Fracture Resistance of CAD-CAM Ceramic Crowns: An in vitro Analysis

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Abstract

Purpose This study evaluated fracture resistance of single CAD-CAM (computer-aided design and computer-aided manufacturing) crowns made from hybrid, nano, and zirconia-reinforced lithium silicate ceramics with that of lithium disilicate ceramic.

Methods A complete coverage preparation was made on a mandibular left first molar placed in a mandibular arch (Standard model ANA-4; Frasaco). The prepared tooth was digitized using an intraoral scanner to generate a 3D cast to design the master dies which were placed in an acrylic resin mandible and scanned using the Omnicam intraoral scanner for the production of 48 crowns. (n=12 per group) All ceramic single crowns were made based on anatomical design and with equal standardized external geometry, from hybrid (Vita Enamic; VE), nano (Lava Ultimate; LU), zirconia-reinforced (Vita Suprinity; VS) lithium silicate ceramics, or lithium disilicate ceramic (IPS e.max CAD; IPS), and then adhesively luted. All specimens were thermocycled 10,000 times between 5 °C and 55 °C. Force was applied in a universal testing machine until the crown fractured. Additionally, failure modes were examined using scanning electron microscopy. Fracture load data were analyzed using one-way analysis of variance and multiple-comparison post-hoc Tukey tests (α = 0.05).

Results The fracture resistance of the LU group (2761.9 ±687.3 N) was found to be significantly higher than that of the VS group (1953.6 ±367.1 N) and IPS group (1915.8 ±521.7 N). However, there was no significant difference in the fracture resistance between the VS and IPS groups. In addition to there was no significant difference between the VE and LU groups.

Conclusion For all tested groups, the fracture resistance values fell within the clinically acceptable range. All materials tested in this in vitro study could withstand normal bite force.

Introduction

New ceramic materials and techniques have been developed to meet the increasing demands for aesthetic dentistry. The routine use of ceramics has produced strengthened as well as novel ceramic materials [1]. Additionally, computer-aided systems are used to produce the most esthetic restoration, as efficiently as possible. Currently, CAD-CAM systems and CAD-CAM blocks allow production of single-appointment esthetic restorations [2]. However, the mechanical properties of material used for restoration also play an important role in material selection, such as fracture resistance. In particular, in


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posterior restorations, failures occur more frequently due to masticatory forces [1]. Depending on the age and facial morphology of the individual, the maximum posterior masticatory force ranges between 500 and 900 N [2-4].

Ceramic systems can be applied as a monolithic structure, which yields greater strength, or as a bilayer structure, which facilitates esthetic goals [5]. The Vita Enamic block (Zahnfabrik; Bad Säckingen, Germany) is a polymer-infiltrated ceramic network (PICN) material used in the CAD-CAM technique [6]. Its manufacturer states that this material is a hybrid ceramic, and the mass percentage of the feldspar ceramic component are 86% (by weight), while that of the polymer component is 14% (by weight) [7]. The ceramic network resists deformation and wear, but it is brittle and fractures [8]. The Lava Ultimate block (3MESPE, StPaul, MN, USA), a resin nano ceramic, is a resin-containing material also used in CAD-CAM systems [2]. Another material used in these systems is the Vita Suprinity block (Zahnfabrik; Bad Säckingen, Germany), a zirconia-reinforced lithium silicate ceramic [9]. This innovative glass ceramic is enriched with zirconia (10% by weight), making it a high-strength material [10]. Such zirconia-reinforced lithium silicate ceramics combine the resistance properties of polycrystalline ceramics with the esthetic characteristics of glass ceramics in a monolithic restoration [9]. One such CAD-CAM block is the IPS e.max CAD (Ivoclar, Vivadent AG, Liechtenstein), which is a lithium disilicate (Li₂Si₂O₅), containing 35-45 vol% of evenly dispersed leucite crystals (1-5 µm), and comprises improved glass-ceramic material with a relatively high fracture strength [11, 12].

Crown fractures are one of the most common clinical complications encountered with ceramic crowns [2]. In vitro testing of clinical situations, combined with the basic assessments (occlusal loading, thermal cycle) using reproducible laboratory conditions, can help to evaluate new materials and restorations before their routine implementation in clinical practice [13]. The ISO TR 11450 standard recommends a thermocycling regimen of 500 cycles between water tanks of 5°C and 55°C to simulate an alistic aging process. A more effective thermocycling regimen would involve 10,000 or more thermocycles [14].

In this study, we compared the fracture-resistance of single CAD-CAM crowns made from hybrid, nano, and zirconia-reinforced lithium silicate ceramics with that of lithium disilicate ceramic. The null hypothesis of this study was that there would be no significant differences in the fracture-resistance values of Vita Enamic, Lava Ultimate, Vita Suprinity, and IPS e.max CAD crowns.

### Materials and methods

#### Preparation of crowns

A full crown preparation for the mandibular left first molar was made for a typodont model (ANA 4, Frasaco, Tettnang, Germany) with a 1.2-mm rounded shoulder as the finish line [15], 1.5-2.0 mm occlusal reduction, and a 6-10° taper angle. The intraoral scanner component of a CEREC M XL unit (Omnicam, Sirona Dental Systems Gmbh, Bensheim, Germany) was utilized to digitize the prepared tooth in order to generate a 3-dimensional model for designing the master dies for four ceramic blocks. For the production of the master dies, the “Bio-generic copy” design was chosen. Then, total of 48 master dies (n=12 per group) were fabricated by duplicating the prepared typodont tooth using the same materials as for the prepared tooth in the Cerec MXL CAD-CAM system (Sirona Dental Systems Gmbh). The materials used in this study are listed in Table 1.

### Table 1. Compositions and manufacturers of the materials

<table>
<thead>
<tr>
<th>Groups</th>
<th>Composition</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vita Enamic</td>
<td>14% polymer, 86% fine structure feldspar ceramic</td>
<td>VITA Zahndfabrik, Bad Säckingen, Germany</td>
</tr>
<tr>
<td>Lava Ultimate</td>
<td>20% composite resin, 80% ceramic</td>
<td>3MESPE AG, Seefeld, Germany</td>
</tr>
<tr>
<td>Vita Suprinity</td>
<td>10% zirconia glass ceramic</td>
<td>VITA Zahndfabrik; Bad Säckingen, Germany</td>
</tr>
<tr>
<td>IPS e.max CAD</td>
<td>70% lithium disilicate glass ceramic</td>
<td>Ivoclar Vivadent, Amherst, NY</td>
</tr>
</tbody>
</table>
IPS and VS specimens were positioned in the porcelain furnace (Programat; Ivoclar, Liechtenstein) with a firing paste (Firing paste; Vita Zahnfabrik, Germany) for the crystallization phase. VE and LU master dies did not require this additional finishing or polishing procedure. The “Bio-generic individual” design technique was also chosen for the production of crowns. Each master die was placed in an acrylic jaw and scanned with an intraoral scanner (Omnicam; CEREC, Sirona Dental Systems GmbH). A cement range of 40 μm was selected. After each crown design was standardized with CEREC software, the information was digitally sent to the milling unit. Twelve crowns were obtained for each group.

IPS and VS crowns were completed after the additional crystallization. VE and LU crowns do not need additional crystallization phase. Mechanical polishing is also performed. VE and LU crowns were prepared first by grinding off the sprue with a coarse rubber wheel, followed by finishing the sprue area with a medium rubber tool. Specimens were polished using the silicon carbide pink rubber disc of the technical kit (Vita Zahnfabrik; Germany) with 8.000 rpm hand piece. After the use of the pink rubber disc, the grey disc of the technical kit with smaller particle size was used with 5.000 rpm according to the manufacturer’s instructions.

Fracture-resistance testing

The specimens for the fracture resistance test were embedded in an acrylic cylinder. Crowns from each group were cemented with a dual-cure self-adhesive resin cement (Panavia SA Cement, Kuraray, Japan), using finger pressure to set the crowns. To ensure that autopolymerization of the resin cement had been completed, 24 h after luting, the specimens were thermocycled for 10,000 cycles between baths held at 5°C and 55°C with a dwelling time of 30 seconds and a transfer time of 7 seconds. We performed 1000 thermocycles per week, totaling 4000 thermocycles at the end of 1 month and 10,000 thermocycles after a 2.5-month period. Fracture loads were measured 24 h after completing thermocycling. The measurements were obtained with a computer-supported universal testing device (Autograph AGS-X, 10 Kn, Shimadzu Scientific Instruments, Kyoto, Japan) and load was applied at a crosshead speed of 0.5 mm per minute, with a 1/5-inch diameter, hardened steel sphere attached to the moving head of the testing machine, until failure occurred.

Failure Analysis

In order to observe the structural changes in the material, one specimen from each group was putter coated (Bal-Tec SCD 050, Bal-tec AG, Liechtenstein) with a 15-nm layer of Au-Pd and imaged using a scanning electron microscope (SEM; LEO Evo 40XVP, Carl Zeiss, Oberkochen, Germany). Images were examined at 20 kV within a magnification range of 50× to 200×.

Statistical analysis

The Shapiro–Wilk test was performed for data from all groups and normal distribution was verified. The fracture load for each crown was analyzed using one-way ANOVA followed by the Tukey HSD multiple-comparison test. (P <0.05)

Results

Table 2 represents the fracture resistance of each of the CAD-CAM ceramic blocks. A significant difference in fracture resistance was found among the groups (P <0.05). After adjusting for multiple comparisons, the fracture resistance of the LU group (2761.9± 687.3 N) was found to be significantly higher than that of the VS group (1953.6 ± 367.1 N) and IPS group (1915.8 ± 521.7 N). However, no significant difference in fracture resistance was found between the VS group and the IPS group. Furthermore, there was no significant difference between the VE and LU groups. No damage was detected on the master dies. Two types of fractures were recorded: in some cases, crown fragments remained partially attached to the master dies, while in others, complete crown fractures, classified as the catastrophic failure type, occurred (Fig. 1) [13]. Failure modes were classified as follows: Type I, a cohesive ceramic fracture without cement fracture; Type II, a cohesive ceramic fracture with a cement fracture (Fig. 2). The CAD-CAM blocks containing resin showed softer fracture lines, whereas the zirconium and lithium disilicate CAD-CAM blocks displayed sharper edges (Fig. 3).

Discussion

CAD-CAM technology makes it possible to provide complete treatment in a single appointment. It also offers opportunities to produce restorations that requireless tooth preparation. The fracture resistance of the new CAD-CAM blocks is important because they are produced without any reinforced substructure. Some studies have used a geometric specimen that complies
Table 2. Fracture-resistance of tested specimens (N)

<table>
<thead>
<tr>
<th>GROUPS</th>
<th>Mean (SD)</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vita Enamic</td>
<td>2123,0 (634,3) AB</td>
<td>1402</td>
<td>3265</td>
</tr>
<tr>
<td>Lava Ultimate</td>
<td>2761,9 (687,3) A</td>
<td>1495</td>
<td>4200</td>
</tr>
<tr>
<td>Vita Suprinity</td>
<td>1953,6 (367,1) CB</td>
<td>1304</td>
<td>2470</td>
</tr>
<tr>
<td>IPS e.max CAD</td>
<td>1915,8 (521,7) CB</td>
<td>1262</td>
<td>3264</td>
</tr>
</tbody>
</table>

N: Newton, SD: Standard deviation.
*Mean values followed by different uppercase letters in same column show a statistically significant difference (p<0.05) by one-way ANOVA and Tukey’s HSD.

Fig. 1: Frequencies of fracture types in percentage

![Fracture Type](image1)

Fig. 2: Frequencies of fracture modes in percentages

![Fracture Mode](image2)
with the ISO standard, whereas in this study, we used anatomically correct specimens to produce results similar to those encountered in actual clinical outcomes [16].

The results of this study led to rejection of the null hypothesis. The testing method applied here has also been used in previous studies [17,18]. The elastic modulus of the die materials (master dies) should be similar to that of dentin to obtain clinically relevant crown fractures. Therefore, these CAD-CAM blocks, which have a dentin-like elasticity modulus, were used as die materials [18].

Several studies have used different thermal cycle parameters [2,4,9,13,19]. The temperatures of 5°C and 55°C were used to simulate in vivo conditions in this study [20]. In other recent studies, thermal cycles and chewing simulators have been used together [4,13,21]; however, this was not the approach used in the present study, and is a limitation of the study.

As new CAD-CAM blocks continue to be produced, their mechanical properties are compared. Harada et al. [18] have reported that the fracture resistance of the Lava Ultimate molar crowns, produced by a CAD-CAM system, was 2880 ±154 N. Dogan et al. [2] have evaluated the fracture resistance of monolithic ceramic molar crowns that were cemented with titanium abutments. The average fracture resistance of the IPS e-max CAD and Lava Ultimate crowns was reported to be 2644 N and 2490 N, respectively. Zesewitz et al. [11] found that the average fracture resistance of IPS e.max CAD restorations was 2705 ±370 N, whereas Yangs et al. [20] showed it to be1721 ±143 N. Albero et al. [6] prepared a new generation CAD-CAM block samples according to ISO standards and compared the fracture loads. The average fracture load of the IPS e.max CAD (0.44 ±0.10 kN) blocks was higher than that of the Vita Enamic (0.25 ± 0.06 kN) blocks and Lava Ultimate (0.26 ±0.06 kN) blocks.

Some of the above studies have reported findings similar to ours, while others found different results. Since the maximum bite force used in the present study was between 500 and 900 N in the posterior region [3,4,13], the average fracture resistance values of all groups were found to be within the clinically acceptable range.

Previous studies have reported different types of

Fig. 3: Scanning electron microscope (SEM) (×200 magnification) view of fracture pattern:
(a) Vita Enamic, (b) Lava Ultimate, (c) Vita Suprinity, (d) IPS e.max CAD.
fractures [13,16,22]. In this study, catastrophic failures and type II, a cohesive ceramic fracture with a cement fractures were the predominant fracture types and modes. In the study of Rohr et al. [23], the first fracturing events occurred at the occlusal surface, while the second fracturing events occurred at the margins of the crown, in uncemented crowns. We obtained similar results in this study while using cemented crowns. This is because the luting cement was not observed in some of the occlusal surfaces and in some of the margins of the master dies. This should be further investigated in future.

SEM images of the fracture surfaces showed some differences among the materials. Depending on the differences in the microstructure, the fracture pattern and fracture surfaces varied. The results of the study by Leung et al. [12], in which the fracture surfaces of Vita Enamic were compared with those of IPS e.max CAD, showed that after a 3-point bend test, the fracture surface of the Vita Enamic was rougher than that of the IPS e.max CAD.

There are several limitations to this study. These results are applicable only to the ceramic and luting system tested by thermal cycling. Therefore, further studies of these CAD-CAM blocks, such as examining different self-adhesive resin cements, along with different long-term mechanical and thermal cycling processes, as well as different types of restorations performed using these blocks, are necessary to confirm the findings of this study.

**Conclusion**

Despite the limitations of this in vitro study, we concluded that the Lava Ultimate and Vita Enamic ceramics had higher fracture resistance than the Vita Suprinity and IPS e.max CAD ceramics. Fracture resistance values were within a clinically acceptable range for all CAD-CAM blocks tested.

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**Reference**


