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The Influence of Material Type,

Preparation Design, and Tooth Substrate on Fracture Resistance of Molar Onlays

A thesis submitted in partial satisfaction

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by

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ABSTRACT OF THE THESIS

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Master of Science in Oral Biology

University of California, Los Angeles, 2016

Professor Shane White, Chair

Tooth colored all ceramic restorations have been the treatment preference of many patients for esthetics and biocompatibility. This study aimed to test the fracture resistance of posterior ceramic onlays milled with computer-aided design and computer aided manufacturing (CAD/CAM) machines.

The effects of material type, preparation design, and tooth substrate were evaluated using a full-block design. Ninety teeth were tested. Three different CAD/CAM ceramic onlay material types were included: a lithium disilicate glass-ceramic (IPS-e max CAD), a nano-filled resin-composite (Lava Ultimate), and a feldspathic porcelain (CEREC Blocs C).

Three different preparation designs were included: an anatomical occlusal onlay preparation, a concave occlusal onlay preparation, and a flat occlusal onlay preparation. Two

different tooth substrates were used: all in enamel, or in dentin with enamel peripheries. All teeth were restored and artificially aged. A load-to-failure test was used to measure the resistance to catastrophic fracture.

Three-way ANOVA determined that of all the simple main effects, and all of their possible interactions, the only significant effect on failure load was that of material type ($p < 0.0001$). The glass-ceramic and resin-composite materials were stronger than the feldspathic porcelain. Multiple range analysis determined that restorations fabricated from feldspathic porcelain were significantly weaker than those made of glass-ceramic or resin-composite materials.

The restorations in all 90 specimens fractured catastrophically; but only 26 of the 90 teeth fractured. Material type influenced the incidence of tooth fracture (Chi-square = 12, $p < 0.05$). Preparation design influenced the incidence of tooth fracture (Chi-square = 7, $p < 0.05$). Tooth substrate type did not influence the incidence of tooth fracture (Chi-square = 2, $p > 0.05$). A glass-ceramic restoration, and a concave preparation design were associated with increased incidences of tooth fracture.

Resistance to catastrophic failure is desirable, as is a failure mode that avoids vertical tooth fracture, but these results showed that these goals might be mutually exclusive.

The thesis of Shahed Ali M. Al Khalifah is approved.

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2016

DEDICATION

To Mom & Dad, the reason of what I became today.

To my idol, my Sister, the person who never stopped believing in me.

To my Brothers, my everyday inspiration.

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CHAPTER 1

INTRODUCTION

1.1 ONLAY RESTORATIONS

Onlays are partial or complete occlusal coverage all-ceramic restorations that are a conservative alternative to the full crowns. They are more conservative of tooth structure because axial and proximal tooth surfaces are largely not reduced (Edelhoff et al. 2002). In the past, onlays were almost exclusively made of gold, but glass-ceramic materials have become widely used. Feldspathic porcelains and resin composites are also used. Onlays may be adhesively bonded to tooth structure, notably to enamel. Such restorations are considered clinically acceptable alternatives to cast gold restorations and amalgam fillings (Wagner et al. 2003, Roulet 1997).

Onlays made of modern glass-ceramics have demonstrated good fatigue resistance, enough to fulfill both the functional and esthetic requirements of the oral environment (Rekow et al. 2011). Most teeth that are prepared for onlay restorations were previously been restored using MOD restorations that proved to be insufficient and needed replacement. The design of a MOD onlay preparation is led by the condition of the tooth, where the isthmus usually follows caries in the central groove of the occlusal surface. Mesial or distal proximal boxes are often used to remove proximal caries (Kishimoto et al. 1983). The loss of tooth structure, either as a result of a carious lesion or a cavity preparation, reduces fracture resistance (Cavel et al. 1985). The importance of conserving enamel and the dentino-enamel junction has long been recognized; however, this is balanced by a perceived need for thickness of the restorative material forming the onlay. When a cavity is wide bucco-lingually, it has lower fracture strength than an intact tooth (Mondelli et al. 1980). Clinically, glass-ceramic onlay restorations and the natural tooth cusps are susceptible to fracture under occlusal forces (Eakle et al. 1986).

Dentists are daily confronted by choices among onlay material type, preparation design, and tooth substrate.

1.2 RESTORATIVE MATERIAL TYPES

Material choices for onlays include glass-ceramics, porcelains and resin-composite materials. Glass-ceramics contain crystalline components within a glassy matrix. Glass-ceramics have adequate strength, excellent wear resistance, excellent stability, and tend to be biologically inert. However, glass-ceramics are inherently brittle and demanding to polish. Furthermore, they are generally formed from homogenous blocks without internal shading, so customization is generally performed through the addition of external stains; these may not appear natural and may be subject to wear. Glass-ceramics are produced either as ingots for pressing, or blocks for machining. Lithium disilicate based glass-ceramics, $Li_2Si_2O_5$ containing 35 to 44-vol% of evenly spread leucite crystals (1 to 5 μm), have a high flexural strength of approximately 340 MPa and high elastic moduli (Leung et al. 2015).

Another machinable tooth-colored restorative material that has been improved and gained popularity during the last few years is the nano-filled resin-composite. This material contains 80 %, by weight, silica or zirconia nanoparticles within a resinous matrix. Resin-composites have moderate flexural strengths of approximately 180 MPa and low elastic moduli (Awada and Nathanson 2015). Although older resin-composite blocks had a high material wear and loss of surface polish, new formulations have been developed to improve these properties. Interestingly, a major manufacturer has recently recommended that one of their resin-composite products be limited to inlays and onlays not crowns “because crowns are debonding at a higher-than-anticipated rate” (3M). Teeth that are restored with composite onlay restorations showed a higher fracture resistance than those restored using a glass-ceramic (Brunton et al. 1999).

Feldspathic porcelain is one of the oldest esthetic restorative materials. With a low to moderate leucite content, it is mainly composed of 63% silicon dioxide and 19% aluminum dioxide. It has a relatively high modulus of elasticity, comparable to enamel and glass-ceramics, but a relatively low flexural strength. Machinable dental porcelains are more structurally reliable than traditionally fired porcelain from powders (Tinschert et al. 2000). Machinable dental porcelains are now available in the form of sintered blocks.

1.3 PREPARATION DESIGNS AND RESTORATION THICKNESS

Restoration fracture is not only be related to the mechanical properties of the material used. Preparation design and restoration outline may contribute to onlay failure (Federlin et al. 2007). Different onlay preparation designs have been described. On one hand, preparation designs have been centered on traditional concepts, using a restrictive retention form (Banks 1990). On the other hand, designs that do not use any retention form, relying solely on adhesive cements have also been described (Broderson 1994, Van Dijken et al. 2001). The mechanical properties of the restorative material should accommodate the preparation design (Esquivel-Upshaw and Anusavice 2000).

The thickness of any onlay restoration must be considered during tooth preparation. In stress bearing areas, a minimum thickness of 1 - 2 mm has been recommended (Mondelli et al. 2007, St-Georges et al. 2003). Occlusal reduction of cusps and pulpal floors are designed to permit 1.5 – 2.0 mm thickness. Axial reduction should have 1.0 – 1.5 mm thickness (Etemadi at al. 1999). With the development of superior CAD/CAM techniques and advanced adhesive technology, more conservative thinner restorations can also be considered (Magne et al. 2010).

1.4 ONLAY FABRICATION

One approach is to use industrially prefabricated blocks, which are milled using computer-aided design and computer-aided manufacturing (CAD/CAM). There is an increase popularity of restorations of this technology among clinicians. CAD/CAM has noticeably evolved in the past few decades. The goal of this technology is standardized, reproducible production that is both efficient and accurate (Miyazaki et al. 2009). It facilitates chairside fabrication of individual restorations. Compared to lab-processed dental ceramic materials, the industrially prefabricated blocks possess better structural homogeneity and fracture strength (Tinschert et al. 2000).

1.5 TOOTH SUBSTRATE

Enamel and dentin with their markedly different characteristics as a bonding substrate, and as a load bearing substrate, affect the performance of the restoration (Reis et al. 2007). Bonds to dentin are generally weaker and less predictable than those to enamel (Swift 2002). Dentin is almost an order of magnitude more flexible than enamel. It has been reported that failures of porcelain laminate veneers are associated with dentin exposure (Gurel et al. 2013). Bonding resin-composites to enamel has been shown to reduce the deformation of cusps under occlusal loading (Morin et al. 1984). Class II restorations bonded to enamel and dentin are more fracture resistant than similarly prepared but unrestored teeth and also than teeth restored with enamel-bonded composite resin (Eakle 1986). At least in the short term, it appears that bonded restorations can restore strength lost to damaged teeth.

1.6 OBJECTIVES

All types of brittle CAD/CAM-fabricated restorations are subject to fracture during mastication (Scherrer and de Rijk 1993). The aim of this study is to test the influence of material type, preparation design, and tooth substrate on fracture resistance of molar onlay restorations.

CHAPTER 2

METHODOLOGY

2.1 EXPERIMENTAL DESIGN

We used 3 different CAD/CAM materials, 3 preparation designs, and 2 different thicknesses to test the influence of Material Type, Preparation Design and Tooth Substrate on fracture resistance of molar onlay restorations. We used a randomized full block design.

2.2 TOOTH SPECIMENS

A sample size of 90 upper and lower third molars, comparable in size, was used. All teeth were cleaned, checked for micro cracks under the microscope, and initially disinfected in 10% formalin solution. Each tooth was mounted centrally in a 1-inch phenolic ring mold (Ted Pella, Redding, California) with a self-cure acrylic resin (Opti-Cryl, New Stetic, Guarne, Colombia). Teeth were inserted in the resin to the level of 1 mm below the cementoenamel junction (CEJ). Specimens were stored in water until the time of onlay preparation.

2.3 TOOTH PREPARATION & TOOTH SUBSTRATE FOR ONLAYS

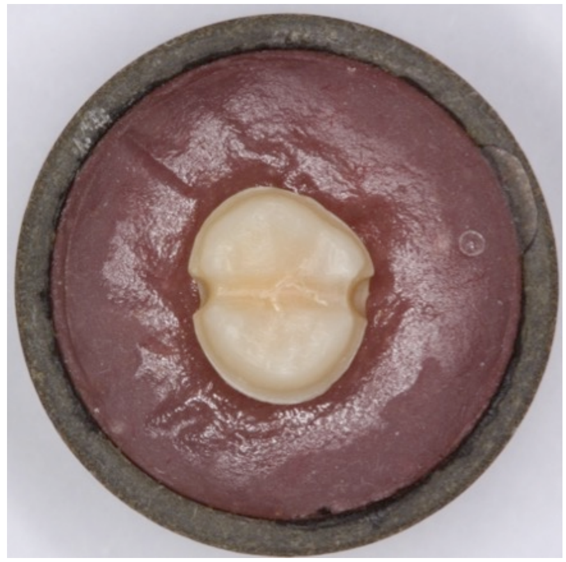
The total number of mounted teeth was divided into 3 groups by preparation design, 30 teeth had an anatomical occlusal onlay preparation (Figure 1), 30 had a concave occlusal onlay preparation (Figure 2), and the remaining 30 had a flat occlusal onlay preparation (Figure 3). All 90 teeth had both mesial and distal proximal boxes. An isthmus preparation was placed in the central groove area, connecting the proximal boxes. All onlay preparations covered both the buccal and lingual cusps. The all enamel substrate preparation had 1.0 mm tooth reduction and a

1.0 mm restoration thickness, whereas the dentin preparation with an enamel periphery had 1.5 mm tooth reduction and a 1.5 mm restoration thickness (Table 1). Occlusal reduction was completed using a KS diamond bur no. 2, the proximal box using a KS diamond bur no. 1, and the preparation was finished with a carbide bur no. 8881 (Brasseler USA, Savannah, GA).

Figure 1. Anatomical type onlay preparations: Enamel only substrate (a & b); Dentin with enamel periphery substrate (c & d).

a.

b.



c.

d.

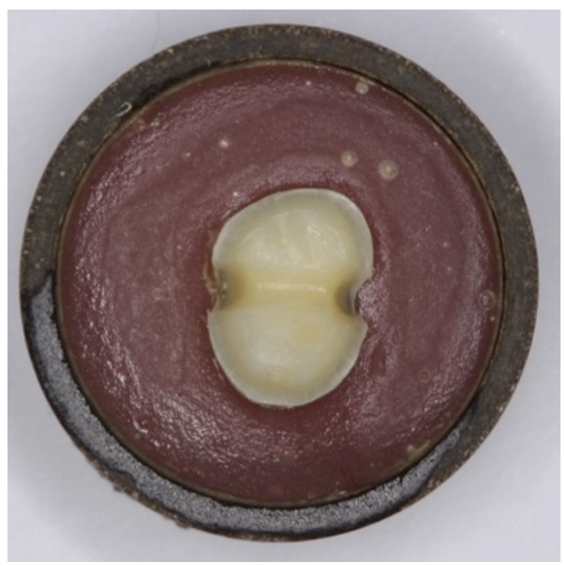
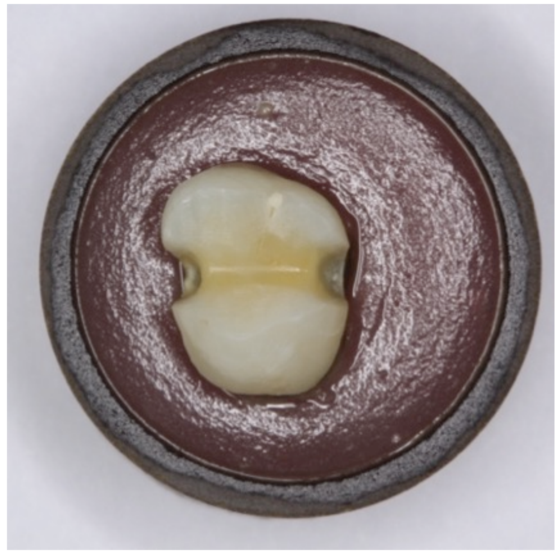


Figure 2. Concave type onlay preparations: Enamel only substrate (a & b); Dentin with enamel periphery substrate (c & d).

a.

b.



c.

d.

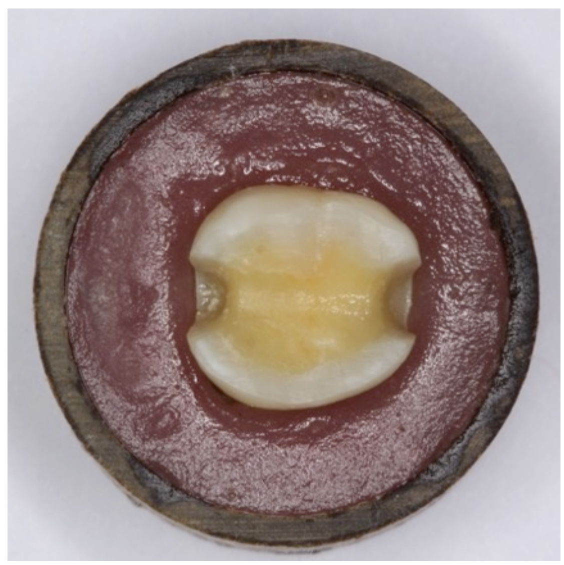
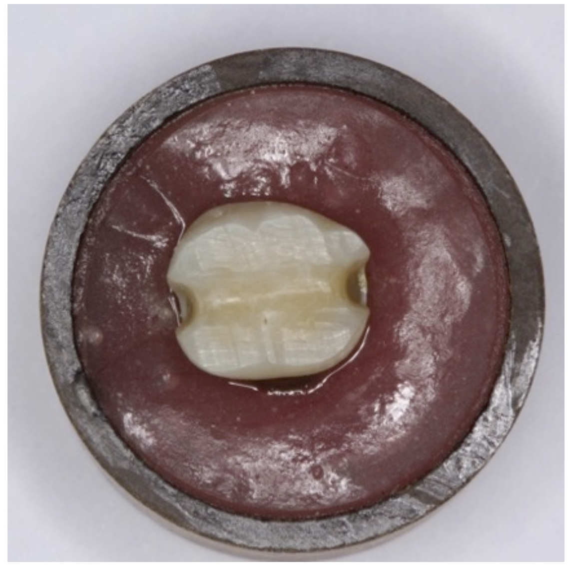


Figure 3. Flat type onlay preparations: Enamel only substrate (a & b); Dentin with enamel periphery substrate (c & d).

a.

b.



c.

d.

Table 1. Sample description, showing distribution of material type, tooth substrate, and preparation subgroups.

	Glass Ceramic	Resin Composite	Feldspathic Porcelain	Total
Enamel Substrate & Anatomical Preparation	5	5	5	15
Dentin with Enamel Periphery & Anatomical Preparation	5	5	5	15
Enamel Substrate & Concave Preparation	5	5	5	15
Dentin with Enamel Periphery & Concave Preparation	5	5	5	15
Enamel Substrate & Flat Preparation	5	5	5	15
Dentin with Enamel Periphery & Flat Preparation	5	5	5	15
Total	30	30	30	90

2.4 ONLAY MATERIAL TYPES, MILLING AND CEMENTATION

Onlay materials tested in this study included: a lithium disilicate glass-ceramic (IPS-e max CAD, Ivoclar Vivadent, Schaan, Liechtenstein), a nano-filled resin-composite (Lava Ultimate, 3M ESPE, Neuss, Minnesota), and a feldspathic porcelain (CEREC Blocs C, Sirona, Bensheim, Germany). Restorations were designed and milled using a CAD/CAM system (CEREC Bluecam, Sirona, Bensheim, Germany). The intaglio surfaces of the Onlays were fitted onto their respective preparations with occlusal articulation spray (Arti-Spray, Bausch, Köln, Germany) to disclose discrepancies, which were subsequently adjusted to insure accurate fit. Glass-ceramic IPS-e max CAD restorations were crystallized in a ceramic furnace (Programat CS, Ivoclar Vivadent, Schaan, Liechtenstein) following manufacturer recommendations. Resin-composite Lava Ultimate and feldspathic porcelain CEREC Blocs C restorations were finished and polished using ceramic polishing system burs (Dialite Ultra Kit, Brasseler USA, Savannah, Georgia). The fitting surfaces of all onlay restorations were sandblasted using aluminum oxide particles (50 μm) avoiding onlay margins. Onlays were cemented using a dual cure resin luting cement (Duo-Link Universal, Bisco, Schaumburg, Illinois) with a total etch two-step adhesive (ACE All-Bond TE, Bisco Schaumburg, Illinois).

2.5 AGING OF THE RESTORATIONS

Bonded specimens were stored in room temperature water for 10 days. Then they were subjected to artificial aging through thermal cycling (Proto-tech, Portland, Oregon) 1,500 times from 5°C to 55°C. The transfer time was 3 seconds. A long dwell time of 45 seconds was used to ensure that the specimens reached the desired temperatures in each cycle.

2.6 TESTING THE RESTORATIONS

Testing of fracture resistance was done using a universal testing machine (Model 5966; Instron Corp, Canton, Massachusetts) at a crosshead speed of 0.1 mm/min. Compressive loading was applied using a tungsten carbide ball bearing (4.75 mm in diameter) centered between the cusps on the occlusal surface of each restoration. Samples were mounted at a 20° axial inclination. Catastrophic fracture loads were recorded for each specimen and the pattern of failure was observed.

2.7 STATISTICAL ANALYSIS

Three-way ANOVA ($p < 0.05$) was used to elucidate the influence of the 3 simple main effects of: Material Type (glass-ceramic, resin-composite, or feldspathic porcelain); Preparation Design (anatomical, concave or flat); and Tooth Substrate (1.0 mm reduction/thickness in enamel or 1.5 mm reduction/thickness in dentin with an enamel periphery), and their 4 possible interactions on the load needed to cause catastrophic failure.

In the event that any of the simple main effects had a significant influence on failure load, a multiple comparisons test, Tukey's honest significant difference test ($p < 0.05$) was used to discern differences among subgroups.

The incidences of tooth fracture, as distinct from restoration fracture, were compared by the main effects of material type, preparation design, and tooth substrate using Chi-square tests ($p < 0.05$). In the event that any of the main effects had a significant influence on the incidence of tooth fracture, pairwise comparisons were performed ($p < 0.05$).

CHAPTER 3

RESULTS

Three-way ANOVA determined that of all the simple main effects of material type, preparation design, and tooth substrate, and all of their possible interactions, the only significant effect on failure load was that of material type ($p < 0.0001$) (Table 2). Multiple range analysis determined that restorations fabricated from feldspathic porcelain were significantly weaker than those made of glass-ceramic or resin-composite materials. All material types demonstrated mean fracture strengths above 800 N.

The restorations in all 90 specimens fractured catastrophically; however, only 26 of the 90 teeth fractured (Figures 4 & 7). Material type influenced the incidence of tooth fracture (Chi-square =11.8, $p < 0.05$). The glass-ceramic material group had a higher incidence of tooth fracture than the feldspathic porcelain material (Chi-square = 11.4, $p < 0.05$) (Table 3); however, it also had a significantly higher resistance to fracture load than feldspathic porcelain (Table 3, Figure 5). Preparation design influenced the incidence of tooth fracture (Chi-square = 7.2, $p < 0.05$). The concave preparation had a higher incidence of tooth fractures than the anatomical design (Chi-square = 6.2, $p < 0.05$) (Table 3); however, preparation design did not influence resistance to fracture load (Table 2). Tooth substrate type did not influence the incidence of tooth fracture (Chi-square = 2, $p > 0.05$).

Table 2. Three-way AVOVA for catastrophic fracture load.

Source of Variation	Sum of Squares	Degrees of Freedom	F-ratio	Significance Level
MAIN EFFECTS				
Material Type (MT)	4358605	2	12	< 0.0001
Preparation Design (PD)	794084	2	2	0.1
Tooth Substrate (TS)	46941	1	0.3	0.6
INTERACTIONS				
MT*PD	889812	4	1	0.3
MT*TS	662140	2	2	0.2
PD*TS	1057554	2	3	0.1
MT*PD*TS	227811	4	0.3	0.9
RESIDUAL	13190816	72		
CORRECTED TOTAL	21227764	89		

Figure 4. Incidence of tooth fracture in material type, preparation design and tooth substrate groups.

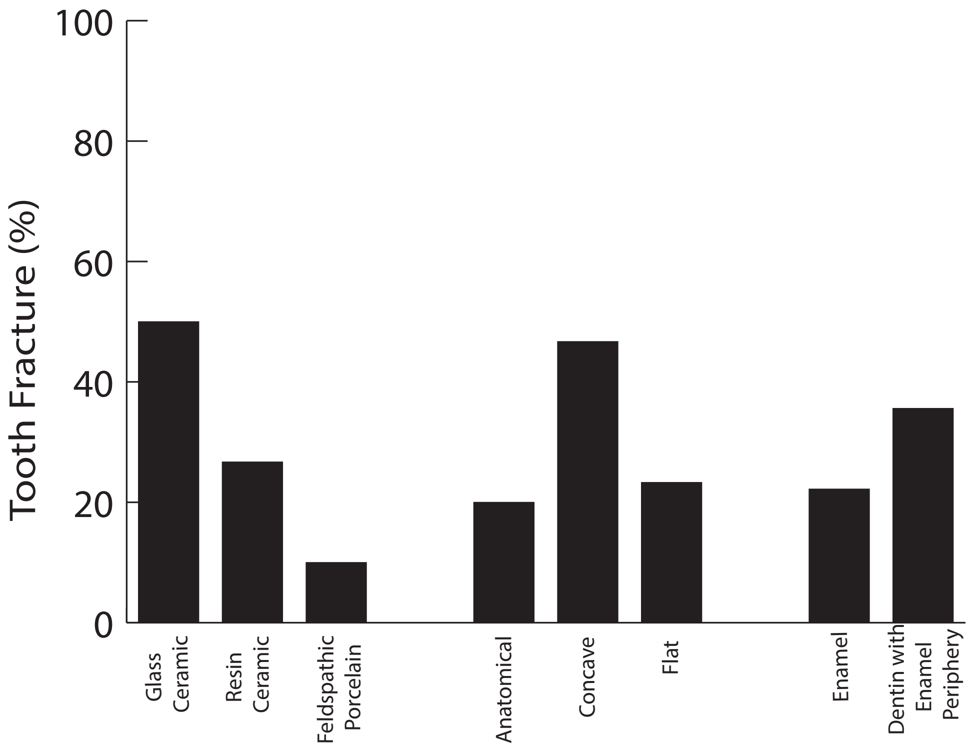


Figure 5. Main effect subtypes, means and standard deviations; groups linked by a horizontal line did not differ from one another.

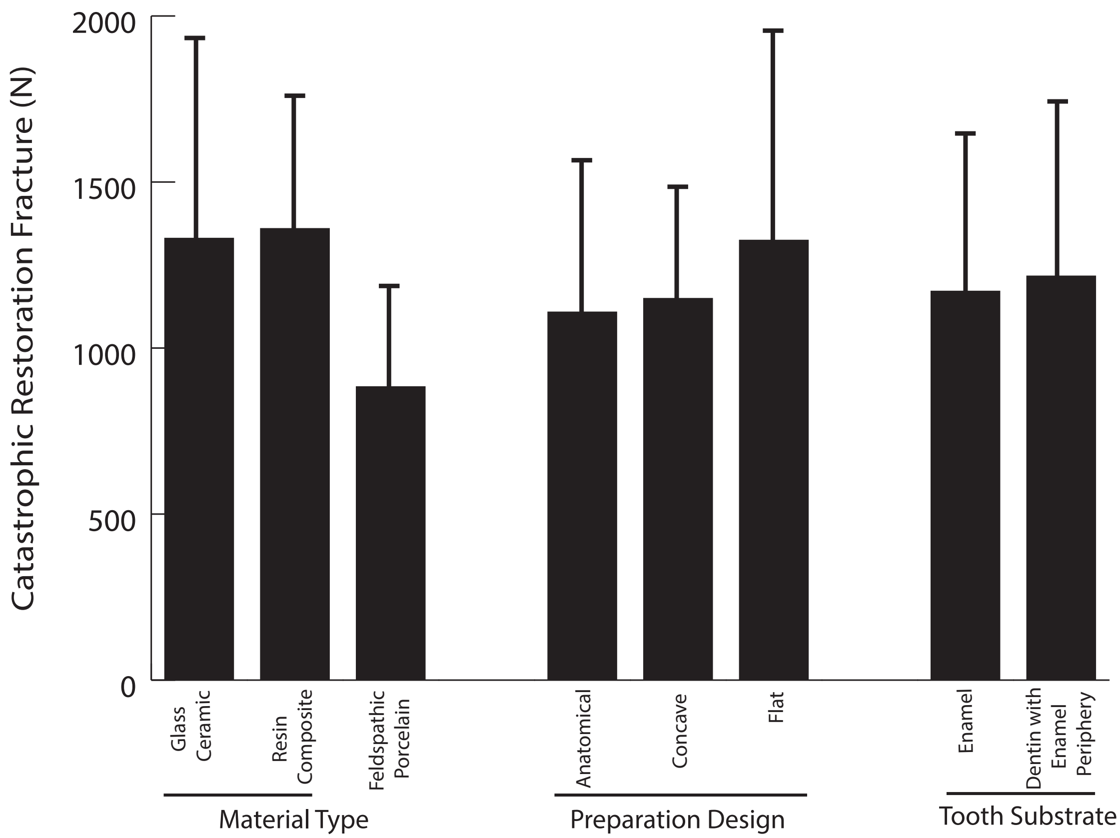


Figure 6. Means and standard deviations of material type, preparation design and tooth substrate subgroups, where glass-ceramic is G, resin-composite is R, feldspathic porcelain is P, anatomical preparation is A, concave preparation is C, flat preparation is F, and enamel substrate throughout is E, and dentin substrate with enamel periphery substrate is D.

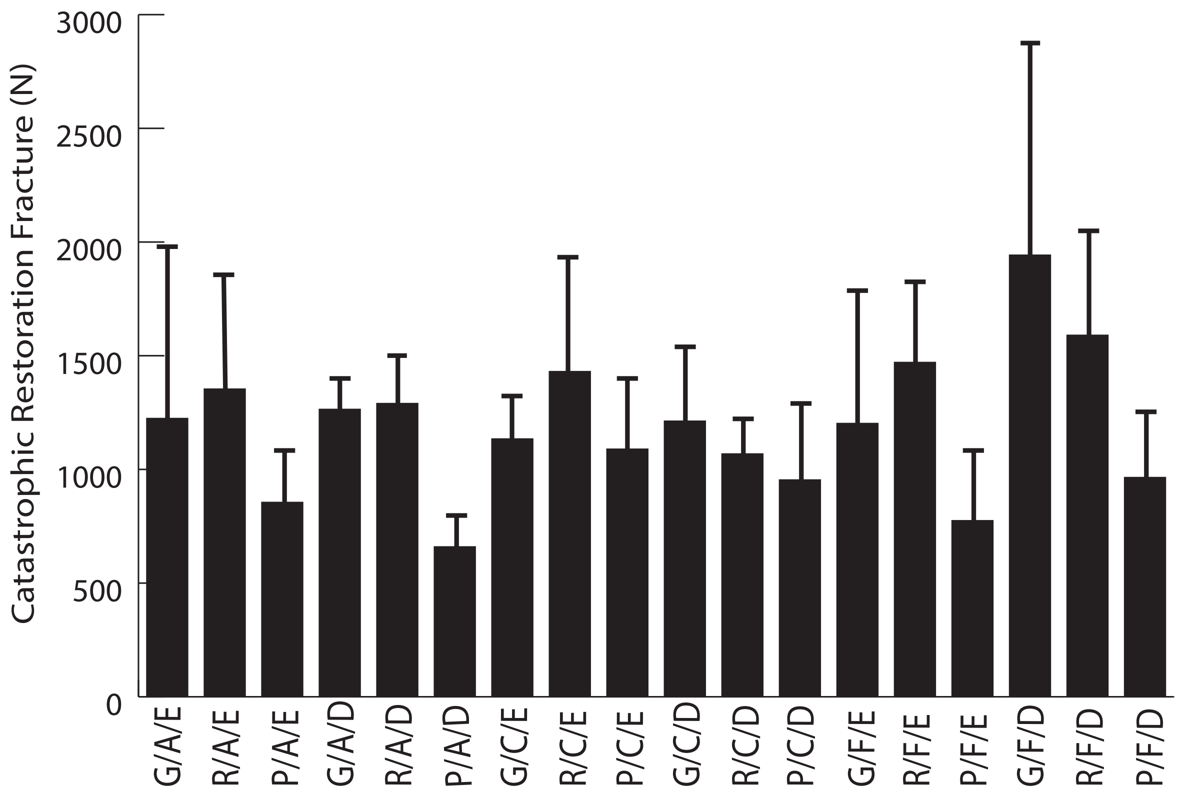
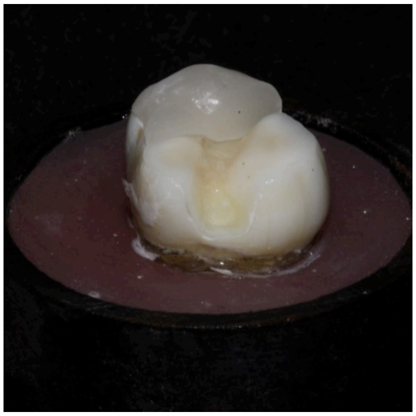


Table 3. Incidence of tooth fracture by material type, preparation design, and tooth substrate.

	Number of specimens with tooth fracture	Chi-square value & p value (Detailed)	Chi-square value & p value (General)
MATERIAL TYPE Glass-Ceramic Resin-Composite	 15 / 30 8 / 30	 3.5, > 0.05	
Glass-Ceramic Feldspathic Porcelain	15 / 30 3 / 30	11.4, < 0.05	11.8, < 0.05
Resin-Composite Feldspathic Porcelain	8 / 30 3 / 30	2.8, > 0.05	
PREPARATION DESIGN Anatomical Concave	 5 / 30 14 / 30	 6.2, < 0.05	
Anatomical Flat	5 / 30 7 / 30	0.4, > 0.05	7.2, < 0.05
Concave Flat	14 / 30 7 / 30	3.6, > 0.05	
TOOTH SUBSTRATE Enamel Dentin with Enamel Periphery	 10 / 45 16 / 45	 1.9, > 0.05	 1.9, > 0.05

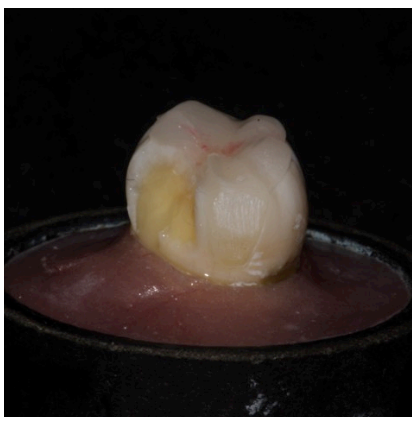
Figure 7. Illustration of representative specimen fractures: Restoration only fractures (a & b); Restoration and tooth cusp fractures (c & d); Restoration and deep vertical fractures involving the pulp chambers (e & f).

a.

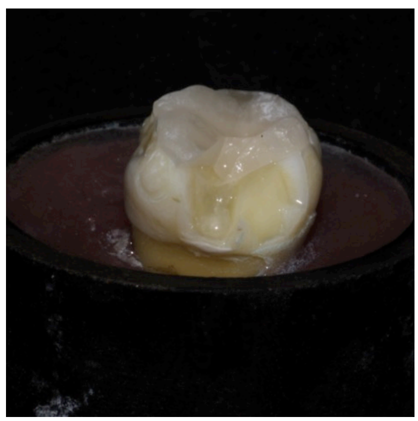


b.

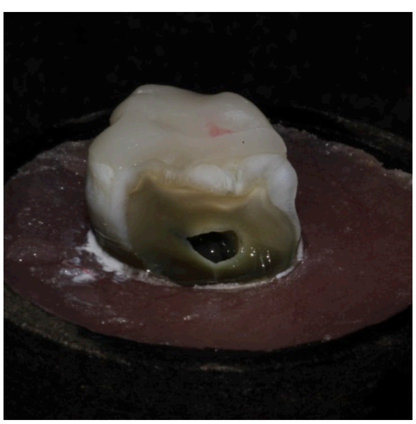
c.



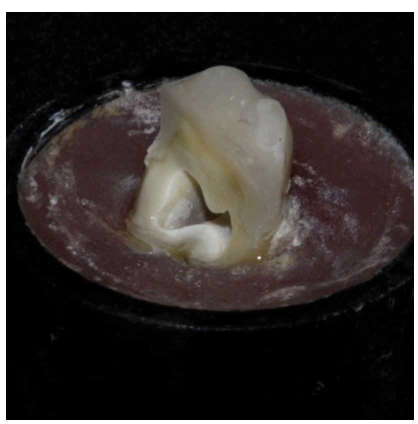
d.



e.



f.



CHAPTER 4

DISCUSSION

Although many different preparation designs, which result in different tooth substrates and material types have been advocated for onlays, this study with 3 main variables and a total of 18 subgroups found surprisingly few differences among these approaches with respect to catastrophic failure load. Of the 3 main variables, only material type produced a significant effect; however, this effect was both strong and highly significant, accounting for more experimental variation than all other factors together (Table 2).

Feldspathic porcelain was significantly weaker than the alternative materials even when bonded completely to enamel (Figures 5 & 6). This static in-vitro test suggested that onlays constructed of feldspathic porcelain were inferior to those fabricated of a glass-ceramic or a resin-composite. Although the pre-cured milled resin-composite restorations were as strong as the glass-ceramic restorations, they are inherently less physically stable, have less color stability, and are less wear resistant. But, resin-composites have some advantages in that they have less chipping during milling, smoother surfaces after milling, and are easier to polish than glass-ceramics or feldspathic porcelains. A recent study that compared a glass-ceramic, new dual-network hybrid resin-composite, and feldspathic porcelain determined that the glass ceramic had superior fracture resistance (Albero et al. 2015).

Whereas, differences were not found among the different tooth preparation designs and tooth substrates with respect to catastrophic failure, this does not mean that they are equal clinically. The anatomical type preparation design was a conservative preparation that over-wrapped or capped the cusps. This design aimed to reduce only a small portion of the occlusal surface, specially preserving an enamel substrate. However, capping the cusp entails removal of enamel on the outer cusp slopes. Also, having a thin circumferential restoration margin might increase the risk of restoration chipping. The concave type preparation design maintained the most occlusal thickness in the center of the restorations, but it was found that this did not increase resistance fracture load (Table 2). Furthermore, the concave design was associated with the highest incidence of tooth fracture (Table 3). The flat preparation type preserved the outer cuspal slopes, but preserved less of the cusp tips. The flat preparation was simpler to design, prepare and mill. The flat preparation also maintained increased restoration thickness at the margins, possibly decreasing chipping.

Tooth substrate type did not influence catastrophic failure load; however, the restorations placed on all-enamel preparations were by anatomical necessity, thinner than those placed on dentin with an enamel periphery. This suggests that there is no cost, in terms of restoration strength, in preserving enamel with a conservative 1 mm shallow preparation. In other words, additional tooth reduction, to make a thicker restoration had no advantage. Preservation of precious tooth structure, particularly of enamel and the dentino-enamel junction (DEJ), is a guiding principle, particularly if we consider the finite life of an artificial restoration in comparison to the long life of a patient; re-restoration is often necessary.

The variables examined in this current study were chosen to directly address the decisions that dentists must make when planning geometrically complex preparation onlay designs in anatomically complex teeth, and spanning a broad range of representative restorative materials choices. We are currently unaware of any directly comparable studies. A few related studies produced some contrasting and some complimentary results, but these studies differed in many ways, principally in making fewer or no restorative materials comparisons; in using fewer, simplified, or just a single preparation design; and in not comparing enamel and mostly dentin substrates (Federlin et al. 2007, Piemjai and Arksornnukit 2007, Guess et al. 2013, Ma et al. 2013, Chen et al. 2014, Aboushelib and Elsafi 2015, Rojpaibool and Leevailoj 2015, Sasse et al. 2015, Shembish et al. 2015). Chen et al found that varying restoration thicknesses of a machinable resin-composite and a machinable glass-ceramic cemented to a dentin analogue did not influence fracture resistance (Chen et al. 2014). Federlin et al investigated machined feldspathic porcelain partial crowns to find that increased restoration thickness significantly reduced the incidence of restoration fracture during combined thermal cycling and cyclic mechanical loading (Federlin et al. 2007). However, it appears that dentin, not enamel, formed the majority of their tooth substrates, even in their "thin" restoration groups (Federlin et al. 2007). Piemjai and Arksornnukit investigated the compressive fracture resistance of planar square flat feldspathic porcelain laminates bonded to enamel or dentin with four adhesive systems (Piemjai and Arksornnukit 2007). They determined that restoration thickness, tooth substrate and cement type all influenced failure load.

Although few differences were found in terms of the effects of material type, preparation design, and tooth substrate on catastrophic failure load; the frequency of tooth fracture was influenced by material type and preparation design (Tables 2 & 3). Restoration failure is disappointing, but tooth failure is far more damaging. The least likely material to produce tooth fracture was feldspathic porcelain, the material least resistant to load. The material that was most resistant to fracture load was the most likely to produce tooth fracture. Resistance to catastrophic failure is desirable, as is a failure mode that avoids vertical tooth fracture. However, the goals of resistance to failure load and a failure mode that avoids tooth fracture may sadly be mutually exclusive.

Interestingly, the concave design, more wedge-shaped than the flat design and less conservative than the anatomical design, produced a higher frequency of tooth fracture than the alternatives. As satisfactory alternatives exist, there is no reason to use the concave design.

This study had 3 variables, material type, preparation design, and tooth substrate, with a total of 18 subgroups. How does all this data guide the clinician? The data on catastrophic failure loads suggests that feldspathic porcelain not be used for molar onlays. The data on tooth fracture suggests that concave tooth preparations be avoided (Table 3, Figure 4). As there is no advantage to removing precious enamel, it should be preserved. On the basis of the two outcome measures, catastrophic failure load and absence of tooth fracture, it appears that resin-composites may be superior to glass-ceramics, but they are inherently less stable. Ultimately, fatigue studies, wear studies, and clinical trials are needed.

This study included storage in water followed by artificial aging through rigorous thermal cycling, exposing the restored specimens to repeated mechanical stresses through differential thermal expansion and contraction and the specimens loaded to failure. Hence, this study was quasi-static in nature. Whereas, restored teeth undergo repeated loading for many years before failure in-vivo. Therefore, the results of this study should be interpreted with caution. However, this study efficiently allowed comparison of 3 main effects and 18 groups. The current findings highlighted the importance of materials selection and preparation design.

Future work should address the effects of high-cycle mechanical fatigue in an aqueous environment on onlay restorations, better simulating oral function. However, fatigue testing is lengthy and resource-intensive. The influences of tooth substrate, including bond strength and elastic modulus differences between enamel and dentin, may become more pronounced. Likewise the influences of the mechanical properties of the restorative materials, including elastic modulus and physical stability differences between glass-ceramic and resin-composite, may become more pronounced. This current work has shown that here is no further need to include feldspathic porcelain or concave preparations; this would reduce the number of groups from 18 to 8, increasing the feasibility of a comprehensive high-cycle fatigue study.

CHAPTER 5

CONCLUSION

Of the three main effects, material type, preparation design and tooth substrate, only material type influenced the load needed to cause catastrophic failure of bonded onlays. Restorations fabricated from feldspathic porcelain were significantly weaker than those made of glass-ceramic or resin-composite materials. However, the incidence of tooth fracture was influenced by material type and preparation design. A glass-ceramic material, and a concave preparation design were associated with increased incidences of tooth fracture. Resistance to catastrophic restoration failure is desirable, as is a failure mode that avoids tooth fracture, but these goals may be mutually exclusive.

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