pre-cementation resistance compared to inlays. However, this difference was not found in lithium disilicate glass ceramic. As a consequence, the previous inlay try-in results were not mirrored by those obtained with onlays in the present study (Fig. 6). It can be hypothesized that for lithium disilicate glass ceramic inlays the load applied to the marginal ridge generated major horizontal vectors of force and tensile stresses, which maybe more likely replicated by the mode of fracture in the aforementioned physical tests. In the onlay situation, the presence of the two "wings" (cusp overlap) generates a different load configuration which seems to better correlate with the work of fracture of the various materials (defined as KIc2/Emod): Paradigm MZ100 (141 J/m^2) > e.max CAD (83 J/m^2) > Mark II (27 J/m^2). The work of fracture represents the energy used within the fracture process where a new surface is generated and it takes into account the elastic modulus of the material. This would explain the superiority of the composite resin onlays with their lower elastic modulus.

Clinicians should keep in mind that loads from 80 N up to 280 N may potentially be generated when the patient is asked to "gently tap his teeth". Therefore, based on the results presented in this study (significant drop in survival rate for all materials when the load was increased from 80 N to 280 N), even lithium disilicate glassceramic and composite resin onlays may possibly fracture during pre-cementation adjustments.

The present study focused on CAD/CAM restorations because they offer the advantage of a standardized design and manufacturing process. Further studies should evaluate the occlusal functional tapping strength of both inlay onlays and overlays made of layered materials (feldspathic porcelain and composite resin) since they provide the most esthetic results.

5. Conclusions

Within the limitations of the present *in vitro* study it can be concluded that material selection and preparation design have a significant effect on the risk of CAD/CAM restoration fracture during pre-cementation functional occlusal tapping. Composite resin onlays showed the lowest fracture risk compared to ceramic ones. Both feldspathic porcelain and composite resin were stronger as onlays compared to inlays.

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