Original Article

Fracture Resistance of Occlusal Ceramic and Composite Molar Onlay Comparing to Lithium Disilicate Molar Crown

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Abstract

This *in vitro* study aimed to evaluate fracture strength and failure modes of thin occlusal onlays fabricated from direct resin composite, CAD/CAM polymer-infiltrated ceramic-network/hybrid ceramic, and CAD/CAM lithium-disilicate glass ceramic under compressive loading. Forty extracted maxillary molars were prepared, including occlusal enamel and dentin removal, leaving two dentin slopes with peripheral enamel. Thirty teeth were restored with 0.6-mm-thick occlusal onlays using direct resin composite (Premise), CAD/CAM polymer-infiltrated ceramic-network/hybrid ceramic (Vita Enamic), and CAD/CAM lithium-disilicate glass ceramic (IPS e.max CAD). Others were restored with IPS e.max CAD crowns (n=10). The milled restorations were luted with adhesive resin cement. All restored teeth were loaded vertically by means of a universal testing machine. Fracture loading data were recorded in Newtons (N) and statistically analyzed. The failure modes were classified, and correlations between fracture strength and failure mode were analyzed. The fracture strengths (mean±SD) were ranging from 1,949.59 to 2,870.44 N. The IPS e.max CAD onlays showed significantly higher fracture strength than the IPS e.max CAD crowns ($p<0.05$). There was no correlation between fracture strength and failure modes found within each material. In conclusion, the fracture strength of the Vita Enamic occlusal onlay was comparable with that of the Premise occlusal onlay and the IPS e.max CAD onlay. The IPS e.max CAD onlay provided higher fracture resistance than the IPS e.max CAD crown. However, all restorations demonstrated higher fracture resistance than that required for the average force of mastication.

Keywords: CAD/CAM, Lithium-disilicate ceramic, Polymer-infiltrated ceramic network, Thin occlusal onlay

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Introduction

Noncarious tooth surface loss is a normal physiological process occurring throughout life, but it usually becomes a problem affecting function and esthetics or causes sensitivity and pain.[1,2] It is the accumulation of a small amount of structure loss each year over time due to multifactorial etiology, including the aging process.[2,3] However, the premature and accelerated loss of enamel by gastroesophageal reflux disease (GERD) or erosion caused by bulimia nervosa may occur in adolescence or childhood.[4,5] The occlusal tooth structure loss in posterior teeth affects mastication capacity, occlusal stability, vertical dimension, and overall patient satisfaction with esthetic, pain, and oral comfort.[6] Early diagnosis and treatment are critical to the cessation of tooth structure loss that leads to tooth sensitivity or pulp pathology. In the past, treatment of advanced occlusal tooth structure loss was by conventional full-coverage crowns, which offer an acceptable esthetic outcome and improved mechanical properties but require significant tooth reduction. Currently, adhesive techniques combined with improved restorative material properties allows for advanced occlusal tooth surface loss to be restored with thin occlusal onlays, not only following the strategy of minimal reduction but also achieving acceptable esthetic, mechanical, functional, and biological outcomes.[7-11]

Dental CAD/CAM (computer-aided design/ computer-aided manufacturing) technology was first developed in 1971[12] and has been developed over time with many advantages, including speed, ease of use, and quality control.[13-15] The first chairside CAD/CAM system, CEREC (Sirona Dental Systems GmbH, Bensheim, Germany), was introduced in 1987. It allows dentists to provide indirect restorations fabricated from commercial blocks in a single visit.[13,14]

Several materials can be fabricated with CAD/ CAM technology, including a lithium-disilicate glass ceramic such as IPS e.max CAD (Ivoclar Vivadent, Schaan, Liechtenstein) and a polymer-infiltrated ceramic-network such as Vita Enamic (Vita Zahnfabrik, Bad Säckingen, Germany). Vita Enamic is comprised of a structure-sintered ceramic matrix with space between ceramic substrates filled with resin material to form a double-network hybrid.[16] It offers the combined benefits of ceramic and composite. The inorganic portion (86 wt%) provides stability, and the infiltrated organic copolymer portion (14 wt%) provides elasticity.[16,18-21] This material is claimed to absorb masticatory forces and stop crack formation.[22-25] Moreover, it can be milled at relatively thin thicknesses to achieve conservative tooth preparations.[9] Thus, Vita Enamic is a potential candidate for thin occlusal onlays utilized for reconstruction of lost occlusal surface.

The fracture strength of thin occlusal onlays fabricated with a polymer-infiltrated ceramic network, direct resin composite, and lithium disilicate ceramic compared with that of a lithium disilicate crown has not been clarified. This study aimed to evaluate the fracture strengths and failure modes of thin occlusal onlays fabricated from direct resin composite or CAD/ CAM hybrid ceramic blocks or CAD/CAM lithium disilicate ceramic blocks compared with crowns under vertical compressive loading. The null hypothesis was that there would be no significant difference in the fracture strengths between groups with various restorative and material types.

Materials and Methods

The Ethical Committee, Faculty of Dentistry, Chulalongkorn University, approved the research protocol involving the collection of human teeth due to non-occlusion (approval number: HREC-DCU 2017-014). Criterias for tooth selection are shown in Table1.

Tooth preparation

Forty extracted maxillary molars were inserted into a polyvinyl chloride (PVC) mold filled with auto-polymerizing acrylic resin (Palapress; Heraeus Kulzer

GmbH, Hanau, Germany). Teeth were embedded up to 3 mm below the cemento-enamel junction (CEJ), controlled by a surveyor.[7,8]

All teeth were subjected to standardized preparation by means of round-ended tapered diamond burs (D8; Intensiv, Montagnol, Switzerland). The entire coronal tooth structure was sectioned axially, leaving 5-mm height of a flat area of exposed dentin and peripheral enamel. Then, the central groove was deepened by 2 mm, and two slopes from buccal and palatal margins were created, smoothed, and ended at the central groove (Fig. 1). After that, all prepared teeth were randomly divided among four groups (n=10) according to the type of restoration and material used (Table 2). Teeth in Cr-EMX group were then additionally prepared for the all-ceramic crowns. Dimensions of preparation were done according to the manufacturer's instructions as follows: 1.0-1.5 mm buccal and lingual reduction and 0.8- to 1.0-mm-deep chamfer margin with 0.5 mm above the CEJ.

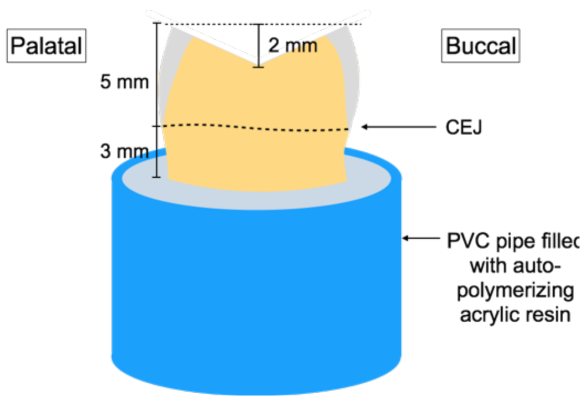

Figure 1 *Tooth preparation for occlusal onlay.*

Restoration design and fabrication

Teeth in O-CF, O-ENM, and O-EMX and Cr-EMX groups were scanned with an Omnicam scanner (Cerec AC Omnicam; Sirona Dental Systems) and designed for thin occlusal onlays and all-ceramic crowns with the Cerec4 CAD/CAM system (Sirona Dental Systems). Thickness and design parameters for occlusal onlays and crowns are shown in Table 3.

All restorations in O-CF, O-ENM, O-EMX, and Cr-EMX groups were milled in Cerec MC XL (Sirona Dental Systems) with Vita CAD Temp Block (Vita Zahnfabrik), Vita Enamic block, and an IPS e.max CAD block for thin occlusal onlays and IPS e.max CAD block for crowns. The IPS e.max CAD restorations were crystallized in a ceramic furnace (Programat P700; Ivoclar Vivadent) and polished with an all-ceramic polisher (Jota set 1358; Jota, Switzerland), while the O-ENM group were finished and polished with the Vita Enamic polishing set (Vita Zahnfabrik).

In the O-CF group, each Vita CAD Temp onlay was temporarily cemented (Temp Bond NE; Kerr) onto its corresponding prepared tooth to stabilize itself while a transparent shell was fabricated at the next step. After that, the restored teeth were scanned and designed for a 1-mm-thick transparent shell. The margin of the transparent shell was set at the height of the contour level. Subsequently, the transparent shells were milled with clear PMMA blocks (CEREC Guide Bloc; Dentsply Sirona). These transparent shells, which replicated the occlusal anatomy and dimensions of the thin occlusal onlay, were used to standardize the direct composite-restoration procedure. After removal of those Vita CAD Temp occlusal onlays, and tooth-cleaning with pumice, the transparent shells were tried-in on corresponding teeth. If the transparent shells were perfectly seated, they were removed to begin the direct composite-restoration procedure. Tooth surfaces were prepared with three-step etch-and-rinse dentin bonding system, following manufacturer's instructions (Gel Etchant, Optibond FL primer, Optibond FL adhesive; Kerr). After the resin composite (Premise A2; Kerr) was applied, the transparent shell was seated on top of the occlusal surface, excess materials were removed, and light-polymerized for 40 seconds (Demi Light Curing Unit; Kerr). All direct composite restorations were finished and polished.

Cementation of indirect restorations

The inner surfaces of restorations in the O-EMX, Cr-EMX, and O-ENM groups were prepared in accordance with manufacturer's instructions (Porcelain Etch; Ultradent, UT, Silane Primer; Kerr, Optibond Solo adhesive; Kerr) Concurrently, tooth surfaces were prepared with a two-step etch-and-rinse dentin bonding system, following the manufacturer's instructions (Gel Etchant, Optibond Solo adhesive; Kerr). All indirect restorations were cemented using dual-cured adhesive resin cement (NX3 Nexus Third Generation; Kerr) and light-polymerized for 20 seconds for each surface.

Fracture resistance testing

All restored teeth were subjected to static vertical loading at a crosshead speed of 0.5 mm/min in a universal testing machine (Instron model 5566; Instron Corp., Canton, MA), with a 3.5-mm-diameter steel tip. The compressive fracture load was recorded in Newtons (N).

Failure mode evaluation

After fracturing, the specimens were examined under a dental loupe at 2.5x magnification (Kerr). Modes of failure were categorized in the following ways: Mode FrR, fracture in the restoration only; Mode FrRE, fracture of the restoration and enamel; Mode FrRED, fracture of the restoration, enamel, and dentin; and Mode FrREDP, fracture of the restoration, enamel, dentin, and exposed pulp.[9]

Table 1 *Tooth selection criterias.*

Inclusion Criteria	Exclusion Criteria
1. permanent human maxillary molars with similar shapes and mesio-distal dimensions of 9 ± 0.5 mm	1. irregularly shaped maxillary molars
2. no dental caries, previous root canal treatment, or cracks	2. maxillary molars with incomplete root formation
3. minimal coronal height of 5 mm	-
4. no previous extractions in the preceding 3 months	-

Table 2 *Experimental group classified by type of restorations and restorative materials used.*

Group #	Group Name	Type of Restorations	Materials	Shade
1	O-CF	Thin occlusal onlay	direct resin composite (Premise, Kerr, Orange, CA)	A2
2	O-ENM	Thin occlusal onlay	polymer-infiltrated ceramic network (Vita Enamic, Vita Zahnfabrik)	2M2 HT
3	O-EMX	Thin occlusal onlay	lithium disilicate glass ceramic (IPS e.max CAD, Ivoclar Vivadent)	LT A1
4	Cr-EMX	Full coverage crown	lithium disilicate glass ceramic (IPS e.max CAD, Ivoclar Vivadent)	LT A1

Table 3 *Design parameters for crowns and thin occlusal onlays.*

Parameter	Value (μm)	
	Crown	Occlusal onlay
Restoration thickness	average uniform thickness of 1-1.5 mm.	minimum thickness of 0.6 mm at the central groove, a maximum thickness of 1.3 mm at cusp tips, 1.0 mm at the internal cusp slope
Spacer	50	30
Marginal adhesive gap	0	0
Minimal thickness (occlusal)	1,500	600
Minimal thickness (radial)	1,000	-
Margin thickness	50	50

Statistical analysis of data

Data on the fracture load and modes of failure were collected and analyzed (IBM SPSS Statistics, v 20.0). The data on the fracture load were heterogeneous and normally distributed. One-way ANOVA and Games-Howell post hoc test were used to analyze the differences in failure load among groups (α=0.05). The correlation between the fracture load and mode of failure was tested by Spearman's rank-order correlation (α=0.05).

Results

The fracture strengths of all groups were analyzed (Table 4, Figure 2). All restorations exhibited fracture at average loads ranging from 1,949.59 N for Cr-EMX to 2,870.44 N for O-EMX. However, one-way ANOVA and Games-Howell post hoc test showed statistically significant differences between O-EMX and Cr-EMX groups (p=0.001). No significant differences in the fracture load were found among the O-CF, O-ENM, and O-EMX groups.

The analysis of failure modes was presented in Table 4 and Figure 3. According to Hinkle's criteria[26], the analysis of the correlation between fracture load and mode of failure found that Spearman's rank-order correlation coefficient (r_s) was categorized as "little if any positive correlation" for O-CF and O-EMX groups, "little if any negative correlation" for the Cr-EMX group, and "low positive correlation" for the O-ENM group, respectively.[26] However, there were no significant differences in correlation between fracture load and mode of failure (p>0.05) in all the groups presented.

Table 4 Average fracture strength (mean ± standard deviation) and mode of failure.

Group	Fracture strength Mean ± SD (Newtons)	Mode of failure					
		FrR	FrRE	FrRED	FrREDP	r_s	p
O-CF	2,438.66 ± 678.25 ^{a,b}	2	1	2	5	0.254	0.497
O-ENM	2,358.86 ± 396.17 ^{a,b}	0	7	2	1	0.315	0.376
O-EMX	2,870.44 ± 414.95 ^{a}	1	4	2	3	0.108	0.766
Cr-EMX	1,949.59 ± 215.15 ^{b}	8	0	0	2	-0.152	0.675

Different letters indicate significant differences in fracture strength between groups (Games-Howell post hoc test; p < 0.05).

rs = Spearman's rank-order correlation   p = p value

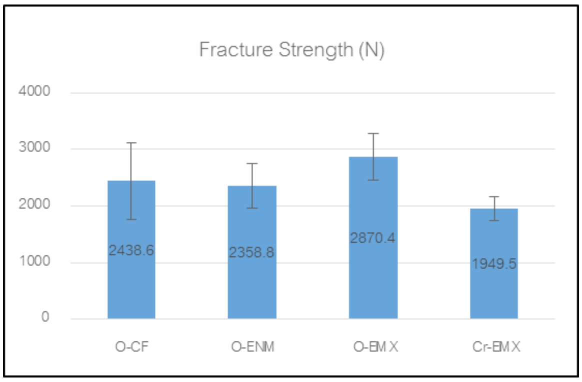

Figure 2 Average fracture strength (in Newtons) of each group.

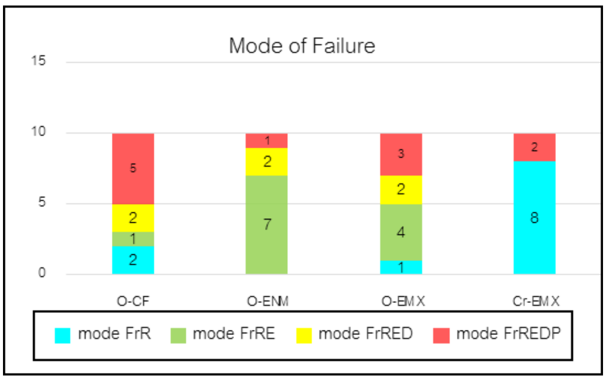

Figure 3 Modes of failure of each group.

Discussion

The thin occlusal onlay is a treatment option with a minimally invasive strategy. It has been used to restore occlusal tooth surface loss occurred for physical and chemical reasons. Compared with crowns, use of thin occlusal onlay decreases the amount of tooth preparation. This study aimed to evaluate fracture strengths and failure modes of thin occlusal onlays fabricated from a direct resin composite or a polymer-infiltrated ceramic-network block or a CAD/CAM lithium disilicate ceramic block compared with conventional crowns under compressive loading. It was found that lithium disilicate ceramic onlays exhibited significantly higher fracture strengths than lithium disilicate ceramic crowns, indicating that a lithium disilicate ceramic onlay could effectively withstand higher static loads. These findings offer further support for the utilization of thin occlusal onlays as functional and predictable means of posterior tooth reconstruction.

The results of this study showed fracture strengths in descending order: IPS e.max CAD onlay, Premise onlay, Vita Enamic onlay, and IPS e.max CAD crown. However, there were statistically significant differences between IPS e.max CAD onlays and crowns. Due to different means of tooth preparation, less tooth reduction was achieved with thin occlusal onlay cemented onto both the dentin and peripheral enamel, whereas more tooth preparation was achieved with crowns mostly cemented onto the dentin, resulting in increased susceptibility to a static compressive load for crowns. Thus the larger the degree of tooth preparation, the weaker the remaining tooth structure. In contrast, Fennis *et al.* (2004) demonstrated that fatigue resistance of cuspal-coverage restorations was increased when the reduced tooth structure was replaced with thicker restorative material. However, in terms of failure mode, the higher tooth-structure loss could cause more irreversible failure.[27] In a study by Wittneben *et al.* (2009), similar 5-year survival rates of crowns (92.3 %) and inlay/onlays (92.9 %) were reported.[28]

Fractures that are limited to the restorative material and do not involve the tooth structure improve the longevity of a restored tooth because it can be easily replaced by an identical milled restoration, without any damage to the natural tooth structure. Fractures that involve pulpal tissue are called “biological failure”, which are also considered severe situations. Such biological failure may force the patient to elect endodontic procedures or extraction, leading to a further compromise of the patient’s dental health. Our results showed that 50 % of O-CF group exhibited fracture in FrREDP mode or biological failure, whereas less biological failure occurred in other groups. The reason was that the higher fracture resistance of the composite onlay might cause less force distribution along the tooth axis, resulting in a more severe fracture due to residual stress. Ninety percent of onlays fractured involving tooth structure (enamel, dentin, or pulp), and only 10 % (3 of 30) fractured in restorative material. It could be inferred that the majority of onlays required more aggressive or complicated treatment when fractures arose. Compared with crowns, most (80 %) fractured in restorative material and only 20 % fractured in tooth structure. Regarding failure mode, 50 % of the O-CF group tended to fail in the FrREDP mode. This was in agreement with the results of a previous study by Kois *et al.* (2013), who found that 2-mm-thick ceramic occlusal onlays tended to fracture in the restorative material itself, but when composite occlusal onlays fractured, they exposed tooth structure, with 74 % of the pulp exposed.[29]

Several studies have determined the mechanical properties and reported the superior mechanical strength of IPS e.max CAD compared with Vita Enamic and other CAD/CAM composite blocks.[20,30-33] It can be hypothesized that IPS e.max CAD onlays would provide higher fracture strength than Vita Enamic onlays. However, the present study found no difference in fracture strength among IPS e.max CAD, Vita Enamic, and Premise thin occlusal onlays.

Today's CAD/CAM technologies are being continuously improved. This technology allows for quality control, for example, the thickness and anatomy of restorations, as well as manufacturer-regulated mechanical properties of the restorative materials. Standardization of the internal fit of restorations has been achieved.[13,14] Many confounding operator factors can be avoided, such as the skils of the dental laboratory technicians and accuracy involved in the fabrication process. In addition, labor and processing time can be reduced, and design and processing data can be saved and reproduced.[14,15]

There have been numerous studies regarding the feasibility of fabricating CAD/CAM thin occlusal onlays with thicknesses of 0.3-1 mm.[8-11] Similar to the present study, thin occlusal onlays could be milled successfully with all materials tested. In contrast, Tsitrou *et al.* (2008) investigated the ability of CAD/CAM system to produce minimal preparation designs: 0.6-mm occlusal reduction and 0.4-mm chamfer margin, for crowns with Paradigm MZ100, ProCAD and VITA Mark II. They found that only the Paradigm MZ100 could fabricate acceptable crowns without any marginal defects. The ceramic materials required more aggressive preparation design to produce clinically acceptable crowns,[34] implying that their ability to mill thin restorations may be influenced by the type of preparation (crown vs occlusal onlay). Hopefully further development of oral scanners, together with improved CAD design software and CAM milling machines, as well as the excellent mechanical properties of prefabricated blocks, can enhance the fabrication of thinner restorations.

Due to time limitations, this study was designed to determine only static strength testing. It was known that static loading could not replicate either the long-term effect of occlusal force on the restoration-tooth system, or the forces generated by patients who exhibit occlusal wear. Occlusal force generated by such patients is multidirectional and non-tripodized. Nevertheless, the tripodization of the contact used in this study is considered the 'gold standard' in restoring patients with fixed restorations,[35] and the static load value could be the maximum strength for restorations. Environmental effects and cyclic loading are likely to reduce this maximum strength value over time. Therefore, many studies were designed to determine dynamic strength testing instead, and found higher fatigue resistance of the composite compared with the ceramic onlays.[7,8] Although the same configuration of tooth preparation was performed, different results of fracture strength were found in this study compared with the studies mentioned above. Thus, to eliminate this controversy, further studies regarding dynamic strength testing should be undertaken.

The high fracture strengths of thin occlusal onlays reported from this study may support various useful clinical applications for patients with lost occlusal tooth structure. With patients suffering from bruxism or clenching, combined with loss of surrounding tooth structure, crowns would provide a preferable manner of fracture. However, all groups of restorations in the present study exhibited fracture strengths exceeding average human masticatory force, ranging between 433 and 906 N.[36-39]

Conclusion

Within the limitations of this in vitro study, it can be concluded that higher fracture strength was shown in IPS e.max CAD occlusal onlays compared with IPS e.max CAD crowns. Fracture strength of Vita Enamic occlusal onlays was comparable with that of Premise and IPS e.max CAD onlays. However, all restorations demonstrated a higher fracture resistance than the average force of mastication. In terms of failure modes, the fracture of direct composite occlusal onlays tended to fail due to biological failure rather than other groups.

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