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The Fracture Strength of Ceramic Overlays With and Without Immediate Dentin Sealing

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USU Operational Gap: IV, A

Abstract

Same-day dentistry is gaining widespread adoption with the advent of digital dentistry. However, limited research is available evaluating whether the reported in vitro benefits of immediate dentin sealing (IDS) can be acquired in the era of same-day dentistry. The purpose of this study was to evaluate the fracture strength of ceramic overlays with an immediate dentin sealing (IDS) technique versus a delayed dentin sealing (DDS) technique performed under same-day (SD, 1-hour) or delayed (D, 2-week) delivery conditions. Forty maxillary third molars were prepared for a lithium-disilicate overlay restoration (IPS e.max CAD, Ivoclar) and divided into four groups of 10 teeth each. The preparations were scanned, and the restorations were designed, milled, and crystallized. In the first group, teeth were prepared, stored for an hour and then the adhesion protocol (bonding agent, resin cement) was applied at the time of delivery (SD, DDS). In the second group, teeth were prepared, the adhesive protocol was applied immediately, and then the teeth were stored for an hour before final delivery (SD, IDS). The protocols for the third (D, DDS) and fourth group (D, IDS) were identical to the first and second, respectively, however, the teeth were provisionalized and stored for two weeks. All specimens were subjected to thermocycling and cyclic loading before loading to failure in a universal-testing machine using a stainless-steel rod resting on the buccal

incline of the palatal cusp at a 60-degree angle to the long axis of the tooth. Data were analyzed with a two-way ANOVA (alpha=0.05). No significant difference in fracture strength was found between the groups ($p>0.05$). Immediate dentin sealing did not provide any significant increase in fracture strength of the overlay restorations compared to delayed dentin sealing, whether the restoration was delivered the same day or after two weeks of storage.

Introduction

Advances in both adhesive technology and CAD/CAM dentistry afford dentists the opportunity to practice more conservative, tooth-saving dentistry. Traditional crown preparations require substantial removal of healthy tooth structure in order to achieve mechanical retention. Specifically, conventional molar crown preparations require a 4 mm axial wall height (Goodacre et al, 2001; Goodacre, 2004). However, the traditional protocols for a crown preparation were formulated in the era of aqueous-based non-adhesive luting cements which relies heavily on mechanical retention.

A traditional preparation design also presents challenges in bonding because it will cause the operator to have to bond to a substantial amount of dentin. Dentin is considerably more technique sensitive to bond because it is a humid, organic substrate (Van Meerbeek et al., 2020). Also, a traditional crown preparation design may also reveal deep dentin, which presents a challenge to adhesive dentistry because it has a twenty-fold increase in water content (Perdigao, 2020). In effect, the conventional approach to crown design becomes more challenging to provide adhesion, which necessitates the need for more mechanical retention.

Non-retentive bonded ceramic partial crowns, also known as overlays, are becoming increasingly popular because of their tooth-preserving quality. The preparation design involves removing all remaining cusps to a thickness of 1 mm or more in such a way that the preparation has flat, simple, and open geometry (Clausen et al, 2010; Politano et al., 2018; Ahlers et al, 2009; Arnetzl and Arnetzl, 2006; Ferraris et al, 2021). Although this design is gaining popularity among dentists, more lab and clinical data is needed to assess its performance in preserving the tooth. Most of the existing data on indirect restorations is related to inlay and onlay restorations (Beier et al, 2012; Frankenberger et al, 2008; Guess et al, 2013; Kramer et al, 2008).

Immediate dentin sealing (IDS), as opposed to traditional delayed dentin sealing (DDS), appears to offer increased bond strength to tooth structure, at least in laboratory studies (Qanungo et al, 2016; Hardan et al, 2022; Samartzi et al, 2021). IDS is the application of an adhesive bonding agent to freshly cut dentin when it is exposed during tooth preparation for indirect restorations. With the advent of digital dentistry, same-day dentistry for indirect restorations is gaining widespread adoption. In this circumstance, the restoration is scanned and then delivered all within a single day or appointment. However, a dearth of literature evaluates whether the purported benefits of IDS, which typically occurs over several days, if not weeks, can be acquired in the era of same-day dentistry. Determining if the reported outcomes of IDS are conceivable with a non-retentive restoration, and more particularly an overlay, in a same-day dentistry setting is important because these restorations have minimal retention and resistance form features, which cause them to be heavily reliant on adhesive dentistry.

The aim of this study was to evaluate the fracture strength of an overlay restoration in which an IDS or DDS protocol has been applied over varying time spans, in an effort to emulate a same-day versus an extended-day approach to restorative dentistry. The null hypotheses tested were that there would be no differences in fracture strength of all-ceramic overlay restorations based on (1) the type of dentin sealing (delayed or immediate) and (2) timing of overlay restoration delivery (same day or delayed).

Materials and Methods

Forty human maxillary third molars, without any caries, restorations, or endodontic treatment, were used in this study. Following extraction, calculus, plaque, and periodontal fibers were removed, and each tooth was stored in 0.5% Chloramine-T (Science Stuff, Austin, TX) at 4°C for up to 30 days. Specimens were individually mounted in acrylic (Vitacrylic, Fricke Dental, Streamwood, IL) to 2.0mm below the cementoenamel junction in a custom cylindrical block.

Teeth were prepared for a 1.5-mm-thick lithium disilicate overlay restoration (IPS e.max CAD, Ivoclar, Amherst, NY). See Figure 1. All overlay preparations were accomplished by one operator using a high-speed electric dental handpiece (EA-51LT, A-dec, Newburg, OR) with diamond and carbide burs under continuous water spray. The overlay preparations were completed with circumferential occlusal reduction and a gradual enamel bevel to create flat, simple, and open geometry. All internal corners and line angles were rounded. Preparation design followed the “full bevel” preparation as described by Ferraris et al (Ferraris 2021).

The prepared teeth were then categorized into four groups of 10 teeth each (n=10). An overview of the test groups is listed below.

Group 1: Same-day, delayed dentin sealing technique (SD, DDS). The teeth were scanned immediately after preparation and stored in artificial saliva. After one hour of storage, the adhesive bonding agents were applied, and the overlay restorations were cemented.

Group 2: Same-day, immediate dentin sealing technique (SD, IDS). Adhesive bonding agents were immediately placed after the preparations and prior to scanning. The teeth were stored in artificial saliva for one hour prior to the cementation of the overlay restoration.

Group 3: Delayed, delayed dentin sealing technique (D, DDS). The teeth were prepared, scanned, provisionalized, and stored in artificial saliva. After two weeks of storage, the provisionals were removed, the adhesive bonding agents were placed, and the overlay restorations were cemented.

Group 4: Delayed, immediate dentin sealing technique (D, IDS). Adhesive bonding agent were immediately placed after the preparations and prior to scanning. The teeth were then provisionalized and stored in artificial saliva. After two weeks of storage, the provisionals were removed and the overlay restorations were cemented to the previously bonded preparation.

Digital impressions of all preparations were made with a chairside acquisition unit (Primescan, Dentsply Sirona, Charlotte, NC). The design of the overlays was created with CAD software (inLab 16, Dentsply Sirona) with a 150-micron cement spacer. The overlay restorations were milled (CEREC MCXL, Dentsply Sirona) from lithium-disilicate blocks

(IPS e.max CAD, MT, shade A-2, Ivoclar). The milled restorations were then crystalized in a ceramic oven (Programat P500, Ivoclar) according to manufacturer's recommendations. The intaglio surfaces were etched with 5% hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar) for 20 secs, rinsed with water for 5 secs and air dried. A thin layer of ceramic primer (Monobond Plus, Ivoclar) was applied with a microbrush for 60 secs and thinned with air.

Adhesive Protocol Steps

Group 1 (SD, DDS): The prepared teeth were scanned and then stored in artificial saliva for one hour at intraoral temperatures (37 °C) in a laboratory oven (Model 20 GC, Quincy Labs, Chicago, IL). The artificial saliva was prepared as described by Lata, et al: Na_3PO_4 - 3.90 mM $NaCl_2$ - 4.29 mM KCl - 17.98 mM $CaCl_2$ - 1.10 mM $MgCl_2$ - 0.08 mM H_2SO_4 - 0.50 mM $NaHCO_3$ - 3.27 mM, distilled water, with a pH set to a level of 7.2 (Lata et al, 2010). A pH meter (Accumet XL50, Fisher Scientific, Walthan, MA) was used to measure pH. After one hour of storage, the prepared tooth surface was rinsed with water and gently dried. A three-step, etch and rinse adhesive bonding agent (Optibond FL, Kerr Dental, Orange, CA) was applied to the prepared surfaces according to the manufacturer's instructions. The restoration was cemented with a dual-cure adhesive resin cement (NX3, Kerr Dental) according to the manufacturer's instructions and polymerized using a light-curing unit in standard power mode (Valo Grand, Ultradent Products, South Jordan, UT). Excess cement was removed and all surfaces (occlusal, facial, and lingual) of the restorations were light-cured for 60 seconds each.

Group 2 (SD, IDS): The adhesive protocol was identical to Group 1 (SD, DDS) except the teeth preparations were immediately sealed with the adhesive bonding agent. A glycerin air barrier (Liquid Lens, Danville Materials, Carlsbad, CA) was applied over the restoration margins and then the tooth was subjected to an additional 10 seconds of light exposure to polymerize the oxygen-inhibited layer. The margins were re-finished using carbide finishing burs and the preparation was scanned. The teeth specimens were stored in artificial saliva as before. After one hour of storage, the bonded surfaces were air abraded (Basic Quatro IS, Renfert, Chicago, IL) for 10 seconds with 30-micron aluminum-oxide particles at 6.5 psi at a standardized distance of 10 mm (Van Meerbeek et al, 2003). The specimens were rinsed, and the enamel was etched for 15 seconds with 37.5% phosphoric acid etch gel and rinsed with water for 15 seconds and gently air dried. The adhesive bonding agent was applied to the enamel, and light cured. The restorations were cemented with the adhesive resin cement according to the manufacturer's instructions and light cured as before.

Group 3 (D, DDS): The adhesive protocol was identical to Group 1 (SD, DDS) except a provisional restoration was placed onto the preparation for two weeks. Restorations were provisionalized with a light-cured, single component material (Telio Onlay, Ivoclar) utilizing a spot-bond approach. A small spot of 37.5% phosphoric acid (1.5 mm diameter) was placed on the dentin for 15 seconds. The etch was thoroughly rinsed and then Optibond FL was placed, according to the manufacturer's instruction, over the site that was etched. The provisional material was then placed over the preparation and light cured. The teeth were stored in artificial saliva as before. After two weeks of storage, the provisional restorations were removed and the prepared surfaces were cleaned with

a fluoride-free pumice (Preppies, Whip Mix, Louisville, KY), rinsed, and air dried. The prepared surfaces were bonded with the adhesive bonding agent and the restorations were cemented with an adhesive resin cement according to the manufacturer's instructions and light cured as before.

Group 4 (D, IDS): The adhesive protocol was identical to Group 3 (D, DDS) with the exception that the tooth preparations was immediately sealed with the adhesive bonding agent before provisionalization.

Thermocycling and Functional Loading

After cementation, all specimens were placed in distilled water at 37°C for 24 hours in a laboratory oven. Then, the specimens were thermo-cycled at 5 and 55 °C in distilled water for 2000 cycles with a dwell time of 30 seconds at each temperature (Sabri Dental Enterprise, Downers Grove, IL). To simulate chewing function, specimens were loaded into a 10-station cyclic loader (Sabri Dental Enterprises). The mounted teeth were subjected to cyclic forces of 10 to 150 N at a rate of 1 cycle per second (1 Hz) for 100,000 cycles while they were still submerged in distilled water. A flat-ended cylindrical piston 12.7 mm in diameter applied force perpendicular to the occlusal surface. A digital force meter (Infinity CS, Cooper Instruments, Warrenton, VA) was used to verify the load prior to each load sequence.

Fracture Strength Testing

Specimens were individually mounted at a 30-degree angle from the horizontal with denture acrylic (Vitacrylic, Fricke Dental, Streamwood, IL) inside a polyvinyl chloride

(PVC) pipe. Specimens were then placed into a vise fixture on a universal testing machine (5943, Instron, Norwood, MA) so that the tooth's long axis was at a 60-degree angle from the testing fixture. A stainless-steel rod, three millimeters in diameter and with a 0.5-millimeter radius of curvature was used to load the buccal incline of the palatal cusp. See Figure 2. Specimens were loaded at a rate of 1.0 mm per minute until failure was reached. The fracture strength was recorded in Newtons. A mean and standard deviation were determined per group. Data was analyzed with statistical software (SPSS, Version 25, IBM, Chicago, IL) with a 95% level of confidence (alpha=0.05). A two-way analysis of variance (ANOVA) test was performed to examine the main effects of type of dentin sealing and timing of overlay restoration delivery and the interaction effects on fracture load. An unpaired t-test was used to compare each group individually. Each tooth was visually examined in order to determine if it fractured from adhesive failure between the ceramic and tooth structure, cohesive fracture of the ceramic, cohesive fracture of the tooth material apical to the preparation, or catastrophic failure of the tooth/restoration complex. Fracture mode data were analyzed with a Kruskall-Wallis test to determine if there were any differences in fracture modes between the groups (alpha=0.05)

Results

The two-way ANOVA found no differences in fracture strength based on type of dentin sealing (p=0.331) or timing of delivery (p=0.314) with no significant interactions (p=0.540). The SD-DDS group showed the highest fracture strength (1518.8 ± 392.7 N), while the D-IDS group showed the lowest fracture strength (1312.3 ± 262.1 N). However,

there was no significant difference in fracture strength between any of the groups ($p>0.202$). See Figure 3.

There were two recorded fracture types between the groups. Either a portion of the ceramic cohesively fractured, leaving the tooth intact or the ceramic and part of the tooth fractured. There were no instances in which the restoration itself delaminated during fracture testing. See Figure 4. The D-DDS group had the greatest number of fractures of the tooth/restoration complex (70%), while the SD-IDS had the greatest number of cohesive fractures of the ceramic (60%). However, there were no statistically significant differences in fracture modes between the groups ($p=0.255$).

Discussion

To date, no study has evaluated CAD/CAM overlay restorations in a same-day setting compared to a delayed, two-week approach. The study design was intended to emulate the typical delivery timeframes of a dental office. Offices with a milling unit can typically deliver restorations within an hour whereas offices without a milling unit may wait about 1-2 weeks for the restoration to be returned from the lab.

This study revealed that non-retentive overlay restorations have a high fracture strength in both a delayed (two weeks) or immediate (one hour) approach to delivery. It also demonstrated that these restorations have a high fracture strength with either an IDS or DDS approach. The null hypotheses that there would be no difference in fracture load based on dentin-sealing approach or delivery timing was not rejected. There were no significant differences in fracture strength between any of the groups.

Systematic reviews of laboratory studies have suggested that IDS may improve the bond strength to dentin (Hardan et al, 2022; Samartzi et al, 2021). However, only a few laboratory studies have evaluated the effect of IDS on the fracture strength of restorations bonded to prepared teeth. With similar results to this study, Hofsteenge et al found no difference in the fracture strength of lithium disilicate overlays bonded to prepared molars with either an IDS or DDS technique (Hofsteenge et al, 2020). However, Saadeddin et al and Yazigi et al found significantly greater fracture strength of lithium disilicate onlays or occlusal veneers, respectively, bonded to premolars with the IDS technique compared to the DDS technique (Saadeddin et al, 2022; Yazigi et al 2017). The clinical performance of bonded ceramic restorations utilizing the IDS technique is also somewhat equivocal. One long-term clinical study appears to demonstrate that IDS increases the survivability of indirect veneer restorations with greater than 50% dentin exposure (Gresnigt et al, 2019). However, a randomized, controlled clinical trial by van den Breemer et al demonstrated there was no difference in success or survival of partial ceramic restorations when comparing IDS versus DDS techniques (van den Breemer et al, 2019).

The overlays in this study were designed so that they were in alignment with the ceramic design guidelines published by Ahlers et. al. and Arnetzl and Arnetzl (Ahlers et al. 2009; Arnetzl and Arnetzl, 2006). The aforementioned authors advocate for “the simplest possible basic geometry” and that "sudden changes in cross-section should be avoided by soft and smooth transitions.” Additionally, finite element analysis has demonstrated that retentive features such as boxes or isthmuses inhibits the uniform

distribution of stress (Gomes de Carvalho 2021). Therefore, the preparations in this study were designed to have flat, open, and simple geometry.

Additionally, substantial advances in adhesive dentistry have been made over the years. Systematic reviews of long-term clinical studies have demonstrated that non-simplified gold-standard adhesives such as Optibond FL, a 3-step-step etch-and-rinse adhesive, and Clearfil SE Bond, a two-step self-etch adhesive, have annual failure rates as low as 1.8% and 2.2% (respectively) in non-carious cervical lesions (Peumans et al, 2014, Van Meerbeek et al, 2020). A practiced-based research network clinical study evaluating ceramic inlays/onlays determined that restorations bonded with simplified adhesives presented a risk of failure of 142% higher risk of failure compared to the non-simplified 3-step etch-and-rinse and 2-step self-etch adhesives (Collares et al, 2016). In a recent systematic review by Hardan et al, the use of a three-step etch-and-rinse adhesive system or the combination of an adhesive system plus a layer of flowable resin seemed to considerably enhance the bond strength to dentin in the long term with the use of the IDS technique (Hardan et al 2022). Therefore, in an effort to maximize survival of the restoration, a gold-standard adhesive with the lowest annual failure rate, Optibond FL, was selected for this study. Although these preparations entirely lacked mechanical retention, they resulted in restorations that had a fracture strength strong enough to withstand masticatory forces of the mouth. The fact that none of the restorations delaminated may be attributed to the reliable bond that may be obtained with gold-standard adhesives. The typical amount of force generated during mastication is reported to be 70-150 N, therefore the magnitude of force applied in this study during cyclic loading (10-150 N) reflects typical masticatory function (Lavelle et al, 2002). The

restorations were strong enough that when they fractured, part of the tooth often fractured with the restoration. Limitations to this study include only one type of preparation design and angulation of force. Future studies should examine the effect of IDS versus DDS techniques under same day or delayed delivery conditions on the fracture strength of other restoration types such as inlays, onlays, or full crowns, along with other types of all-ceramic restorative materials.

Conclusions

Immediate dentin sealing did not provide any significant increase in fracture strength of the overlay restorations compared to delayed dentin sealing, whether the restoration was delivered the same day or after two weeks of storage.

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Figure 1 -Teeth were prepared for a 1.5-mm-thick lithium disilicate overlay restoration

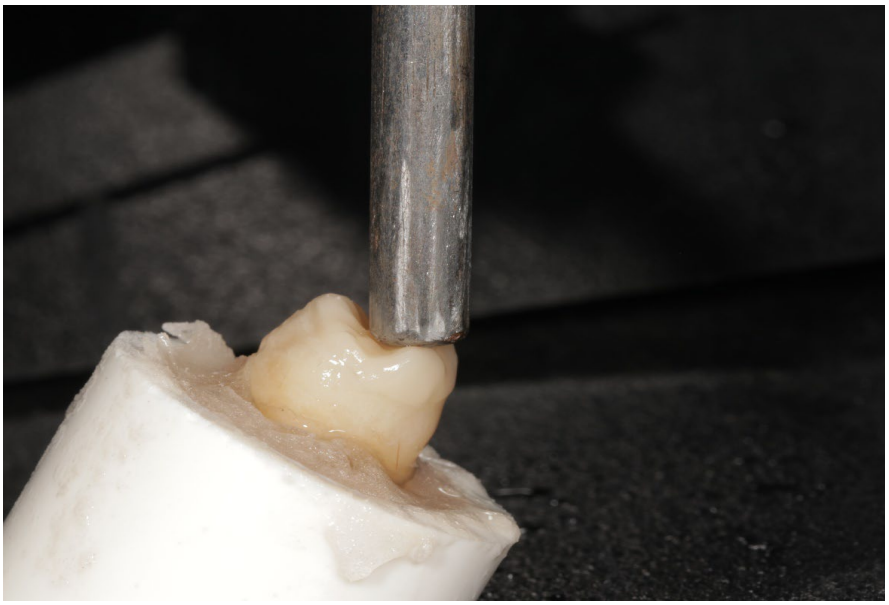

Figure 2 - A stainless-steel rod, three millimeters in diameter and with a 0.5-millimeter radius of curvature was used to load the buccal incline of the palatal cusp

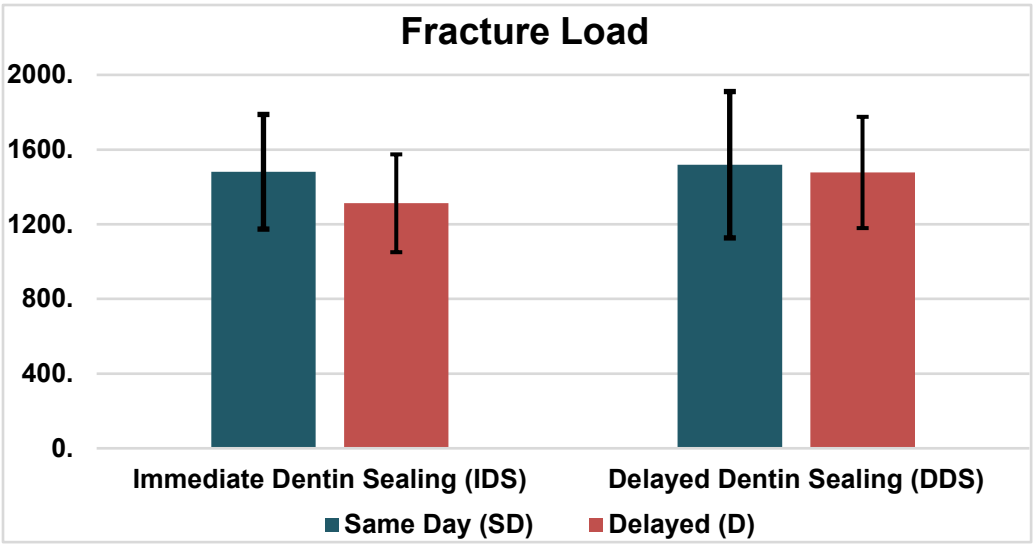

Figure 3 - Figure 1: Fracture strength of the various groups. Error bars represent ±1 standard

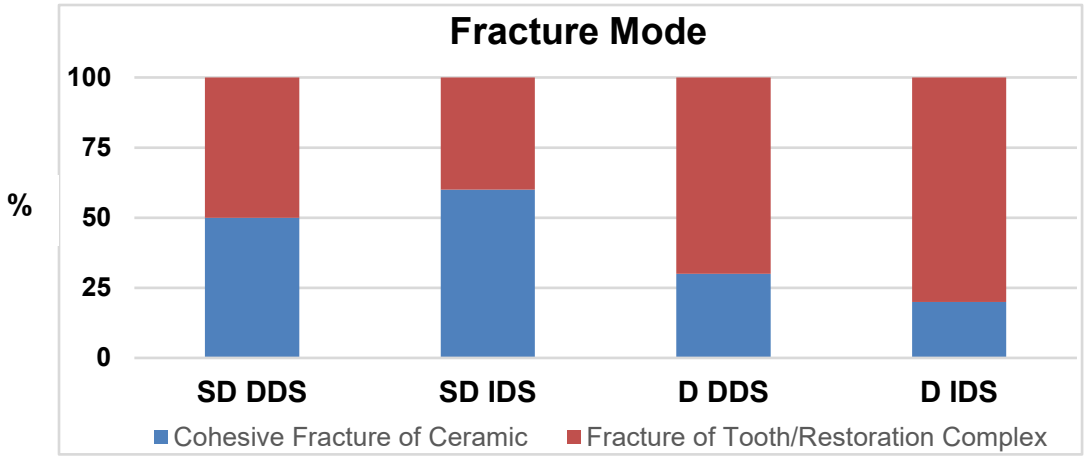

Figure 4 - Fracture mode of various groups