Effect of overglazed and polished surface finishes on the compressive fracture strength of machinable ceramic materials

Tetsuya ASAI1, Ryunosuke KAZAMA2, Masayoshi FUKUSHIMA3 and Takashi OKIJI1

1Division of Cariology, Operative Dentistry and Endodontics, Department of Oral Health Science, Niigata University Graduate School of Medical and Dental Sciences, 2-5274 Gakko-cho-dori, Chuo-ku, Niigata 951-8514, Japan
2Removable Partial Denture Prosthodontics, Department of Masticatory Function Rehabilitation, Division of Oral Health Sciences, Graduate School, Tokyo Medical and Dental University, 1-5-45 Yushima, Bunkyo-ku, Tokyo 113-8549, Japan
3Department of Oral Health and Welfare, Faculty of Dentistry, Niigata University, 2-5274 Gakko-cho-dori, Chuo-ku, Niigata 951-8514, Japan

Corresponding author, Tetsuya ASAI; E-mail: tetsu@dent.niigata-u.ac.jp

Controversy prevails over the effect of overglazing on the fracture strength of ceramic materials. Therefore, the effects of different surface finishes on the compressive fracture strength of machinable ceramic materials were investigated in this study. Plates prepared from four commercial brands of ceramic materials were either surface-polished or overglazed (n=10 per ceramic material for each surface finish), and bonded to flat surfaces of human dentin using a resin cement. Loads at failure were determined and statistically analyzed using two-way ANOVA and Bonferroni test. Although no statistical differences in load value were detected between polished and overglazed groups (p>0.05), the fracture load of Vita Mark II was significantly lower than those of ProCAD and IPS Empress CAD, whereas that of IPS e.max CAD was significantly higher than the latter two ceramic materials (p<0.05). It was concluded that overglazed and polished surfaces produced similar compressive fracture strengths irrespective of the machinable ceramic material tested, and that fracture strength was material-dependent.

Keywords: Compressive fracture strength, Machinable ceramic, CAD/CAM

INTRODUCTION

Conventional porcelain-fused-to-metal restorations have been used for many years to provide strong and functional tooth-colored restorations. However, while the metal substructure provides functional stability, it presents several esthetic deficiencies such as an opaque, lifeless look and a dark black line at the gingival margin1. Consequently, the desire for an excellent esthetic appearance created a demand surge for all-ceramic restorations.

On the other hand, all-ceramic restorations are not without flaws. Dental ceramics are inherently fragile in tension, such that fractures are a major concern constantly plaguing all-ceramic restorations. In a bid to improve the fracture strength, studies on this issue have identified several factors that influence the fracture resistance of all-ceramic restorations, namely, type of ceramic material12-20, surface finish of all-ceramic restoration1-7,15,16, cement thickness17-19, and type of luting agent12,20-25.

On the preferred surface treatment for ceramic restorations, glazing is generally advocated to improve their strength1,2,13,16,26,27 and reduce their surface roughness12,16,26,28-30. The reinforcing effect of glazing is believed to be due to a reduction in the depth and sharpness of surface flaws and porosities, which can otherwise be critical fracture origins31. However, some studies have reported that glazing had no effect on the strength of ceramic materials7,10,14,16. Amid these contradicting reports, no definitive conclusion has been reached as to whether glazing confers superior fracture resistance on dental ceramic materials.

On the fabrication of ceramic restorations, several manufacturing systems based on the use of different ceramics and techniques have been developed. However, the physical properties of ceramic restorations are strongly influenced not only by the manufacturing procedure used (such as condensation, melting, and sintering), but also by the degree of skill and precision of individual dental technicians32. To reduce the dependence on dental technicians’ skills and experience and hence the discrepancies that arise thereof, computer-aided design/computer-aided manufacturing (CAD/CAM) technology for dentistry was developed in the late 1980s. These CAD/CAM systems use computer-aided design/computer-aided manufacturing of all-ceramic restorations, hence yielding the two-fold advantages of reduced manufacturing time and technical inaccuracies33. Notably, for chairside fabrication of all-ceramic restorations, the CEREC CAD/CAM system (Sirona Dental Systems GmbH, Bensheim, Germany) allows dentists to create well-fitting and esthetically pleasing ceramic restorations within one office visit33.

After all-ceramic restorations are produced using CAD/CAM, they require surface finishing after machining because of the limited polishing effect achieved using diamond milling burs34. Overglazing, a means of surface staining, may be applied not only to strengthen the ceramic material but also to improve its esthetic appearance, since monochromatic machinable ceramic materials have poor color reproducibility33. On the other hand, polishing with rotary abrasive instruments is practical and widely used for surface finishing, especially for restorations fabricated...
chairside.

To date, information is scarce on the effects of different surface finishes on the fracture strength of machinable ceramic materials\(^2\). Therefore, the aim of this study was to compare the compressive fracture strengths of polished and overglazed machinable ceramic materials: Vita Mark II, (a fine-particle feldspar ceramic), ProCAD and IPS Empress CAD (leucite-reinforced glass-ceramics), and IPS e.max CAD (a lithium disilicate glass-ceramic).

**MATERIALS AND METHODS**

The ceramic and glazing materials used in this study are listed in Tables 1 and 2.

**Experimental design**

To fulfill the objective of this study, the final surface finishing method and type of ceramic material must be isolated as the only variables. To preclude any unexpected influence from other variables, the current study used a simple experimental design: pressure was loaded only at one point at the center of a uniformly supported rectangular ceramic plate, the latter being adhesively luted to dentin.

**Tooth specimens**

In this study, the tooth selection criteria were that the teeth must be sound and free from defects and cracks on visual examination. Eighty extracted human molars which satisfied these criteria were stored in a 10% thymol solution before use.

**Table 1  Ceramic materials used in this study**

<table>
<thead>
<tr>
<th>Material</th>
<th>Batch code</th>
<th>Basic chemical structure (Chemical components)</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vita Mark II</td>
<td>11530</td>
<td>Fine particle feldspar ceramic (SiO(_2), Al(_2)O(_3), Na(_2)O, K(_2)O, CaO, TiO(_2))</td>
<td>Vita Zahnfabrik, Bad Säckingen, Germany</td>
</tr>
<tr>
<td>ProCAD</td>
<td>K41828</td>
<td>Leucite-reinforced glass-ceramic (SiO(_2), BaO, Al(_2)O(_3), CaO, CeO(_2), Na(_2)O, K(_2)O, B(_2)O(_3), TiO(_2))</td>
<td>Ivoclar Vivadent, Schaan, Liechtenstein</td>
</tr>
<tr>
<td>IPS Empress CAD</td>
<td>L14006</td>
<td>Leucite-reinforced glass-ceramic (SiO(_2), BaO, Al(_2)O(_3), CaO, CeO(_2), Na(_2)O, K(_2)O, B(_2)O(_3), TiO(_2))</td>
<td>Ivoclar Vivadent, Schaan, Liechtenstein</td>
</tr>
<tr>
<td>IPS e.max CAD</td>
<td>L30276</td>
<td>Lithium disilicate glass-ceramic (SiO(_2), Li(_2)O, K(_2)O, P(_2)O(_5), ZrO(_2), ZnO, Al(_2)O(_3), MgO)</td>
<td>Ivoclar Vivadent, Schaan, Liechtenstein</td>
</tr>
</tbody>
</table>

**Table 2  Glazing materials and conditions**

<table>
<thead>
<tr>
<th>Ceramic type</th>
<th>Glazing materials</th>
<th>Batch code</th>
<th>Initial temperature (°C)</th>
<th>Heating rate (°C/min)</th>
<th>Preheating time (min)</th>
<th>Final firing temperature (°C)</th>
<th>Holding time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vita Mark II</td>
<td>Vita Shading Paste</td>
<td>11770</td>
<td>600</td>
<td>58</td>
<td>6</td>
<td>950</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7451</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ProCAD</td>
<td>ProCAD Glazing Paste</td>
<td>J04540</td>
<td>400</td>
<td>60</td>
<td>4</td>
<td>780</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>J09912</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPS Empress CAD</td>
<td>IPS Empress Universal Glazing Paste</td>
<td>K49951</td>
<td>403</td>
<td>60</td>
<td>6</td>
<td>770</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>IPS Empress Universal Glaze and Stain Liquid</td>
<td>L07990</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPS e.max CAD</td>
<td>IPS e max Glaze Paste</td>
<td>L33388</td>
<td>403</td>
<td>60</td>
<td>6</td>
<td>770</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>IPS e max Glaze and Stain Liquid</td>
<td>L20925</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The teeth were sectioned 1.0 mm above the cementoenamel junction. The root segment was embedded in a resin (Technovit 4071, Heraeus Kulzer, Wehrheim, Germany) to a depth approximately 13.0 mm away from the cut surface. The dentin surface was ground sequentially with 320- and 600-grit silicon carbide abrasive papers, and specimens were kept in distilled water until they were cemented to the ceramic plates.

Ceramic plates
Ceramic blocks (Vita Mark II, ProCAD, IPS Empress CAD, and IPS e.max CAD; Table 1; n=20 for each type of ceramic material) were cut into rectangular slices (3.0×6.0×2.0 mm) using a low-speed diamond micro-cutter (Micro-cutter 201, Maruto, Tokyo, Japan). The dimensions of the ceramic plates were measured using a micrometer (PK-1021, Mitutoyo Corporation, Kanagawa, Japan).

IPS e.max CAD, a lithium disilicate glass-ceramic block, required crystallization firing at 850°C to improve the strength. Thus, IPS e.max CAD ceramic plates were fired in a furnace (P700, Ivoclar Vivadent, Schaan, Liechtenstein) according to the firing program recommended by the manufacturer: standby temperature at 403°C, rate of increase for the first temperature at 60°C/min, first closing time for 5 minutes; rate of increase for the second temperature at 30°C/min, second closing time for 10 minutes; first vacuum-on temperature at 550°C, first vacuum-off-temperature at 770°C; second vacuum-on temperature at 770°C, second vacuum-off temperature at 850°C; final firing temperature at 850°C, long-term cooling at 700°C at a cooling rate of 20°C/min.

Final surface finish
1. Surface polishing
The surfaces of 10 plates, which were chosen randomly from each ceramic material, were polished to provide a fine surface finish. The polishing procedure was carried out by a sequential use of medium, fine, and super-fine diamond-containing rubber polishing points (Ceramida, 8-M, 8-F and 8-SF; Morita, Tokyo, Japan) rotated with a low-speed handpiece (ACTY-2, Yoshida, Tokyo, Japan) at a rotational speed of 4,000 rpm for 3 minutes.

2. Overglazing
With each ceramic material, the remaining 10 plates were overglazed after being finished with a diamond point (Meister Point, Noritake, Aichi, Japan). Overglazing was carried out in a furnace (Vita Vacumat 40T, Vita Zahnfabrik, Bad Säckingen, Germany) according to the firing program and using the glazing materials as recommended by the respective manufacturers (Table 2). After the glazing procedure, ceramic specimens were kept in distilled water until they were luted to the dentin surfaces.

Cementation procedure
With the ceramic plates, two plastic films of 100 µm thickness were placed at the opposite sides of each ceramic plate. These plastic films served as spacers to control cement film thickness and the size of the bonding area (3.0×5.0 mm). Each ceramic plate surface was first etched with a 37% phosphoric acid gel (K-etchant, Kuraray Medical, Tokyo, Japan) for 5 seconds. All etched surfaces were thoroughly cleaned using a water spray and air-dried. Then, a silane coupling agent (Ceramic Primer, Kuraray Medical, Tokyo, Japan) was applied on the surfaces of the ceramic plates.

With the dentin substrate, the dentin surface was first cleaned using a water spray and then air-dried. ED primer II (Kuraray Medical, Tokyo, Japan) was applied on the dentin surface for 30 seconds and then dried with gentle air-blowing. The ceramic plates were then bonded to the flat dentin surfaces with a composite resin cement (Clearfil Esthetic Cement, Kuraray Medical, Tokyo, Japan), and the latter was light-cured for 20 seconds using a light curing unit (Jetlite 3000, Morita, Tokyo, Japan). Each bonded specimen was stored in water for 24 hours.

Compressive load test
After 24-hour storage, the bonded specimens were subjected to compressive loading at a crosshead speed of 0.5 mm/min in a universal testing machine (EZ Test, Shimadzu, Kyoto, Japan). Compressive force was applied using a 3.0-mm-diameter tungsten carbide ball being placed at the center of the ceramic plate. A small amount of lubricant was placed between the ball and the ceramic plate to keep the ball centered on the plate.

The crosshead movement was stopped when the first discontinuity appeared in the recording chart, indicating early crack formation. The compressive force required to cause fracturing in each ceramic plate was recorded in Newtons (N). Two-way analysis of variance (ANOVA) was performed to determine significant differences between the different types of surface finishes and among the different types of ceramic materials, and their interaction. Multiple comparisons were performed with the Bonferroni/Dunn test (significance level at 5%).

Scanning electron microscopy
The surfaces of the ceramic plates, either polished or glazed, were gold-coated with an ion coater (IC-50, Shimadzu, Kyoto, Japan) and observed under a scanning electron microscope (SEM; EPMA-1610, Shimadzu, Kyoto, Japan) at ×3,000 magnification.

RESULTS
Fracture strength
With each ceramic material, the fracture load values (N; mean±SD) were as follows for the polished and overglazed ceramic plates respectively: 591.3±114.9 and 684.2±121.5 for Vita Mark II, 820.2±210.2 and 818.1±160.6 for ProCAD, 858.1±121.9 and 892.8±123.1
for IPS Empress CAD, and 1,107.9±220.8 and 1,200.5±304.0 for IPS e.max CAD. As shown in Table 3, two-way ANOVA indicated no significant differences in mean fracture load between the polished and overglazed groups ($p > 0.05$), but presence of significant differences among the ceramic types ($p < 0.001$). There was also no significant interaction between these two variables ($p = 0.816$). The Bonferroni/Dunn test showed that the load value of Vita Mark II was significantly lower than those of IPS Empress CAD and ProCAD, whereas that of IPS e.max CAD was significantly higher than the latter two ceramic materials ($p < 0.05$) (Fig. 1).

**Table 3 Two-way analysis of variance of fracture load values**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Sum of square</th>
<th>Degree of freedom</th>
<th>Mean square</th>
<th>$F$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface finish</td>
<td>59,514.3</td>
<td>1</td>
<td>59,514.3</td>
<td>1.715</td>
<td>0.1945</td>
</tr>
<tr>
<td>Ceramic type</td>
<td>2,746,708.0</td>
<td>3</td>
<td>915,569.3</td>
<td>26.385</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Interaction</td>
<td>32,524.7</td>
<td>3</td>
<td>10,841.6</td>
<td>0.312</td>
<td>0.816</td>
</tr>
<tr>
<td>Error</td>
<td>2,498,414.5</td>
<td>72</td>
<td>34,700.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**DISCUSSION**

Generally, glazing is a procedure that increases the overall mechanical strength of all-ceramic restorations with a three-fold effect: reduces porosity, reduces the depth and/or sharpness of surface flaws, and blunts the flaw tips$^{31}$. In this study, however, no significant differences in compressive fracture strength were found between the overglazed and polished groups. These results agreed with those of previous studies in that glazing did not improve the strength of ceramic materials$^{7,10,14,16}$. The fracture strength and longevity of all-ceramic crowns is influenced by a number of factors such as inherent mechanical properties, fabrication techniques, luting agents, and intraoral conditions$^{22}$. Before doing time-consuming and costly clinical studies, preclinical *in vitro* studies should be conducted to evaluate the durability of these crowns$^{22}$. However, while compressive strength testing of all-ceramic crown systems in simulated clinical situations may provide an estimated range of the load-bearing capacities$^{2,22,23,34}$, the compressive fracture strength obtained is influenced by myriad experimental conditions such as the design, geometry, and size of crown specimens, the film thickness of luting agents, and the direction and position of force application$^{32,35}$. To isolate the final surface finishing method and type of ceramic material as the only variables in this study, a simple experimental design was adopted whereby rectangular ceramic plates adhesively luted to dentin were loaded with pressure only at one point at the center. Although this experimental design was also adopted in previous studies$^{17,19}$, further studies are required to verify if different test methods would yield consistent results.

When a ceramic plate is supported by a material with a lower stiffness (such as luting agent or dentin) and that its surface is loaded with pressure at a single point, the thickness of the ceramic plate becomes a primary influence on the fracture mode$^{35}$. When the thickness of the ceramic plate falls below 1.0 mm, single-point pressure loading causes the ceramic plate to become bent and the bottom (cemented) surface to become tense. Consequently, flexural radial cracking originating from the bottom surface becomes the predominant fracture mode$^{35}$. However, with a thicker ceramic plate, the bulk properties of the ceramic
Fig. 2  SEM photomicrographs of the polished (a–d) and overglazed (e–h) surfaces of the following ceramic materials: Vita Mark II (a, e); ProCAD (b, f); IPS Empress CAD (c, g); and IPS e.max CAD (d, h). Original magnification ×3,000; bar=10 µm.
material increase, thereby reducing the influence of the stiffness of the substrate (such as the luting cement or tooth structure). Consequently, cracks are predominantly initiated from the top outer surface of the ceramic plate in the form of a Hertzian fracture. In the present study, plate thickness of 2.0 mm was expected to result in Hertzian fracture, which was better suited for testing the effect, if any, of surface finishing on fracture strength.

On surface morphology, SEM examination revealed that the surfaces of overglazed specimens were homogenously smooth as opposed to the striated surfaces of the polished specimens (Fig. 2). This finding agreed with those of previous studies which examined the effects of polishing and overglazing on the roughness of dental ceramic surfaces. Nevertheless, surface pores, which could act as starting points of crack growth, were observed even on the glazed specimens, especially those made of Vita Mark II and IPS e.max CAD (Fig. 2). As glazing was carried out on as-ground surfaces, it was likely that the coarse surface was not uniformly coated with the glazing material, thereby resulting in incomplete removal of surface defects. This conjecture was supported by a finding that surface roughness was reduced when specimens were polished prior to overglazing. On the presence of surface irregularities after overglazing, it has also been reported previously, thereby explaining—at least in part—the reason why overglazing did not increase the compressive fracture strength in this study. However, it remained to be clarified whether fracture strength is influenced by the method/degree of polishing prior to glazing.

As for the polished specimens, although their surfaces were not as homogenously smooth as the overglazed specimens, surface porosities were not manifestly prominent even on the polished specimens (Fig. 2). This surface porosity feature also helped to explain the absence of significant differences in compressive fracture strength between the polished and overglazed specimens in this study. As to why there was minimal surface porosity even on polished specimens, it could be attributed to the structural reliability of industrially manufactured ceramic materials, which are supposedly produced under optimal conditions and hence contain minimal defects and voids.

ProCAD and its successor, IPS Empress CAD, are leucite-reinforced glass-ceramic materials constructed of a feldspar-leucite composite system. By means of three-point bending tests, it was reported that they exhibited a greater flexural strength than Vita Mark II, a feldspathic ceramic material. By means of compressive strength tests using all-ceramic crowns, it was also reported that ProCAD exhibited a greater fracture load than Vita Mark II. Indeed, results of the current study confirmed the improved strength of this material. Although SEM observation revealed detectable porosity on the overglazed surface of IPS e.max CAD (Fig. 2), its fracture strength was not adversely affected probably due to the inherent strength of this material.

Results of this study suggested that regardless of the type of ceramic material, both polishing and overglazing produced similar compressive fracture strengths. Nevertheless, overglazing might be the preferred surface finishing method since it produced a smoother surface—which is important for esthetics and hygiene, as well as helps to maintain high wear resistance in long clinical use. However, polishing is a more practical and widely used surface finishing method and is thus recommended in clinical settings where a less smooth surface would not cause major functional and/or esthetic problems.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn:

1. Overglazed and polished surfaces produced statistically similar compressive fracture strengths irrespective of the machinable ceramic material tested, although overglazed surfaces appeared smoother than polished surfaces.

2. The fracture load of Vita Mark II was significantly lower than those of ProCAD and IPS Empress CAD, whereas that of IPS e.max CAD was significantly higher than the latter two ceramic materials.

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