Fracture Resistance and Failure Mode of Occlusal Veneer Restorations: Effect of Material Type and Bonded Substrate

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Abstract:
Purpose: To assess the effect of material type and bonded substrate on fracture resistance and failure mode of occlusal veneer restorations.
Materials and Methods: 90 natural mandibular first molars received occlusal veneer restorations of 1.0 mm thickness, divided into three main groups (n=30) according to the CAD/CAM material type: lithium disilicate ceramic (L), monolithic zirconia (Z) and hybrid ceramic (H). Each main group was further divided into 3 subgroups (n=10) depending on the bonded substrate: dentin (D), dentin with intracoronal cavity (C) and dentin / composite filling (F). Lithium disilicate and hybrid ceramics restorations were etched with 9.5% HF acid and silanated. Monolithic zirconia restorations were sandblasted with 50 µm aluminum oxide particles, then zirconia primer was applied. All restorations were adhesively luted using a dual cure adhesive resin cement. After thermocycling process (5000 cycles; 5-55^{o} C), specimens were subjected to dynamic loading in a chewing simulator (120.000 cycle; 98N/1.6 Hz). All specimens loaded until fracture using a universal testing machine.
Results: ANOVA and post hoc tukey tests revealed that no statistical significant difference in fracture resistance ($P>$ 0.05). A significant difference was found regarding the restorations bonded to dentin (D) and dentin / composite filling (F) ($P<0.05$).
Conclusion: Materials type and bonded substrates showed no effect on the fracture resistance of occlusal veneer restorations after aging while, they affect the failure mode of occlusal veneers.
Keywords: Occlusal veneers, CAD/CAM, ceramics, fracture resistance and failure mode.

Introduction

Occlusal veneers are non-invasive partial coverage restorations require limited tooth structure removal and alternatives to traditional posterior restorations.[1] Attrition, abrasion and erosive tooth wear are examples of occlusal wear defects that are multifactorial in origin.[2] Extensive preparations are regarded unacceptable in patients with compromised tooth structure.[3] Thinner and more conservative restorations can be made due to developments in ceramics.[4] CAD/CAM technology, bonding protocols and indirect minimal invasive approaches resulted in considering occlusal veneers as a posterior substitute for onlays and full coverage crowns.[5]

Many authors performed an anatomical occlusal preparation of occlusal veneers in molars with an angle of 150-degree between cusps.[6] However, premolars showed more conservative occlusal preparation with an angle of 120-degree between cusps.[7,8] Magne et al. (2010)[6] suggested that the overall occlusal veneer restoration thickness must not fall below 0.7-1 mm regardless the material. Ahlers et al. (2009)[9] suggested that cavities designed for ceramics must have the simplest possible basic geometry and the restoration must be appropriate with a minimum thickness of 1.5 to 2.0 mm. A study suggested that class I cavity can form a part of lithium disilicate occlusal veneers without underlying composite filling.[10] The bonded substrate nature as well as the adhesive technique must be taken into account to achieve a stable bonding interface and a clinically durable restoration.[5] Sasse et al. (2015)[11] suggested to restore the lost occlusal dentin in a class I prepared cavity with a composite filling to elevate fracture resistance, and reduce catastrophic failures. However, Krummel et al. (2019)[12] showed that the fracture resistance of occlusal veneers bonded to dentin was higher than bonded to enamel only or bonded to enamel /composite filling with appropriate bonding strategy. CAD/CAM lithium disilicate ceramic and hybrid ceramic can be constructed with reduced thickness and easily etched with hydrofluoric acid.[7,13] Also, monolithic zirconia showed high fracture resistance, fatigue strength, and survival rates sufficient to be used in molar regions even in thin thicknesses.[14,15]

The first null hypothesis of this study was the restorative material type would affect the fracture resistance of occlusal veneer restorations. The second null hypothesis was the bonded substrate would affect the failure mode of occlusal veneer restorations.

2. Materials and methods

2.1 Specimen fabrication: Ninety intact, unrestored human first mandibular molars, extracted for periodontal reasons were selected. The ethical approval (A19110220) was obtained from Dental Research Ethics Committee, Faculty of Dentistry, Mansoura University. Each tooth was mounted in epoxy resin using a special custom made centralizing device. Specimens were randomly distributed into three main equal groups (n=30) according to restorative material (L; Lithium disilicate, Z; Monolithic zirconia, H; Hybrid ceramic), then each group was divided into three equal subgroups (n=10) according to the bonded substrates (D; dentin only, C; dentin with intra coronal cavity, and F; dentin / composite filling). A standardized anatomical occlusal preparation, simulate advanced wear, limited to occlusal surface was performed using surveyor device (Marathon 103 surveyor, Marathon, China) holding a low speed straight handpiece through guided depth holes connected using a tapered round end diamond stone. Occlusal reduction of 1.0 mm with a divergence angle of 150 degrees between the cusps. A class I intracoronal cavity of 1.0 mm deep was further prepared in LC, ZC HC. While in LF, ZF and HF subgroups, a 1.0 mm deep class I intracoronal cavity was restored with a composite filling (Tetric N-Ceram Bulk Fill, Ivoclar Vivadent, Schaan, Liechtenstein). Each preparation was checked with pre-preparation putty indices and a graduated periodontal probe. Occlusal veneers were CAD/CAM constructed. Each specimen was scanned by the 3D dental scanner (Identica hybrid, MEDIT corp, Seoul, Korea), designed using a CAD software (exocad Chairside CAD software, version 2.2 Valletta, exocad GmbH, Germany) and restorations were milled in a 5-axis wet/dry machining system (CORiTEC 250i, imes-icore GmbH, Germany) from 3 different ceramic materials; Lithium disilicate blocks (IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein), Ultra translucent Monolithic zirconia disc (Katana UTML Zirconia, Kurary Nuritake Dental Inc, Japan), and hybrid ceramic blocks (Vita Enamic, VITA Zahnfabrik, Germany).

Bonding procedures: For IPS e.max CAD and Vita Enamic occlusal veneers, the intaglio surface of each restoration was etched with a porcelain etch 9.5 % hydrofluoric acid gel for 20 seconds, rinsed, dried, then silanized with a porcelain Primer (Bisco Porcelain Primer, BISCO Inc., USA). Zirconia restorations were sandblasted with 50µm aluminum oxide particles in sandblasting unit at 2 bar pressure for 10 secs. A zirconia primer (Bisco Z-Prime plus, BISCO Inc., USA) was applied on the etched zirconia surfaces. Peripheral marginal enamel was etched with 37% phosphoric acid gel (Total Etch gel, Ivoclar Vivadent, Schaan, Liechtenstein) for 30 secs, a universal bond (Bisco All-Bond Universal BISCO Inc., USA) was applied and light cured, then dual cure adhesive resin cement (DUO-LINK UNIVERSAL, BISCO Inc. IL, USA) was used to cement the ninety occlusal veneer restorations.

Ageing: All specimens were thermo-cycled for 5000 cycles in a thermocycler machine (Themocycler The-1100/ The-1200, SD Mechatronic, Germany) between 5^{o} C and 55^{o} C in tap water with 20 seconds dwell time. Specimens were further subjected to a computerized dynamic load in multimodal chewing simulator of 1.6 Hz (ROBOTA ACH-09075 DC-T model, AD-TECH Technology LTD, GERMANY) for 120,000 cycle.

Testing: All specimens were loaded to fracture in a computer-controlled universal testing machine with a load cell of 5 kN (Instron universal testing machine, Model 3345, Instron, USA). Failure modes were visually examined, digitally photographed and were categorized.

Statistical analysis: Data were statistically analyzed using the Statistical Package for Social Science (IBM SPSS Corp 2013, Version 22.0, IBM Corp, Armonk, NY, USA). Shapiro–Wilk test revealed that all data showed normal distribution. For data analysis, one-way ANOVA test followed by Post Hoc Tukey test and two-way ANOVA test were used. Statistical significant level was set at $P \leq 0.05$. Also, Monte Carlo test was used to illustrate the qualitative data of failure pattern percentage in all test groups.

Results:

Fracture analysis: One-way ANOVA test revealed that there was no statistical significance difference in fracture resistance between different study subgroups regarding material type and bonded substrate as ($P > .05$) (Table 1).

Failure mode analysis: the mode of failure was examined and classified according to a classification proposed by Al Akhali et al. (2019)[7] and Lannidis et al. (2019)[16] into 4 categories; Class I; extensive crack formation within the restoration, class II; cohesive fracture of restoration and cement, class III; adhesive fracture between restoration and tooth, and class IV; longitudinal fracture of restoration and tooth. Monte Carlo test was used to illustrate the failure mode percentage of all test groups. There was statistical significant difference between subgroups regarding failure mode.

Discussion: Natural molars were used to improve the clinical relevance rather than resin or metal abutments and they were selected to be comparable in dimensions. A ceramic thickness of 1.0 mm was selected to conserve tooth structure especially in cases of severe wear associated with compensated eruption.[11] Based on the result of this study, the first null hypothesis was rejected. While the second hypothesis was accepted. Despite differences in the modulus of elasticity and flexural strength between L, Z and H ceramic groups, there was no significant difference in the fracture resistance of occlusal veneers in this study. This finding comes in agreement with another study by Al Akhali et al. (2019).[7] In contrast to Loannidis et al. (2019)[11], there was a significant difference regarding the mean fracture resistance of 1.0 mm thickness occlusal veneers fabricated from monolithic zirconia, lithium disilicate and hybrid ceramic occlusal veneers. The highest mean fracture resistance values were recorded in L group of 2313.16 ± 651.48 N. This comes in agreement with a study by Andrade et al. (2018)[13] in which the fracture resistance value of lithium disilicate occlusal veneers were higher than hybrid ceramic. While Z group showed the least mean fracture resistance values may be attributed to the decrease in the mechanical properties in UTML monolithic zirconia, increase of sintering temperature to 1550 °C can cause a flexural strength decreasing, grain enlargement and grain boundaries reduction making the material more susceptible to transformation.[17] There was no statistical significant difference between the tested substrates. This comes in accordance to Valenzuela et al. (2020)[18] study and Clausen et al. (2010).[4] On the other hand, in Andrade et al. (2018)[13] fracture resistance of occlusal veneers bonded to dentin fabricated from 1.5 mm thick lithium disilicate exceeded the fracture resistance values in LD and HD subgroups in the present study. In contrast to a study by Yazigi et al. (2017)[8] occlusal veneers fabricated from 0.8 mm lithium disilicate ceramics and bonded to dentin showed lower fracture resistance values than LD subgroup. Fracture resistance values in LC subgroup was higher than LF subgroup. This comes in agreement with a study by Leirop et al. (2019)[19] in which fracture resistance of lithium disilicate occlusal veneers with a class I cavity was higher than fracture resistance of restorations where a composite filling in the class I dentin cavity. These findings have shown that the restoration of a tooth with a lithium disilicate ceramic material does not require composite in the cavity preparation of the class I with the cavity design optimization approach.[20] The results of the current study disclosed that there was statistical significant difference in failure mode of occlusal veneers in L, Z and H groups. The HD and LD showed the most catastrophic longitudinal fracture within ceramic and the underlying tooth structure. Similar findings were obtained from a study by Krummel et al. (2019)[12] as the most extensive failure pattern in lithium disilicate occlusal veneers bonded to dentin showed fractures within ceramic and tooth structures. ZD occlusal veneers showed both class II and III failure modes with the least destruction of the underlying tooth structure. In contrast to a study by Weigl et al. (2018)[21] in which 80% of adhesively bonded monolithic zirconia crowns showed fractures through crowns and underlying dies. In the present study, ZD, ZC, and ZF are the only subgroups experienced class III failure mode of adhesive fracture between restoration and tooth. This could be attributed to the absence of any glass matrix in zirconia resist chemical interlocking between glass containing restoration and adhesive luting agent.[22] The highest percentage of mode I failure was observed in HF subgroup with the most favorable pattern of cracks limited to the restorations only as hybrid ceramic, dentin substrate, composite filling and the luting composite cement are structures with compatible elastic modulus, tend for less bending under load and distribute stresses more evenly to prevent the underlying tooth structure from damage.[23] HC showed increased percentage of mode IV failure than LC which comes in contrast a study Kanat-Ertürk et al. (2018)[24] in which short depth hybrid ceramic endocrowns revealed less harmful failure pattern with fractures in endocrowns only in contrast to lithium disilicate endocrowns, fractures extended to the tooth complex.

Limitations of the current study

Some limitations may still exist in the current in vitro study as the intraoral environment is difficult to be replicated because of individual differences. Only one occlusal thickness was tested. This study only determined the quasi-static strength at one loading condition.

Conclusions: 1) All tested occlusal veneer materials proved to have a relatively high fracture strength. 2) Occlusal veneers bonded to dentin, composite filling, or extended into intracoronal cavity can withstand high compressive forces and show high resistance to fractures.

Table 1. Comparison of maximum load (N) among studied sub-groups using one- way ANOVA test

	Group (L) Lithium disilicate ceramic	**Group (Z) Monolithic Zirconia**	**Group (H) Hybrid ceramic**	**Test of significance (between groups)**
D	2251.05±604.89	2285.18±491.06	2505.62±600.89	F=0.592 P=0.560
C	2505.91±723.01	2073.32±426.45	1947.13±650.45	F=2.28 P=0.121
F	2182.53±643.77	1859.88±422.75	2364.55±648.14	F=1.93 P=0.164
Test of significance (Within subgroups)	F=0.669 P=0.521	F=2.25 P=0.124	F=2.10 P=0.142	

D. bonded to dentin only, C. bonded to dentin with intracoronal cavity, F. bonded to dentin and a composite filling, P. probability all

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