Fracture Resistance of Chairside CAD/CAM Molar Crowns Fabricated with Different Lithium Disilicate Ceramic Materials

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**Purpose:** To compare the fracture resistance of five different groups of chairside CAD/CAM molar crowns fabricated from various lithium disilicate ceramic materials (LDC): one conventional precrystallized CAD/CAM LDC, two novel precrystallized LDCs, and one fully crystallized LDC tested both with and without optional sintering. **Materials and Methods:** A total of 60 chairside CAD/CAM lithium disilicate molar crowns (n = 12 per group) with 1.5-mm occlusal thickness and a 1.0-mm chamfer finish were designed and fabricated with a chairside CAD/CAM system (CEREC, Dentsply Sirona). The restorations were divided into five groups: (1) IPS e.max CAD; (2) Amber Mill; (3) Straumann n!ce; (4) Straumann n!ce with optional sintering; and (5) Supreme CAD. Restorations were cemented using conventional resin luting cement and primer system to 3D-printed resin dies. Bonded restorations were loaded for 100,000 cycles with 275-N force, and the load at break (LB) and peak load (PL) until fracture were measured. SEM images of fracture surfaces on the printed dies were obtained. **Results:** Fracture resistance was significantly different depending on the material. Supreme CAD showed the highest fracture resistance (LB: 1,557.2 N; PL: 1,785.8 N), followed by Amber Mill (LB: 1,393.0 N; PL: 1,604.2 N) and IPS e.max CAD (LB: 1,315.7 N; PL: 1,461.9 N). Straumann n!ce without (LB: 862.4 N; PL: 942.9 N) and with the optional sintering (LB: 490.4 N; PL: 541.0 N) showed significantly lower fracture resistance than the others. **Conclusion:** The fracture resistance of chairside CAD/CAM lithium disilicate molar crowns varied depending on the material, and the novel materials did not perform as well as the conventional equivalents. Fully crystallized lithium disilicate ceramic block materials showed lower fracture resistance than precrystallized counterparts and should be used with caution in the clinic, especially with optional sintering. Int J Prosthodont 2022 August 25. doi:10.11607/ijp.7802. Online ahead of print.
The introduction of CAD/CAM in restorative dentistry has provided clinicians with the ability to fabricate final restorations in fewer appointments. The development of CAD/CAM ceramic restorative materials has expanded the possibilities for fabricating crowns with high biocompatibility, exceptional esthetics, and improved biomechanics beyond those offered by conventional techniques. Recently, single-visit crowns produced with chairside CAD/CAM technology have become a common treatment in dentistry, as this approach improves patient comfort and requires neither laboratory procedures nor transportation of the restoration.

Currently, chairside CAD/CAM lithium disilicate ceramic material (LDC) is a popular choice for the fabrication of many kinds of restorations. LDC is a reinforced glass-ceramic material that has proven to have high esthetic qualities with higher fracture toughness (2.15 to 2.18 MPa/m) than leucite-reinforced ceramic and resin composite counterparts (0.71 to 1.47 MPa/m). Moreover, systematic reviews of survival and complication rates for all-ceramic posterior single crowns have shown it to be a reliable treatment option for posterior teeth, with excellent survival rates similar to metal-ceramic equivalents. Most of the LDCs are delivered as CAD/CAM blocks and manufactured in a “green” precrystallized form, which is relatively soft and enables rapid manufacturing with low damage to the milling burs. Precrystallized LDC has been shown to have a low flexural strength of 120 MPa, but after the crystallization process, the flexural strength increases to 336 to 360 MPa.

IPS e.max CAD (Ivoclar Vivadent) was launched in 2006 as the first chairside CAD/CAM LDC. It has been used for 15 years, and though whether press or CAD techniques provide the superior marginal fit for restorations is still debatable, the marginal gaps of both restorations are within the clinically acceptable range. The material is manufactured in a precrystallized state, and the restoration becomes fully crystallized after the firing process. After performing the intraoral scan and design of the restoration, the clinician needs to place the milled restoration in a furnace for a sintering cycle of 20 to 25 minutes before cementing the restoration in the mouth. This firing process allows the material to undergo a crystalline phase transition to maximize its fracture resistance properties for clinical use.

This CAD/CAM version of the material contains both 40% lithium metasilicate (Li2SiO3) crystals and lithium disilicate (Li2Si2O5) crystal nuclei and is available in different shades and grades of translucency depending on the size and density of the crystals.

Novel chairside CAD/CAM LDCs that make use of different compositions or that are based on different concepts have recently been introduced to the market. These newer materials include a precrystallized LDC in which it is possible to vary the translucency within a single block through different firing temperatures (Amber Mill CAD, HASSBIO), a fully crystallized novel lithium disilicate strengthened with lithium aluminosilicate glass-ceramic (Straumann n!ce, Straumann), and a precrystallized lithium disilicate with a blue-violet toned traditional color (Supreme CAD, Axsys Dental Solutions). The ability to adjust the translucency of the Amber Mill CAD by choosing the firing temperature to achieve the desired translucency is novel and provides increased flexibility for clinicians. Straumann n!ce is an innovative material because the conventional in-office sintering process is not mandatory and extra firing processes are only optional. Clinicians may be attracted to this novel product because sintering is the longest stage between the initial tooth preparation and delivery of the chairside restoration. The third material (Supreme CAD) claims to have improved properties in all respects compared to the conventional equivalent.

The aim of this study was to compare the fracture resistance of five groups of chairside CAD/CAM molar crowns with different fabrications: one conventional precrystallized CAD/CAM LDC, two novel precrystallized LDCs, and one fully crystallized LDC tested both with and without optional sintering. The first null hypothesis was that there would be no difference in the fracture resistance of chairside CAD/CAM lithium disilicate molar crowns between the five different conditions. The second null hypothesis was that there would be no difference in fracture resistance of the crowns between the conventional and the novel LDCs. The third null hypothesis was that there would be no difference in the fracture strength of the crowns among the novel LDCs. The fourth and final null hypothesis was that there would be no difference in fracture resistance of the crowns between the precrystallized and the fully crystallized LDCs.

**MATERIALS AND METHODS**

A mandibular right first molar typodont tooth (1560 Dentoform, Columbia Dentoform) was prepped for a high-strength ceramic restoration with 1.5-mm occlusal clearance and a 1.0-mm chamfer margin. The prepped typodont tooth was scanned with an intraoral chairside scanner (Primescan, Dentsply Sirona) and a design software (CEREC SW 5.1, Dentsply Sirona) for the restoration. A total of 60 CAD/CAM crowns were milled (MCXL, Dentsply Sirona) from different LDCs, 12 for each group as follows: (1) IPS e.max CAD for CEREC/inLab C14 (EM; Ivoclar Vivadent); (2) Amber Mill C14 (AM; HASSBIO); (3) Straumann n!ce (SN; Straumann); (4) Straumann n!ce with optional firing process (SNW; Straumann); and (5) Supreme CAD (SU; Axsys Dental Solutions). The components of the ceramics are as follows: IPS e.max CAD is available in a presintered stage and is composed primarily of lithium metasilicate (Li2SiO3) crystals 0.2 to 1.0 μm in size, along with lithium disilicate nuclei. Amber Mill is a...
Table 1  Fracture Resistance (N) of the Surviving Specimens of the Chairside CAD/CAM Molar Crowns in Different Lithium Disilicate Ceramics

<table>
<thead>
<tr>
<th>Type</th>
<th>Material</th>
<th>No. of surviving specimens</th>
<th>LB</th>
<th>PL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional material</td>
<td>EM</td>
<td>11</td>
<td>1,315.7 (373.3)a</td>
<td>1,461.9 (424.1)a</td>
</tr>
<tr>
<td>Novel materials</td>
<td>AM</td>
<td>12</td>
<td>1,393.0 (204.1)b</td>
<td>1,604.2 (220.5)b</td>
</tr>
<tr>
<td>SN</td>
<td>9</td>
<td>862.4 (191.8)b</td>
<td>942.9 (212.7)b</td>
<td></td>
</tr>
<tr>
<td>SNW</td>
<td>12</td>
<td>490.4 (118.9)b</td>
<td>541.0 (140.3)b</td>
<td></td>
</tr>
<tr>
<td>SU</td>
<td>12</td>
<td>1,557.2 (209.4)a</td>
<td>1,785.8 (233.5)a</td>
<td></td>
</tr>
</tbody>
</table>

Data are reported as mean (SD) unless otherwise indicated. The same superscript letter in the same column indicates no significant difference (P > .05).

glass-ceramic composed of crosslinked crystal structures of silicon dioxide (SiO₂), lithium oxide (Li₂O), potassium oxide (K₂O), phosphorus pentoxide (P₂O₅), and aluminum oxide (Al₂O₃). Straumann n!ce is a fully sintered glass-ceramic for which the in-office firing process is optional and is fabricated out of lithium disilicate strengthened with lithium aluminosilicate glass-ceramic (Li₂O-Al₂O₃-SiO₂).¹⁴

Supreme CAD is a precrystallized ceramic made up of silicon dioxide (SiO₂), lithium oxide (Li₂O), potassium oxide (K₂O), and other oxides. The restorations were fabricated in a precrystallized state—except for SN, which was fabricated in a fully crystallized state—and the firing process was only performed for one group. Groups 1, 2, 4, and 5 were glazed and sintered following the manufacturers’ recommendations.

A laboratory scanner (Freedom HD, DOF) was used to scan the prepped typodont tooth and to digitally design a die matching the preparation. A total of 60 dies were printed with a laboratory printer (FormLab 3, Formlabs) using a resin (Model Resin, Formlabs) that has a similar modulus of elasticity to dentin. The fabricated crowns were treated following the manufacturer recommendations: The adherent surfaces of the restorations were treated with 4.9% hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar Vivadent) for 20 seconds, rinsed with tap water for 20 seconds, and then coated with silane (Monobond Plus, Ivoclar Vivadent) for 60 seconds. All restorations were then luted to the tooth dies with conventional resin luting cement (Multilink Automix, Ivoclar Vivadent) and light cured from a distance of 5 mm with a halogen light-curing unit (Elipar 2500, 3M) on the mesial, distal, buccal, lingual, and occlusal surfaces for 20 seconds each, then allowed to self-cure for 6 minutes with 200 g of applied weight. The power density (> 600 mW/cm²) of the curing unit was confirmed before specimen preparation. All specimens were luted at ambient temperature and humidity before being stored in 37°C distilled water for 24 hours.

The sample size was determined using the effect size = 0.25 (medium) or 0.5 (large), α = .05, power = 0.8, and number of groups = 3. The results indicate that a total of 200 specimens (medium effect size) or 55 (large effect size) were needed for the fracture loading tests. The analysis showed that 11 to 40 specimens were needed for each group for the test, and therefore using 12 specimens/group, which is within the results of the G*Power calculation, was considered appropriate.

Cyclic loading was performed for each type of restoration in room-temperature water using 100,000 cycles at 1 Hz with 275 N of force. Specimens were secured with a steel jig in a vertical position and loaded against a polyoxymethylene ball (Delrin 6.28 mm, DuPont) that was used to make contact with the occlusal surface of the restoration. At the end of the fatigue test, the crowns were examined to determine if any catastrophic failure had occurred. The crowns that survived the fatigue process were secured on a steel jig and then loaded to fracture via compression in a universal testing machine (Instron 4204). A tapered cone-shaped (3.2 mm at the tip) applicator was placed vertically along the central groove of the crown, with a 1 mm/minute compressive load rate. During the fracture testing, the applied force was monitored, and the load at break (LB) and the peak load (PL) were recorded.

The fractured restoration and the 3D-printed dies were observed with field-emission scanning electron microscopy (ERA 8800FE, Elionix). A thin coat of gold was applied to the specimens in a sputter coater (Quick Coater Type SC-701, Sanyu Electron) to provide electrical conductivity. The fractured surface of the restoration on the resin dies was observed with an accelerating voltage of 15 kV.

Statistical analysis was conducted with a commercial software package (SPSS version 25, IBM). Kruskal-Wallis test was used to analyze the data for the influence of the type of material, comparison between conventional and novel materials, within novel materials, and between precrystallized and fully crystallized ceramic materials with a significance level of .05.

RESULTS

The LB and PL of the surviving specimens of the chairside CAD/CAM molar crowns in different LDCs are shown in Table 1. The LB and PL were influenced by the type
of material ($P = .000$; $PL: P = .000$). SU displayed the highest values, with 1,557.2 N for LB and 1,785.8 N PL, followed by AM with 1,393.0 N LB and 1,604.2 N PL and EM with 1,315.7 N LB and 1,461.9 N PL. SNW showed the lowest outcome with 490.4 N LB and 541.0 N PL, followed by SN with 862.4 N LB and 942.9 N PL. Straumann n!ce without and with the optional sintering showed significantly lower fracture resistance than the others. The rank order was SU = AM = EM > SN = SNW for both LB and PL.

Representative SEM observations of the fracture surfaces of the restorations on printed dies are shown in Figs 1 to 5. It should be noted that the varying location of the fracture in the restoration can obscure the differences between the specimens. The fracture surfaces of EM, AM, SN, and SU were much cleaner, more defined, and had fewer cracks present than those of SNW, regardless of the specimen.

**DISCUSSION**

Chairside CAD/CAM lithium disilicate restorations have become very common in daily practice. A recent practice-based study reported that lithium disilicate glass-ceramics...
were the second most common material used for single-unit restorations, covering 21%. Thus, manufacturers around the world are developing their own LDCs for chairside CAD/CAM restorations. Most LDCs are fabricated in a precrystallized state that requires the clinician to apply a sintering process in-office, even among newer materials. Interestingly, only one manufacturer has developed a fully crystallized chairside LDC that allows clinicians to fabricate the final crown without the need to provide the traditional in-office firing process, with the option of a firing process in-office in order to glaze and stain the restorations. Compared to the conventional material, IPS e.max CAD, the manufacturers of all the newer materials claim superior mechanical and esthetic properties; however, independent studies evaluating these properties are either very limited or not available. Thus, the present study has evaluated the fracture resistance of molar crowns fabricated with the conventional, two new precrystallized, and one fully crystallized LDC.

One of the principal strengthening mechanisms of glass-ceramic is the interlocking effect of the crystals within the microstructures of the ceramic. Crack propagation has been demonstrated to happen at the interface of the crystals and the glass, creating intergranular...
fractures.\textsuperscript{20,21} Unfortunately, the full composition of the other oxides that make up the microstructure is not fully disclosed by the companies, and these details may cause differences in physical properties such as fracture resistance. Based on the results of this study, statistically significant differences (LB and PL: $P = .000$) in fracture resistance were found between the different materials ($n = 56$); therefore, the first null hypothesis—that there would be no difference in the fracture resistance of chairside CAD/CAM lithium disilicate molar crowns between the five different conditions—was rejected. Previous studies showed that the mean occlusal force on the molar is 619.3 N (women: 579.0 N; men: 659.5 N)\textsuperscript{22} or 601.8 N (women: 553.0 N; men: 650.67 N),\textsuperscript{23} and approximately 600 N is considered as the highest occlusal force occurring during mastication in the posterior area for adults. In the fatigue process, 100,000 cycles were applied with a force of 275 N, and a repeated consistent load stress was applied as a fatigue aging process. The consistent load was set at 40\% to 50\% of the reported occlusal force on molars. For the number of cycles, 100,000 cycles for fatigue testing have been widely used and reported in previous studies, and this number represents 1 year of service time.\textsuperscript{24–26} Thus, all the tested restorations—apart from the restoration fabricated using Straumann n!ce with optional in-office sintering—exhibited a fracture resistance considerably exceeding, by a comfortable margin of safety, the reported occlusal force in molars.

No differences (LB: $P = .477$; PL: $P = .307$) in fracture resistance values were detected between the conventional and novel LDCs ($n = 56$). Thus, the second null hypothesis—that there would be no difference in fracture resistance of the crowns between the conventional and the novel LDCs—was not rejected. When looking at individual materials, the fracture resistance of the conventional material was similar to that of AM (LB and PL: $P = 1.000$), SN (LB: $P = .182$; PL: $P = .288$), and SU (LB: $P = .657$; PL: $P = .866$), and significantly higher than that of SN with optional sintering (LB: $P = .002$; PL: $P = .004$). In addition, SEM observation of the fracture surfaces of restorations also showed that the restorations made of novel materials, apart from SNW, were similar to IPS e.max CAD. These results are consistent with a previous study of the fatigue resistance of crowns of conventional and newer LDCs, and it was difficult to determine whether the newer materials are better than the conventional counterpart.\textsuperscript{14}

Statistically significant differences (LB and PL: $P = .000$) in fracture resistance were found between the novel materials ($n = 45$), and thus the third null hypothesis—that there would be no difference in fracture strength of the crowns among the novel LDCs—was rejected. If the results for the fully crystallized material—Straumann n!ce with or without optional sintering—were compared, the fracture resistance of the crown made from the material was not influenced (LB: $P = .521$; PL: $P = .532$) by the presence or absence of optional sintering. Thus, it cannot be said that the optional firing process has any influence on the fracture resistance of the crown. On the other hand, the fracture resistance of the molar crown for Straumann n!ce was significantly lower than that for Amber Mill and Supreme CAD. Based on the present study, although there was basically no difference between conventional and novel chairside CAD/CAM ceramic materials, there is a difference among the newer products. In other words, it is important for clinicians to check the basic research

\begin{figure}
\centering
\includegraphics[width=\textwidth]{Fig5}
\caption{SEM images of molar crowns fabricated with n!ce with the optional in-office sintering process. Full crown specimens are shown at $\times 20$ magnification, and crack initiation and propagation are shown at $\times 100$ magnification.}
\end{figure}
data and fully understand the characteristics of each newer LDC before deciding whether to use it. Furthermore, statistically significant differences (LB: \( P = .006; \) PL: \( P = .005 \)) in fracture resistance were found between the precrystallized and fully crystallized LDCs (\( n = 56 \)), and so the fourth null hypothesis—that there would be no difference in fracture resistance of the crowns between the precrystallized and the fully crystallized LDCs—was rejected.

Published studies comparing conventional precrystallized to fully crystallized lithium disilicate are very limited. Fully crystallized lithium disilicate is a novel material on the market, which could be one of the reasons for limited data. One study has compared the fracture resistance of polished crowns fabricated with this novel fully crystallized lithium disilicate (SN) to that of traditional precrystallized lithium disilicate (EM) and found higher fracture resistance for conventional lithium disilicate (2,044 ± 302) than novel fully sintered lithium disilicate (1,214 ± 293).\(^\text{14} \) Another recent study also evaluated the fracture strength of precrystallized and fully crystallized lithium disilicate both with and without mastication simulation, and the raw data suggest a higher resistance for lithium disilicate with fatigue (304 ± 34 MPa) and without fatigue (259 ± 62 MPa) than for fully crystallized lithium disilicate with fatigue (202 ± 17 MPa) and without fatigue (172 ± 11 MPa).\(^\text{27} \) The results of the present study concur with the raw data presented in the previous studies, with higher values for the traditional lithium disilicate e.max CAD (1,315.7 ± 373 MPa) than the novel fully crystallized lithium disilicate (826.4 ± 191.8 MPa).

Precrystallized LDCs required time-consuming laboratory procedures such as milling and crystallization, and the use of fully crystallized LDC for the fabrication of restorations can reduce the working steps, as it only requires milling and chairside polishing in most cases. In addition, if the patient wants to have a more esthetic restoration, the restoration can be glazed by hand chairside and then given the sintering process over 3 minutes (heating time of 2 minutes and cooling time of 1 minute, start and holding temperature 400°C and firing temperature 700°C). Thus, this may be an appealing option for clinicians, and the material would be more suitable as a chairside CAD/CAM restorative material due to the elimination of the sintering process for crystallization. However, the fully crystallized LDC showed a statistically significant difference compared to the precrystallized materials, and the fracture resistance of the fabricated crown with fully crystallized material with optional sintering was lower than the other groups. Although a previous study reported that the fatigue resistance of a molar crown of fully crystallized lithium disilicate was similar to a conventional equivalent,\(^\text{14} \) the recommendations of the present authors would be that precrystallized LDCs are a safer choice for the material for molar crowns than fully crystallized material. Nevertheless, fully crystallized LDCs have a great potential to accelerate the chairside restorative workflow, and further research is needed to improve their fundamental physical properties, especially under the optional firing conditions.

**CONCLUSIONS**

The fracture resistance of molar crowns fabricated with chairside CAD/CAM lithium disilicate materials varied according to the brand selected. More recently developed materials are not necessarily better than the conventional option and showed different fracture resistances by material. Fully crystallized lithium disilicate materials showed lower fracture resistance than their precrystallized counterparts and should be used with caution in the clinic, especially with optional sintering.

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