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Influence of material selection on the risk of inlay fracture during pre-cementation functional occlusal tapping

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ABSTRACT

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

Methods. An extracted tooth model (molar and premolar) with simulated bone and periodontal ligament was used to make a medium-size mesio-occlusal inlay preparation (molar). Immediate dentin sealing was applied to the prepared tooth. The corresponding inlays were fabricated with Cerec either using composite resin (Paradigm MZ100) or ceramic (e.max CAD and Mark II) blocks ($n = 14$). A high marginal ridge was designed in order to generate 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 ($p = 0.016$, Bonferroni method).

Results. Survival probability was e.max CAD > MZ100 > Mark II. None of the specimens survived the 70 cycles except for two e.max CAD inlays (survival: 14%).

Significance. Material selection has a significant effect on the risk of Cerec inlay fracture during pre-cementation functional occlusal tapping.

1. Introduction

Bonded restorations have been widely recommended as a conservative and biomimetic treatment option, considering that significantly less tooth structure removal is needed when compared to conventional crown procedures [1]. Prior to cementation, intracoronal indirect restorations should be tried in the patient's mouth and assessed for interproximal contact, marginal fit, and occlusal contact [2]. These delicate restorations resulting from minimally invasive preparations are fragile and brittle until bonded to the prepared tooth. It has been recommended therefore that those restorations not be subjected to occlusal forces before adhesive placement [3]. There are significant drawbacks, however, of not being able to perform pre-cementation occlusal adjustments. Even in the case of optimal clinical conditions and the finest dental laboratory support, it is very likely that minor modifications of the restoration will be needed. While some changes can easily be done after cementation, other problems such as significant hyperocclusion or infraocclusion require substantial extraoral work, which cannot be carried out intraorally. In addition, major alterations of the restoration usually call for additional procedures such as staining, polishing and glazing. Both the patient's and clinician's discomfort can become substantial when major occlusion discrepancies are only detected after

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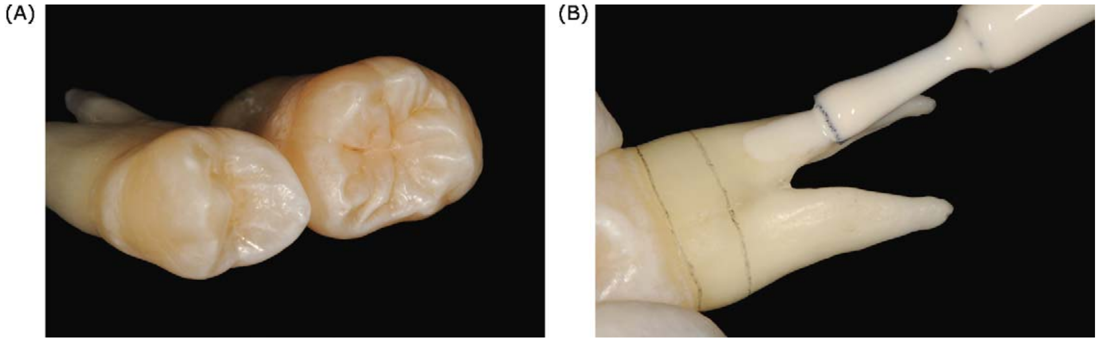

Fig. 1 – (A) Extracted maxillary molar and premolar. (B) Application of Rubber-Sep (Kerr) to simulate the periodontal ligament up to 3 mm below the cement–enamel junction.

cementation. This will require lengthy corrective procedures resulting in altered anatomy, surface roughness, color discrepancies, as well as a stressful scheduling for the clinician.

Optimal patient comfort during the try-in process can be maintained by utilizing the immediate dentin sealing technique (IDS) [4], in which all the exposed dentin is etched, primed and resin-coated immediately after tooth preparation, before impression making. The resin coating acts as insulation so that anesthesia might not be needed during restoration delivery, allowing 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 [5–7]. Maximum bite force varies significantly and is in the range of 234–597 N for women and 306–847 N for men [8–10]. De Boever et al. [11], however, demonstrated that the controlled bite force during tapping is much lower, approximately 22 N. Another aspect to consider is the maximum cementation force, approximately 25 N [12]. Considering the development of stronger materials compared to traditional feldspathic porcelain, it calls into question whether those inlays/onlays require cautious handling during try-in and cementation. It can be hypothesized 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 inlays subjected to functional occlusal tapping. The influence of different machinable materials was assessed: high-strength ceramic, composite resin, and feldspathic porcelain. The null hypothesis was that the try-in resistance of the inlays would not be different among the different inlay materials.

2. Material and methods

2.1. Specimen preparation

One freshly extracted maxillary first 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 a water-based liquid latex (Rubber-Sep; Kerr Corporation, Orange, CA) were applied on the roots in order to simulate the periodontal ligament (Fig. 1B) [13]. Teeth were positioned in 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 inlay preparation (using a round-ended tapered diamond bur (6856-027; Brasseler, Savannah, GA), including a narrow occlusal isthmus in order to predetermine the location where the fracture would occur 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. An air-blocking barrier (K-Y Jelly; Personal Products Company, Skillman, NJ) was applied and followed by 10 s of additional light exposure (Allegro; Den-Mat, Santa Maria, CA) to polymerize the oxygen-inhibition layer.

2.2. Restoration design and manufacturing

Standardized inlays 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 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 intentional flaw was included

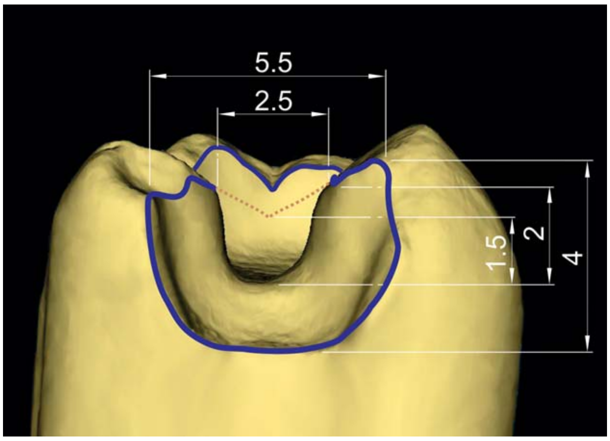

Fig. 2 – Dimensions of the mesio-occlusal inlay preparation (mm).

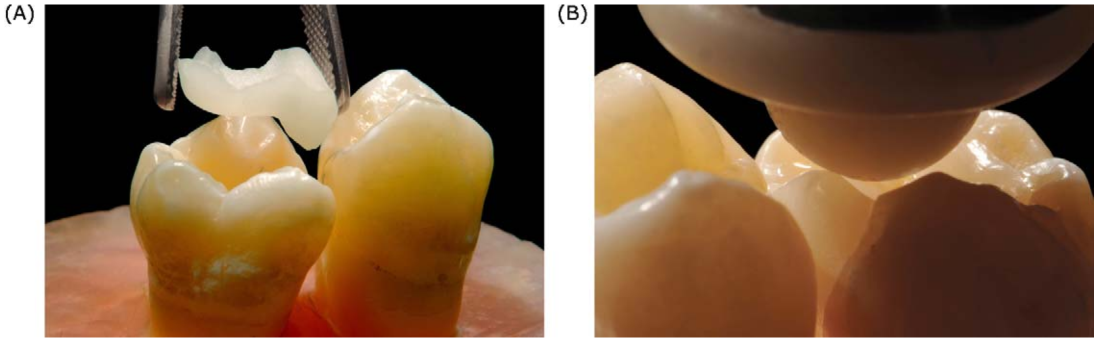

Fig. 3 – (A) Standardized inlay generated with the Cerec 3 CAD/CAM system being positioned on the preparation. (B) Simulated load cusp contacting the inner slope of the mesial marginal ridge.

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). The restorations milled with lithium disilicate blocks were crystallized in a ceramic furnace (Austromat D4, DEKEMA Dental-Keramiköfen GmbH, Freilassing, Germany) following the manufacturer's instructions (Ivoclar Vivadent AG). The surface polishing of the Mark II and e.max CAD inlays was performed mechanically using diamond ceramic polishers (Dialite, Brasseler), while the Paradigm MZ100 inlays were finished with brushes (Jiffy Composite Polishing Brushes, Ultradent, South Jordan, UT). A stone replica of the preparation was used for holding the inlay during finishing procedures.

2.3. *Occlusal tapping test*

The inlay was positioned inside the wet prepared tooth. An artificial mouth using closed-loop servohydraulics [14] (Mini Bionix II; MTS Systems, Eden Prairie, MN) was used to simulate occlusal tapping forces. The try-in cycle was replicated by an isometric contraction (load control) applied through a 7-mm-diameter composite resin sphere (Filtek Z100, 3M/ESPE) post-cured at 100 °C for 5 min. 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 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. At each time interval (defined by each load step), the number of inlays starting the interval intact and the number of inlays 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). The statistical analysis was carried out with MedCalc Version 11.0.1 (Mariakerke, Belgium).

3. Results

Inlays fractured at the isthmus as predicted (Fig. 4) and did not generate damage to the teeth. None of Paradigm MZ100 and Mark II inlays withstood all 70 load cycles (survival = 0%). Two inlays survived the test in groups e.max CAD (survival = 14%). The life table survival analysis (Fig. 5) revealed significant differences among groups ($p < 0.0001$). Post hoc tests showed higher fracture resistance of e.max CAD compared to both Paradigm MZ100 ($p = 0.011$) and Mark II ($p < 0.0001$), as well as higher fracture resistance of Paradigm MZ100 compared to Mark II ($p < 0.0001$).

4. Discussion

The present study evaluated the pre-cementation resistance of CAD/CAM inlays subjected to functional occlusal tapping. The first null hypothesis was rejected since the different inlay materials showed significantly different fracture resistance, where e.max CAD was the strongest material, followed by Paradigm MZ100 and Mark II. The second null hypothesis can

Fig. 4 – Inlay isthmus fracture as predicted.

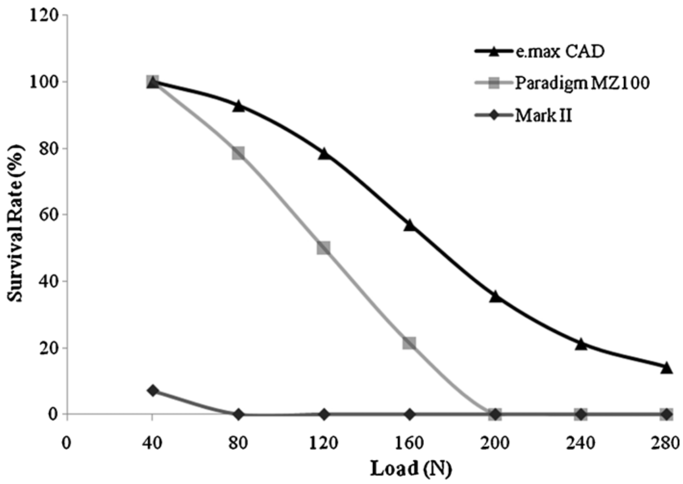

Fig. 5 – Life table survival analysis of CAD/CAM inlays at each load step of pre-cementation occlusal tapping.

be partially rejected since two e.max CAD inlays resisted the 280-N load application during simulated tapping.

In order to represent the intra-oral environment during tooth preparation, a latex liner was applied to the roots to simulate the periodontal ligament. It has been demonstrated that the stress distribution is influenced by the presence of an artificial periodontal membrane [13]. The resilience and deformation capability of elastic materials used for this purpose allow absorption of forces during load application, modifying not only the fracture load of restorations but also their mode of failure [13]. In order to preserve the integrity of the remaining tooth structure during the experiment (i.e. enable the re-use of the teeth), the inlay preparation was intentionally designed to generate an inlay with a fragile isthmus (minimum recommended for the most conservative inlays, namely 2.5 by 2 mm) [15]. This principle can be deemed valid because all inlays fractured in the programmed location and the teeth withstood the whole experiment without damage.

The immediate dentin sealing (IDS) performed on the tooth before testing, consists of applying the dentin bonding agent to the freshly cut dentin prior to the final impression [4]. There are numerous advantages to this bonding strategy. The sealed dentin allows more comfort for the patient and a controlled bite force during try-in since no anesthesia is needed. IDS, along with the use of composite resin base materials, may also prevent the remaining tooth substance from fracturing during provisionalization and try-in procedures. It could be assumed that the resilience generated by the low elastic modulus resin coating (<5 GPa compared to 12–18 GPa of dentin and 80 GPa for enamel) allowed stress absorption by deformation, preventing the non-cemented inlay from fracturing. This hypothesis requires validation by means of an experimental group without IDS. This was omitted in the present study because IDS is considered a routine procedure at the University of Southern California Dental School. Another omission was the use of a silicone disclosing medium, which was deemed unnecessary (all restorations were fitting appropriately and equally due to the use of CAD/CAM) and would have introduced an additional confounding variable.

Closed-loop servo-hydraulics was used in this study because it is an accurate and adaptable method to test dental materials, allowing a more physiologic simulation of mastication [14]. The load cell acts as the "brain" of the system providing constant feedback to the controller. The signal is analyzed and used to correct loading parameters in order to maintain the ideal sine function of the load despite the changes in the seating of the inlay during try-in. According to the results, e.max CAD inlays demonstrated higher resistance during try-in, followed by Paradigm MZ100 and Mark II. Those results are reflecting the strength of the same materials subjected to flexural test or fracture toughness (manufacturer's data): e.max CAD (257 MPa, 2–2.5 MPa-m$^{1/2}$) > Paradigm MZ100 (150 MPa, 1.3 MPa-m$^{1/2}$) > Mark II (103 MPa, 0.8 MPa-m$^{1/2}$). One limitation of the present study is the lower limit of the load cell, which did not allow generating predictable tapping forces below 40 N. Controlled bite force during occlusal functional tapping (and cementation) is approximately 22 N [11,12] but could be higher when considering the patients' individual variations in the ability to "gently" tap their teeth, as well as the effect of anesthesia [10]. In other words, patients are not always capable of reproducing exactly what is subjectively requested by the dentist during occlusal adjustments. In any case, loads higher than the tapping force (22 N) [11] and lower than the voluntary bite forces (234–306 N) [8] may be achieved. In spite of this possible load discrepancy, it is significant to note that 100% of e.max CAD and Paradigm MZ100 inlays resisted the 40 N load step. Two e.max CAD inlays (14%) even withstood the 70 cycles (280 N) without fracturing. Paradigm MZ100 inlays fractured at a significantly higher load increment than Mark II. It is possible that the fracture toughness of those materials (Paradigm MZ100 – 1.3 MPa-m$^{1/2}$/Mark II – 0.8 MPa-m$^{1/2}$) is responsible for this tendency.

Further studies should evaluate the occlusal functional tapping resistance of different designs of indirect bonded restorations, including onlays and overlays. The use of layered feldspathic porcelain restorations would also be valuable, since it still provides the most esthetic results. The present study focused, however, on CAD/CAM restorations because of the standardized design and manufacturing process.

5. Conclusions

Within the limitations of the present study it can be concluded that material selection has a significant effect on the risk of CAD/CAM inlay fracture during pre-cementation functional occlusal tapping. It is recommended that no adjustment of feldspathic porcelain inlays be made before adhesive placement. When using e.max CAD or Paradigm MZ100, adjustments can be made with care for the benefit of improved predictability of function, biomechanics, and esthetics.

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