Original Article

Fracture strength of ultrathin occlusal veneer restorations made from CAD/CAM composite or hybrid ceramic materials

Jonathon S. Egbert, Andrew C. Johnson, Darannee Tantbirojn, Antheunis Versluis

Abstract

Purpose: This study compared the fracture strengths and failure modes of ultrathin (0.3-mm) occlusal composite or hybrid ceramic veneers.

Methods: Sixty extracted maxillary molars were sectioned to remove the entire coronal structure 4 mm occlusal to the cementoenamel junction (CEJ), leaving a flat area of exposed dentin and peripheral enamel. Standardized occlusal veneers with a central fossa thickness of 0.3 mm were milled from a computer-aided design (CAD)/computer-aided manufacturing (CAM) composite (Paradigm MZ100), a resin nanoceramic (Lava Ultimate), and a hybrid ceramic (Vita Enamic) (N = 20). Each occlusal veneer was cemented with a self-adhesive resin cement (ReliaUnicem) on the prepared teeth. The restored teeth were loaded vertically to determine the fracture strength. Strength values were statistically analyzed using one-way analysis of variance (ANOVA) and Scheffe’s post hoc test (significance level 0.05). The mode of failure of each specimen was classified and the correlation between fracture strength and failure mode was analyzed using Spearman’s rank-order test.

Results: The fracture strengths (mean ± standard deviation) were 2416 ± 640, 1752 ± 676, and 1777 ± 697 N for Lava Ultimate, Paradigm MZ100, and Vita Enamic, respectively. Lava Ultimate had significantly higher fracture strength than the other two materials (p < 0.05); the fracture strengths of Paradigm MZ100 and Vita Enamic were not significantly different. No correlation between fracture strengths and failure modes was found within each material. Most specimens (48 out of 60) fractured in the restoration without involving tooth structures.

Conclusions: The fracture strength of ultrathin occlusal veneers made from the novel ceramic hybrid matched the strength of CAD/CAM composite. The highest strength was found with the resin nanoceramic material.

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1. Introduction

Excessive loss of coronal tooth structure or severe tooth wear is not uncommon in the general population [1]. The multifactorial etiology of tooth wear is associated with dietary habits, medical conditions, and/or oral habits that lead to attrition, abrasion, and erosion of the enamel and dentin [2]. The destruction of tooth structure has been a significant concern as it affects musculoskeletal harmony, occlusal stability, oral comfort, esthetics, and overall the patients’ satisfaction with their dentition [3,4].

Restorative treatment of severely worn dentition may involve multiple full-coverage restorations, crown lengthening, and elective tooth devitalization [5]. Traditionally, these procedures require removal of healthy tooth tissues to accommodate the preparation design. A conservative approach to restore tooth surface loss using direct resin composite restorations has utilized adhesive concepts to preserve tooth structures [6]. Although pragmatic, direct composite restoration of tooth wear is not an ideal treatment option considering its limitations in terms of esthetics and durability.

Ceramic materials have the desired esthetics and durability. However, the feasibility of their application in thin conservative preparations depends on their fabrication options and fracture properties. Recent advances in CAD/CAM (computer-aided...
design/computer-aided manufacturing) technology and materials are offering new options for restoration of severely worn dentition where space is limited. New composite and ceramic hybrid materials have been introduced, which can be milled at relatively thin thicknesses to accommodate conservative tooth preparations [7]. Thin occlusal veneers fabricated from composite resin blocks have been shown to have higher fatigue resistance than reinforced ceramics [8,9]. A recent study showed that the thickness of occlusal veneers made with CAD/CAM composite (3M Paradigm MZ100, 3M ESPE, St Paul, MN) or resin nanoceramic (3M Lava Ultimate, 3M ESPE) can be decreased to 0.3 mm without affecting the fracture strength [10]. The CAD/CAM composite is manufactured from a restorative composite material (Z100, 3M ESPE) under optimized process conditions to obtain a high degree of cross-linking [11]. The resin nanoceramic, according to the manufacturer, is neither a composite nor a pure ceramic, but a mixture of both and it primarily consists of ceramics [12]. A new CAD/CAM ceramic hybrid material has been developed by infiltration of a polymer into a porous ceramic network (Vita Enamic, Vident, Brea, CA, USA) [13]. This polymer-infiltrated ceramic network material has a microstructure similar to a natural tooth and has mechanical properties that fall between those of porcelains and resin composites [14]. This material is a potential candidate for ultrathin occlusal veneers. There have been few publications about occlusal veneers and no studies that compared the new polymer-infiltrated ceramic network material with composite-based CAD/CAM materials.

The objective of the present study is to compare the fracture strengths and failure modes of ultrathin (0.3-mm) occlusal veneers fabricated from CAD/CAM composite (3M Paradigm MZ100), resin nanoceramic (3M Lava Ultimate), or ceramic hybrid (Vita Enamic) blocks under vertical compressive loading.

2. Materials and methods

2.1. Tooth preparation

Sixty extracted human maxillary molars (IRB Exempt #14-03359-XM) with similar dimensions were mounted in autopolymerizing acrylic resin 4 mm apical to the cementoenamel junction (CEJ) and stored in distilled water (Fig. 1A). The entire coronal structure 4 mm occlusal to the CEJ was sectioned perpendicular to the long axis of the tooth using a diamond saw (Isomet Plus Precision Saw, Buehler, Lake Bluff, IL, USA), leaving a flat area of exposed dentin and peripheral enamel (Fig. 1B). This replicated a clinical situation of severe tooth wear, in which rehabilitation would be the proper treatment. It also allowed for properly contoured and standardized occlusal cusp morphology during the CAD/CAM process. Indexing notches were created on the mesial and distal finish lines with a high-speed round-ended diamond rotary bur (#ZR 850 FG.01, Komet USA, Rock Hill, SC, USA). The prepared teeth were visually examined and discarded if any damage such as pulpal exposure or microcracks was found. The prepared teeth were then randomly assigned to three groups based on the three restorative materials to be tested: 3M Paradigm MZ100 (3M ESPE), 3M Lava Ultimate (3M ESPE), and Vita Enamic (Vident, Brea, CA). The material information is listed in Table 1. The sample size of each group was 20.

2.2. Restoration design

A standardized occlusal form of a right maxillary first molar was created based on an anatomic denture tooth (Phonares SR Typ NHC Mould NU3, Ivoclar Vivadent, Amherst, NY, USA). The denture tooth was scanned and digitally adjusted to a 0.3-mm thickness at the central fossa (Fig. 2). Each prepared tooth surface was scanned and combined with the standardized occlusal tooth form using Dental Wings operating software version 7.0 (Dental Wings Inc., Montreal, Canada). A custom visual reference jig was created to provide reference points for correct surface alignment between the preparation and the occlusal images, for example, to line up the buccal surface with buccal surface, etc. Subsequently, occlusal veneers were designed in the software using the correlation feature, which helped orient the preparations to fit the occlusal contours of the CAD/CAM restorations. The restorations were designed to have similar occlusal morphologies while maintaining marginal adaptation of the individual preparations.

2.3. Occlusal veneer fabrication

The occlusal veneer restorations were milled to their prescribed central fossa thickness of 0.3 mm (350i imes-icore, Renfert GmbH, Eiterfeld, Germany). After milling, the sprues were trimmed with a high-speed diamond bur (ZR 850 FG.01, Komet USA, Rock Hill, SC, USA) and the occlusal veneers were checked for defects and proper fit. Occlusal veneers without a passive fit on the prepared tooth or those that had marginal discrepancy detectable with an explorer were discarded, the preparation was rescanned, and a new occlusal veneer was fabricated.

2.4. Cementation

Before the occlusal veneers were cemented, the inner surfaces were air-abraded per manufacturer specifications using 50 μm of aluminum oxide at 1.8 bar of pressure (Basic Quatro 230/240, Renfert GmbH), cleaned with alcohol, and dried with oil-free
Table 1
Material information [3–15].

<table>
<thead>
<tr>
<th>Material and manufacturer</th>
<th>Type</th>
<th>Composition and structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paradigm MZ100 3M ESPE, St Paul, MN</td>
<td>CAD/CAM composite</td>
<td>85 wt% ultrafine zirconia–silica ceramic particles in a highly cross-linked polymeric matrix of bis-GMA (bisphenol A diglycidyl ether dimethacrylate) and TEGDMA (triethylene glycol dimethacrylate), and a patented ternary initiator system. Spherical particles (average size 0.6 μm) of nanocrystalline zirconia dispersed in amorphous silica.</td>
</tr>
<tr>
<td>Lava Ultimate 3M ESPE, St Paul, MN</td>
<td>Resin nanoceramic</td>
<td>~80 wt% nanoceramic particles embedded in ~20 wt% highly cross-linked resin matrix, processed multiple hours in a special heat treatment process. Monodisperse, nonaggregated, and nonagglomerated silica nanoparticles (20–nm diameter) and zirconia (4–11 nm) and zirconia-silica nanocluster particles (0.6–10 μm). Proprietary silane coupling agent treatment.</td>
</tr>
<tr>
<td>Vita Enamic 3M ESPE, St Paul, MN</td>
<td>Hybrid ceramic</td>
<td>Porous structure-sintered ceramic matrix infiltrated with polymer material. Inorganic ceramic 86 wt%: fine-structure feldspar ceramic enriched with aluminum oxide (silicon dioxide 58–63%, aluminum oxide 20–23%, sodium oxide 9–11%, potassium oxide 4–6%, boron trioxide 0.5–2%, zirconia &lt;1%, calcium oxide &lt;1%). Organic polymer 14 wt% (urethane dimethacrylate, triethylene glycol dimethacrylate).</td>
</tr>
</tbody>
</table>

Pressurized air. The enamel and dentin were etched with 37.5% phosphoric acid (Total etch, Ultradent, South Jordan, UT, USA) for 15 s. The prepared teeth were rinsed and blot-dried to avoid desiccation. The occlusal veneers were cemented with a self-adhesive dual-cure resin cement (RelyX Unicem, 3M ESPE). The manufacturer’s instruction includes an option of applying etchant to the tooth. A uniform vertical seating pressure of 6 N was applied using a custom-fabricated seating device [10], and residual cement was removed. Buccal, lingual, mesial, and distal surfaces were light-polymerized, each for 20 s (SmartLite Max LED, Dentsply, York, PA, USA). The restored teeth were stored in distilled water at room temperature for 7 days prior to testing.

2.5. Fracture strength testing

After 7 days of storage, the restored teeth were placed in a universal testing machine (Instron 5567, Norwood, MA, USA) and subjected to an increasing vertical load until fracture under displacement control at a crosshead rate of 0.5 mm/min. Loads were recorded by a 10-kN load cell. The load was applied with a rounded (3.5-mm-diameter) stainless-steel tip that simulated an opposing cusp. The rounded tip was positioned to achieve tripodization of contacts along the cuspal inclines over the central fossa. The restored teeth were loaded along their long axis, perpendicular to the prepared surface. An angle adjustment table was used to ensure longitudinal load application of all teeth, even if they had not been mounted entirely straight (Fig. 3). The fracture strength was the highest recorded load value before an at least 25% drop in load...
was observed. One-way analysis of variance (ANOVA) followed by Scheffé’s post hoc test was used to statistically analyze the differences in failure load among the three material groups (significance level 0.05).

2.6. Failure mode

After fracture, the specimens were examined under a stereomicroscope with a charge-coupled device (CCD) camera (SZX16 and UC30, Olympus, Tokyo, Japan). The modes of failure were categorized as follows: Mode I, fracture in the restoration only; Mode II, fracture of the restoration and enamel; or Mode III, fracture of the restoration, enamel, and dentin. The correlation between the fracture load and mode of failure within each material was tested using Spearman’s rank-order correlation.

3. Results

The fracture strengths (Table 2) were significantly different between the three groups (one-way ANOVA, p = 0.002). The Lava Ultimate (resin nanoceramic composite material) occlusal veneers had significantly higher fracture strengths than the restorations made with the other two materials (Scheffé’s post hoc test, significance level 0.05). No statistically significant difference in fracture strengths was found between occlusal veneers made with Paradigm MZ100 (composite material) or Vita Enamic (ceramic hybrid material).

Fig. 4 shows the three modes of failure. The numbers of specimens for each failure mode and material type are shown in Table 2. Of the 60 specimens (all materials combined), 48 fractured in the veneer material (Mode I), and one of these 48 had a complete delamination of the fractured restoration. Eight specimens fractured in the restoration and enamel (Mode II). Four specimens fractured in the restoration, enamel, and dentin (Mode III). Of these four specimens, three did not result in a delamination of the restoration. Spearman’s rank-order correlation coefficient r for the bivariate set of data did not show significant correlation between fracture strength and failure modes within each material (Table 2).

Table 2

<table>
<thead>
<tr>
<th>Material</th>
<th>Fracture strength (N)</th>
<th>Failure mode</th>
<th>r&lt;sub&gt;i&lt;/sub&gt;</th>
<th>p&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lava Ultimate</td>
<td>2415 ± 640 (a)</td>
<td>I: 15/20</td>
<td>II: 3/20</td>
<td>III: 2/20</td>
</tr>
<tr>
<td>Paradigm MZ100</td>
<td>1752 ± 376 (b)</td>
<td>17/20</td>
<td>2/20</td>
<td>1/20</td>
</tr>
<tr>
<td>Vita Enamic</td>
<td>1727 ± 721 (b)</td>
<td>16/20</td>
<td>3/20</td>
<td>1/20</td>
</tr>
</tbody>
</table>

<sup>a</sup> Different letters indicate significant differences in fracture strength between material groups (Scheffé’s post hoc test; p < 0.05).

<sup>b</sup> Spearman’s rank-order correlation.

4. Discussion

A recent study comparing composite and newer resin nanoceramic composite occlusal veneer concluded that restoration thickness between 0.3 and 1.0 mm had no significant effect on fracture strength, and it suggested that restorations as thin as 0.3 mm could be used in areas subjected to masticatory stress [10]. The objective of this study was to compare the fracture strengths of three non-ceramic materials used in an ultrathin occlusal veneer, including one novel material about which little information is available. We found that the occlusal veneers made with the novel ceramic hybrid (Vita Enamic) matched the strength of a composite material (Paradigm MZ100), while the highest fracture strength under vertical loading was found with a resin nanoceramic composite material (Lava Ultimate). The Lava Ultimate and Paradigm MZ100 are highly cross-linked particle-reinforced composites, while the Vita Enamic has resin infiltrated into a sintered ceramic structure. The sintered ceramic structure is porous with a composition similar to feldspar ceramic enriched with aluminum oxide [15]. In our study, neither type of material design ensured superior fracture properties. However, within the composite types, advancements in nanotechnology, coupling agent, and heat treatment of the resin matrix may have contributed to improved strength values for the Lava Ultimate material. The ceramic particles in the Paradigm MZ100 blocks are spherical in shape with an average particle size of 0.6 μm, and they have a structure of nanocrystalline zirconia dispersed in amorphous silica [11]. The Lava Ultimate blocks contain monodisperse, nonagglomerated, and nonagglomerated nanoparticles of silica (20-nm diameter) and zirconia (4–11-nm diameter) forming nanoclusters (0.6–10 μm) that give structural integrity and allow a high proportion of ceramic fillers to be incorporated [12]. In addition, the interstitial spaces between the particles are filled with more nanomers leading to higher ceramic content. The nanocomposites are treated with a proprietary silane coupling agent treatment to chemically bond with the resin matrix during manufacturing of the blocks. According to the manufacturer of Lava Ultimate, extended heat treatment of the resin matrix results in high strength [12]. The fracture strengths of the occlusal veneers in this study seem to reflect the flexural strengths of the three materials, which were reported to be approximately 150–160 MPa for the Vita Enamic and MZ100, and about 205 MPa for the Lava Ultimate [11,12,15].

Increases in veneer failure strengths may generally be viewed as favorable outcomes. However, if such an increase is accompanied by an increased incidence in tooth harm during fracture (Mode II or III failures), pursuing those higher veneer strengths may not be worth it. In this study, the failures of the occlusal veneers were mostly within the restorative materials (48 out of 60 were Mode I failures) and were not correlated with the fracture strengths. This means that higher veneer strength values did not cause more undesirable damage to tooth structures than the veneers with lower failure strengths in our study. Other in vitro studies involving

![Image of failure modes: Mode I, failure of restoration; Mode II, failure of restoration and enamel; and Mode III, failure of restoration, enamel, and dentin.](http://dx.doi.org/10.1016/S1348-8643(15)00017-8)
ultrathin composite or ceramic veneers also reported that most failures were cracks and fractures limited to the restorative material [9,10,16]. This suggests that the most likely failure of occlusal veneers is cracking or chipping of the restoration. There is little information available on the longevity of occlusal veneers, but for facial veneers, long-term clinical studies show that the main cause of failure is chipping or fracture of the restorative material [17,18]. These findings are in line with the failure modes we observed in the failure of ultrathin occlusal veneers. Failures that are limited to the restorative material and do not involve the tooth structure improve the longevity prognosis of a restored tooth because the occlusal veneer can be easily replaced by milling an identical veneer. Failures that involve the tooth structure may necessitate elective endodontic procedures and can lead to extraction and further compromise of a patient’s dental health.

Inspection of the samples after fracture frequently showed cement to the intaglio of the occlusal veneer as well as to the tooth surface, suggesting failure of the cement. For ceramic materials, it has been known that bonding increases the failure strength [19,20]. This is likely also true for the new ceramic hybrid materials, but additional studies are needed to investigate the bonding capability of these materials and how it affects the strength and failure modes.

The higher fracture loads of the Lava Ultimate occlusal veneers may suggest superior performance compared to the other two investigated CAD/CAM materials. However, such a conclusion should be considered premature. Our study only determined the quasi-static strength at one loading condition, and it could not replicate the entire spectrum of occlusal loading or the long-term effect of an oral environment on the strength of the restoration-tooth system. The static axial load may also not replicate the forces generated by most patients who exhibit occlusal wear, as these are not unidirectional and non-tripodized in most patients. Nevertheless, the tripodized contact we used is considered the gold standard when restoring patients with fixed restorations [21], and the value could be viewed as the maximum attainable strength for an occlusal veneer with these materials. Environmental effects and cyclic loading (mechanical and thermal fatigue) are likely to reduce this maximum strength value over time. Fatigue properties have been found to be better for composites compared to ceramic materials [8,22]; thus, it is possible that the new composite and composite-ceramic hybrids in this study will also be less sensitive to cyclic loading.

The large standard deviations that were obtained in this study could be attributed to various factors, including natural variations in tooth properties and anatomy as well as defects introduced during preparation and the CAM processing. However, these variations are likely to exist in clinical situations as well. Therefore, the range of values can be considered relevant as it was related to actual performance.

The fracture strengths measured in this study appear promising because they may support various useful clinical applications. For patients with severely worn dentition, ultrathin occlusal veneer restorations made from CAD/CAM composite or hybrid ceramic materials can be an alternative to full-covereage restorations. An in vitro study reported the failure load of teeth restored with full-covereage all-ceramic crowns with 1.5–2-mm occlusal thickness to be 771–1183 N [23], which is lower than the fracture strength of the 0.3-mm occlusal veneers in this study (1727–2415 N). The demonstrated fracture strengths also appear to exceed the reported range of human masticatory forces (585–880 N) [24–26]. Therefore, the main advantage of the occlusal veneers is conservation of tooth structure, as they require little tooth reduction. Before long-term clinical studies are available to support their longevity, occlusal veneers can be viewed as provisional restorations. More often than not, patients are in need of prolonging their oral rehabilitation period due to financial issues. Occlusal veneers could maintain vertical dimensions to allow a patient to prolong their treatment and secure necessary funds through a rehabilitative process. The occlusal veneers can also be used to assess a patient’s ability to withstand an increased vertical dimension. Many patients with severely worn dentition have lost the vertical dimension, and vertical dimension opening can be extremely challenging. Occlusal veneers could serve as a reversible method of evaluating one’s vertical dimension opening. In conclusion, the clinical durability of the minimal invasive ultrathin occlusal veneers has yet to be proven, but their ease of fabrication and practicality may help protect vital tooth structure while maintaining vertical dimensions throughout rehabilitative treatments, at least as interim restorations.

5. Conclusions

Within the limitation of this in vitro study, the following conclusions can be made:

1. Ultrathin veneers made of Lava Ultimate had significantly higher failure loads than those with Vita Enamic and Paradigm MZ100.
2. The failure strength cannot be assumed based on the material type, either composite or ceramic hybrid.
3. The failure load of ultrathin CAD/CAM composite-based and ceramic hybrid occlusal veneers found in this study exceeded the reported range of human masticatory forces.

Conflicts of interest

The authors have no conflicts of interest.

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