Zirconia-reinforced dental restorations
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Citation for published version (APA):

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CHAPTER 5

The fracture resistance of a CAD/CAM Resin Nano Ceramic (RNC) and a CAD ceramic at different thicknesses
5.1 Abstract

Objectives: This study aimed to investigate the influence of restoration thickness to the fracture resistance of adhesively bonded Lava Ultimate CAD/CAM, a Resin Nano Ceramic (RNC), and IPS e.max CAD ceramic.

Methods: Polished Lava Ultimate CAD/CAM (Group L), sandblasted Lava Ultimate CAD/CAM (Group LS), and sandblasted IPS e.max CAD (Group ES) discs (n = 8, Ø = 10mm) with a thickness of respectively 0.5 mm, 1.0 mm, 1.5 mm, 2.0 mm, and 3.0 mm were cemented to corresponding epoxy supporting discs, achieving a final thickness of 3.5 mm. All the 120 specimens were loaded with a universal testing machine at a crosshead speed of 1 mm/min. The load (N) at failure was recorded as fracture resistance. The stress distribution for 0.5 mm restorative discs of each group was analyzed by Finite Element Analysis (FEA). The results of fracture resistances were analyzed by one-way ANOVA and regression.

Results: For the same thickness of testing discs, the fracture resistance of Group L was always significantly lower than the other two groups (P < 0.05). The 0.5 mm discs in Group L resulted in the lowest value of 1,028 (112) N. There was no significant difference between Group LS and Group ES when the restoration thickness ranged between 1.0 mm to 2.0 mm (P > 0.05). There was a linear relation between fracture resistance and restoration thickness in Group L (R = 0.621, P < 0.001) and in Group ES (R = 0.854, P < 0.001). FEA showed a compressive permanent damage in all groups.

Significance: The restorations with the thickness above 0.5 mm can be clinically used for both materials. When Lava Ultimate CAD/CAM is used, sandblasting is suggested.
5.1 Introduction

Due to increasing concerns about the aesthetics and biocompatibility of dental restorations, patients and dentists have become more and more interested in metal-free tooth-colored materials. Ceramic materials were developed in response to this increasing demand [1]. Although ceramics are routinely used for dental restorations, a major drawback is their high clinical failure rate in posterior sites [2]. All-ceramic crowns are often replaced because of bulk fracture, a catastrophic failure mode noted in both monolithic and layered crowns [3]. The fracture resistance of a ceramic crown depends mainly on the mechanical properties of the veneering ceramics [4]. Because of the presence of inherent flaws within the material [1, 4], most dental ceramics are brittle, having low tensile strength and fracture toughness. Tensile stresses caused by external loading can lead to a propagation of cracks starting at these inherent flaws and other defects [4]. Therefore, cracks usually initiate from the inner surface of ceramics, i.e. the cementation surface, where tensile strength is the highest, and then propagate through the material to the outer surface, ultimately leading to bulk fracturing [3].

In an attempt to improve the mechanical properties, industrially made CAD/CAM ceramics blocks have been introduced to dentistry [1, 4]. As ceramics are not manufactured in a dental laboratory, but under industrial conditions, voids, flaws, and cracks are reduced to a minimum [5, 6]. One of these CAD/CAM ceramics is IPS e.max CAD (Ivoclar Vivadent AG, Liechtenstein), an improved glass-ceramic material with a relatively high fracture strength [7, 8].

Lava Ultimate CAD/CAM Restorative (3M-ESP, St Paul, USA) is another material for CAD/CAM technique. As introduced by its manufacturer, this material is called Resin Nano Ceramic (RNC), which is supposed to be unique in durability and function. However, from the material science perspective, this material is still belonging to the resin composite category. It was reported that the CAD/CAM resin composites that are marketed as ‘classified as ceramic’ may show less crack propagations under fatigue forces than that of some CAD/CAM ceramics [9]. They may even provide better fracture resistance for non-retentive occlusal veneers in posterior teeth than some CAD/CAM ceramics [8].

Despite the material properties and the restoration designs, the thickness of ceramic restorations can also be an important factor in fracture resistance [1, 3, 4, 8, 10]. While the usual recommendation for porcelain restoration thickness is 1.5 to 2.0 mm [11-13], with the development of stronger materials in combination with
CAD/CAM techniques and innovative adhesive technology, a more conservative thinner crown can also be considered [8].

Furthermore, the fracture resistance of ceramic restorations can be also influenced by the properties of the support [10], for example, by its elastic modulus [14], or the bond strength. It was reported that well-luted specimens were usually more fracture resistant [1, 10, 15, 16]. It was supposed that luting agents had a possible bridging effect on the interfacial surface defects, which restricted and resisted against the propagation of cracks from the internal surface of the bonded resin [10, 17] and led to a higher fracture resistance.

The purpose of this study was to investigate the influence of thickness to the fracture resistance of Lava Ultimate CAD/CAM RNC and the IPS e.max CAD ceramic. Furthermore, the effect of bonding on the fracture resistance of Lava Ultimate CAD/CAM RNC was evaluated and the results were rationalized with Finite Element Analysis. Ultimately, we planned to find a recommended minimum thickness for both materials.

5.2 Materials and methods

A simplified tri-layer onlay model was designed to mimic the restoration for posterior tooth (Figure 5.1). The testing disc, which represented the occlusal restoration, had a diameter of 10 mm to mimic the average dimension of molars. The testing disc was cemented to the substrate epoxy disc, e.g. simulated dentin, with an equal diameter. The epoxy material (similar to G10, previously used in other studies; see Discussion) had an elastic modulus of 18 MPa, which was similar to dentin [8, 17, 18]. The bonded two-layer disc had a final thickness of 3.5 mm, which was chosen as equivalent to the average thickness from pulp wall to occlusal surface [19-21]. Then the two-layer disc was bonded to a steel ring with an inner diameter of 6.5 mm, an outer diameter of 10 mm, and a thickness of 1.5 mm mimicking the pulp chamber.

Fracture resistance: The testing specimens were divided into three groups: L, LS and ES, according to testing materials and surface treatment. The testing discs in Group L were made of Lava Ultimate CAD/CAM Restorative (3M ESPE, USA), with a polished surface and cemented to polished epoxy substructures (Epoxydplatte, Carbotec GmbH & Co. KG, Aachen, Germany). Specimens in Group LS were also made of Lava Ultimate, with a sandblasted surface and cemented to sandblasted epoxy discs. In Group ES, testing discs were made of a IPS e.max CAD (Ivoclar Vivadent
AG, Liechtenstein), also with a sandblasted surface and cemented to sandblasted epoxy discs. Each group was further divided into five subgroups (n = 8) according to the thickness of the testing disc. The thicknesses of the testing discs were 0.5 mm, 1.0 mm, 1.5 mm, 2.0 mm, and 3.0 mm; the thicknesses of their corresponding epoxy discs were 3.0 mm, 2.5 mm, 2.0 mm, 1.5 mm, and 0.5 mm, respectively, achieving a final thickness of 3.5 mm.

![Schematic representation of the set-up model use for this study.](image)

**Figure 5.1** Schematic representation of the set-up model use for this study.

For Groups L and LS, RNC cylinders were made from Lava Ultimate blocks, by a water-cooled drilling machine (Metabo SBE 1010 Plus, Metabowerke GmbH, Nürtingen, Germany) and a hollow drill with an inner diameter of 10 mm. The cylinders were further cut into 80 discs by a sawing machine (Isomet 1000; Buehler, USA), according to the five demanded thicknesses. For Group ES, 40 ceramic discs were made in the same way from IPS e.max CAD blocks. 120 epoxy discs were cut from five large epoxy plates, with the corresponding five demanded thicknesses, by the same drilling machine and drill. All the 240 discs were polished by 600 grit SiC polish papers. 160 discs for Groups LS and ES were sandblasted for 10 s on one surface, by 50 µm Al₂O₃ at a distance about 10 mm (Sand Storm, Vaniman Manufacturing CO., CA, USA). All the 240 discs were cleaned by an ultrasonic machine (Bransonic 3510; Branson Ultrasonics Corp, USA) for 5 minutes.

The bonding surfaces of the Lava Ultimate discs were treated with mixed Clearfil SE bond primer (Kuraray CO. LTD, Japan) and a silane coupling primer (Clearfil Porcelain Bond Activator; Kuraray CO. LTD, Japan) for 10 s, according to manufacturer’s recommendation. The ceramic bonding surface was first etched with 9.5% hydrofluoric acid (PorcelEtch Syringe Green; Cosmedent, Inc., USA) for 20 s, rinsed with water, air dried and then applied 20 s of the mixture of SE bond primer and
the porcelain activator. The dentin-like epoxy surface was etched with 40% phosphoric acid (K-Etchant Gel; Kuraray Medical Inc, Japan) for 30 s to clean the surface, rinsed with water and lightly air dried prior to a 10 s application of the SE bond primer. The epoxy discs were bonded to the metal rings by SE bond. For each specimen, the testing disc was then cemented to the corresponding epoxy disc with a resin cement (Panavia F2.0; Kuraray Medical Inc, Japan). During curing a load of 50 N was applied on the specimen. The cement was cured in five directions, for each direction 30 s, by a curing light (Astralis 10, Ivoclar Vivadent, Liechtenstein). All the specimens were stored in 37°C water for 24 hr.

The completed specimens were loaded with a hemispherical steel indenter (Ø = 4.9 mm), centered on the top surface. The load was applied until failure, with a universal testing machine (Instron 6022, Instron Corp., MA, USA) at a crosshead speed of 1 mm/min. The load (N) at the failure was recorded as fracture resistance. The results of 0.5 mm restorative discs were further used in the finite element analysis (FEA) for each group, for the analysis of the stress distribution.

**Finite Element Analysis:** Three dimensional FEA models of the test set-up with the dimensions according to the testing specimens were made (loading sphere models). The Finite Element modelling was carried out using FEMAP software (FEMAP 10.1.1; Siemens PLM software, Plano, Texas, USA), while the analysis was done with NX Nastran software (NX Nastran; Siemens PLM Software, Plano, Texas, USA). The models consisted of the layer of the supporting ring, the supporting epoxy, the testing disc, and the loading sphere. Since the models were symmetrical in geometry in two directions, they were split in quarter specimens to facilitate the border conditions, with the nodes in the centric planes allowing for sliding in the surface only. The contact surface between the loading sphere and the testing disc was modelled as contact surface with a friction coefficient of 0.45. For the models of Group L the interface of the testing disc and the epoxy was also modelled as a contact surface with a friction coefficient of 0.30, assuming an insufficient bond between these surface, while for the models of Group LS and ES the bond was assumed to be sufficient (not contact surface, but a fixed surface). The fracture load for the three models, shown in Table 5.1, was loaded on the cut surface of the loading sphere (Figure 5.1). The nodes in the bottom of the supporting ring were fixed. The models were composed of 8,730 parabolic tetrahedron solid elements. The material properties used for the FEA were summarized in Table 5.2. The Solid Maximum Principal stresses were calculated to establish the maximum tensile stress in the testing disc. Since the highest Solid von
Mises stresses were in all cases higher than the Solid Maximum Principal stress, the Solid von Mises stress was used to calculate the maximum compressive stress.

Since the compressive stresses in the contact surface between loading sphere and testing disc were in the FEA higher than the material strength, we assumed that the surface of the testing disc was permanently deformed. For this reason, new models of the test setup (deformed surface models) were made. The deformation was designed by lowering the loading sphere into the surface of the testing disc and shaping the surface around the part of the loading sphere in the surface. The displacement of the loading sphere for the permanent deformation was calculated by the difference of the displacement of the crosshead of the universal testing machine on the test set-up, e.g. the total deformation of the test set-up, and the elastic deformation in the FEA. The models were symmetrical in geometry and were split in half specimens to facilitate the border conditions, with the nodes in the centric plane allowing for sliding in the surface only. The nodes in the centre were allowed to move only in the vertical direction. For the models of Group L the interface of the testing disc and the substrate epoxy was modelled as a contact surface with a friction coefficient of 0.30, assuming an insufficient bond between these surface, while for the models of Group LS and ES the bond was assumed to be sufficient (no contact surface). The fracture load for the different models, shown in Table 5.1, was loaded on the surface of the permanent deformation. The nodes in the bottom of the supporting ring were fixed. The models were composed of 8,960—14,464 parabolic tetrahedron solid elements. The material properties used for the analysis were summarized in Table 5.2. The Solid Maximum Principal stresses were calculated to establish the maximum tensile stress in the testing disc, since the highest Solid von Mises stresses were in all cases higher than the Solid Maximum Principal stress, the Solid von Mises stress was used to calculate the maximum compressive stress.

Statistics: The values obtained for each subgroup were analyzed by one-way ANOVA, and the Turkey test was adopted for the post-hoc test. The relation between fracture resistance and thickness was analyzed by linear regression. The statistics were done with IBM SPSS statistics 20 (IBM Corp., USA) at a significance level of $\alpha = 0.05$.

5.4 Results

None of the supporting dentin-like epoxy was fractured. Only the testing RNC or ceramic discs fractured and delaminated from the substrates. Means and standard
deviations of the fracture load for all the subgroups are summarized in Table 5.1 and graphically depicted in Figure 5.2. For the same thickness of testing discs, the fracture load of Group L was always significantly lower than the other two groups. When the thickness of testing discs changed from 1.0 mm to 2.0 mm, there was no significant difference of the fracture load between Group LS and Group ES. The fracture load of Group LS was significantly higher than that of Group ES at the thickness of 0.5 mm, while it was the other way around at the thickness of 3.0 mm.

Table 5.1 Means and standard deviations of the fracture load (N) for polished Lava Ultimate CAD/CAM (Group L), sandblasted Lava Ultimate CAD/CAM (Group LS), and sandblasted IPS e.max CAD (Group ES) discs.

<table>
<thead>
<tr>
<th>Group</th>
<th>0.5 mm</th>
<th>1.0 mm</th>
<th>1.5 mm</th>
<th>2.0 mm</th>
<th>3.0 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>1028 (112)\textsuperscript{a1}</td>
<td>1201 (160)\textsuperscript{a1}</td>
<td>1097 (149)\textsuperscript{a1}</td>
<td>1095 (249)\textsuperscript{b1}</td>
<td>1574 (143)\textsuperscript{b1}</td>
</tr>
<tr>
<td>LS</td>
<td>2221 (110)\textsuperscript{a2}</td>
<td>1764 (261)\textsuperscript{b2}</td>
<td>1771 (265)\textsuperscript{b2}</td>
<td>1994 (208)\textsuperscript{ab2}</td>
<td>2174 (389)\textsuperscript{a2}</td>
</tr>
<tr>
<td>ES</td>
<td>1418 (314)\textsuperscript{a3}</td>
<td>1516 (309)\textsuperscript{a12}</td>
<td>1613 (429)\textsuperscript{a2}</td>
<td>2288 (270)\textsuperscript{b2}</td>
<td>2754 (241)\textsuperscript{c3}</td>
</tr>
</tbody>
</table>

For each horizontal row: values with identical letters indicate no statistically significant differences (P > 0.05). For each vertical column: values with identical numbers indicate no statistically significant differences (P > 0.05).

**Figure 5.2** Fracture resistance for polished Lava Ultimate CAD/CAM (Group L), sandblasted Lava Ultimate CAD/CAM (Group LS), and sandblasted IPS e.Max CAD (Group ES) discs.
The regression results for the relations between fracture load and testing thickness for each group are graphically depicted in Figure 5.3. In Group LS, there was no linear relation between fracture load and thickness of testing discs ($R^2 = 0.023; P = 0.35$). The highest fracture load in Group LS appeared both at 0.5 mm and 3.0 mm level (Table 5.1). In Group L, there was a linear relation between fracture load and thickness although it was not very strong ($R^2 = 0.386; P < 0.001$). Moreover, the fracture load of 3.0 mm disc was significantly higher than that of the other four thicknesses, while there was no significant difference from 0.5 mm to 2.0 mm in Group L (Table 5.1). However, there was a stronger linear relation between fracture load and thickness in Group ES ($R^2 = 0.729; P < 0.001$). Although the fracture load of Group ES did not change too much ($P > 0.05$) from 0.5 mm to 1.5 mm, it increased significantly at 2.0 mm and 3.0 mm (Table 5.1).

**Finite Element Analysis:** The results of the FEA for the 0.5 mm specimens and the displacement values measured (Table 5.3) showing the stresses in the testing disc of loading sphere and deformed surface models and the deformations of the test set-up, consisting of the total deformation under the universal testing machine, the elastic...
deformation from the FEA, and the calculated permanent deformation. The highest compressive stresses in the loading sphere analysis were at the contact point between loading sphere and testing disc, whereas in the deformed surface analysis the highest compressive stresses were found at the interface between the testing disc and the epoxy substrate under the loading area. The stresses for the sandblasted specimens were distributed over a wider area. Figure 5.4 is showing the maximum compressive stresses (Solid von Mises) in the model of Group L 0.5 mm.

**Table 5.2** The material properties used in the FEA.

<table>
<thead>
<tr>
<th></th>
<th>Young’s modulus (GPa)</th>
<th>Poisson ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lava Ultimate</td>
<td>12.8</td>
<td>0.30</td>
</tr>
<tr>
<td>IPS e-Max CAD</td>
<td>95.0</td>
<td>0.30</td>
</tr>
<tr>
<td>Substrate epoxy</td>
<td>18.0</td>
<td>0.30</td>
</tr>
<tr>
<td>Sphere / supporting ring</td>
<td>195.0</td>
<td>0.30</td>
</tr>
</tbody>
</table>

**Table 5.3** The stresses (in MPa) in the testing disc found in the FEA and the deformations (in µm) of the test set-up: total deformation under the universal testing machine, elastic deformation in the FEA, and the calculated permanent deformation.

<table>
<thead>
<tr>
<th></th>
<th>L 0.5 mm</th>
<th>LS 0.5 mm</th>
<th>ES 0.5 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Loading sphere</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid Maximum Principal Stress</td>
<td>144</td>
<td>16</td>
<td>380</td>
</tr>
<tr>
<td>Solid von Mises Stress</td>
<td>996</td>
<td>1576</td>
<td>1850</td>
</tr>
<tr>
<td><strong>Test set-up</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total deformation</td>
<td>173</td>
<td>351</td>
<td>225</td>
</tr>
<tr>
<td>Elastic deformation</td>
<td>106</td>
<td>229</td>
<td>71</td>
</tr>
<tr>
<td>Permanent deformation</td>
<td>67</td>
<td>122</td>
<td>154</td>
</tr>
<tr>
<td><strong>Deformed surface</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid Maximum Principal Stress</td>
<td>35</td>
<td>6</td>
<td>230</td>
</tr>
<tr>
<td>Solid von Mises Stress</td>
<td>340</td>
<td>342</td>
<td>420</td>
</tr>
</tbody>
</table>
5.5 Discussion

The irregular geometry of a tooth crown makes it difficult to determine the effect of specimen thickness on the fracture resistance of composite or ceramic under occlusal loading [15]. Nevertheless, in severe tooth wear cases more and more non-retentive occlusal veneer restorations are made, which restoration geometry is more simple. Hence, the current study used a modified specimen design from a biaxial ball-on-ring test [17, 18]. This simplified onlay model was designed to mimic the occlusal non-retentive veneer restoration for posterior tooth. The dimension of the specimen was designed from the average dimension of molars [22]. The substrate supporting material was a continuous woven glass-fiber-reinforced epoxy resin like G10 [17]. The

**Figure 5.4** The maximum compressive stresses (Solid von Mises) in the test set-up of the deformed surface models for polished Lava Ultimate CAD/CAM with a testing disk thickness of 0.5 mm and an epoxy disc with a thickness of 3.0 mm as substrate.
elastic modulus of this material is 18 MPa, which is similar to dentin [8, 17, 18]. Kelly et al. reported that G10 was not significantly different from hydrated dentin in terms of blunt contact elastic behavior or resin cement bond strength [23]. G10 was supposed to be a good substitute for dentin, and was widely used in blunt contact tests [17, 18, 23-25]. The test protocol involved a spherical indenter contacting on flat-surface structures, like the Hertzian testing. This test simulated basic elements of occlusal function, so it was clinically relevant to the characterization of dental occlusal non-retentive veneer restorations [25]. As failure loads were also sensitive to indenter contact radius [26], the indenter radius we used was equivalent to the radius of dental cusps [25].

Our results showed that there was a linear relation between the ceramic thickness and the fracture resistance of the IPS e.max CAD in Group ES. However, between 0.5 mm and 1.5 mm, fracture resistance did not change much; there was a sharp increase at 2.0 mm. Despite the linear relation, the fracture mechanism and the fracture mode may have differed between at thin and thick specimens. The literature suggested that due to the tension in the lower (inner) surface caused by the flexure of the ceramic layer on the soft support [3, 15, 25], the fracture mode for thin ceramic specimens is mainly radial cracking at the interface. In this mode, the Hertzian contact may be regarded simply as a generic applied load which can induce ceramic plate flexure and hence initiate inner surface radial stresses, eventually resulting in cracks [25]. It has been proposed that this radial cracking is relevant to the failure of all-ceramic dental crowns [25].

Our FEA results were a little bit different from this view. From the results of loading sphere model of Group ES 0.5 mm, the Solid von Mises Stress, which was considered to represent the compressive stress, was higher than the compressive strength of e.max CAD, which was reported as 1,244 MPa [27]. This meant that the surface of e.max CAD disc had been already permanently deformed before the final fracture load. As a result, a modified deformed surface model was established and in this new model, the Solid von Mises Stress was reduced to 420 MPa. However, the Solid Maximum Principal Stress in the deformed surface model was only 230 MPa, which was still lower than the reported flexural strength from 360 MPa to 420 MPa from the manufacturer and some recent publications [28, 29], whereas the value was within the range of some earlier publications around 260 (80) MPa [30, 31]. One explanation is that the permanent surface deformation occurred before the final fracture caused some surface cracks, which could compromise the mechanical properties of the ceramic, and lead to a catastrophic fracture at a relatively low stress.
distribution level. The permanent surface deformation was observed by the scanning electronic microscope (SEM) in our later study.

Since the Young’s modulus of IPS e.max CAD was much higher than the supporting epoxy, the whole specimen would apparently become stiffer with increasing ceramic layer thickness, and as a consequence a thicker specimen could finally support higher load. It was reported that when the ceramic is thick, ‘bulk properties’ dominate. For dental porcelains and fine-grained glass ceramics, cone cracking is the main fracture type [3, 15]. This cone cracking is independent of the substrate and is responsible for chipping and surface cracks in porcelain inlays and onlays, as well as in veneering porcelains [3]. Alternatively, in coarse-grained glass ceramics and in structural ceramics such as glass-infiltrated ceramics, alumina and zirconia, quasi-plastic yield can occur beneath the indenter [3]. Because ceramics are also susceptible to surface flaws and cracking introduced during fabrication, which could include machining damage or sandblasting procedures [3], the ‘pre-existing’ surface flaws made the fracture mechanism more complex.

Since the RNC contains resin which provide an elastic property, the stress distribution of this material is supposed to be different from that of the stiff ceramic. Whereas stiff ceramics seem to induce large internal stresses under horizontally directed loads, and transmit this to marginal areas, stress distributed within resin composite crowns seems to be concentrated at the loading point and not to be transmitted to marginal areas [32, 33]. Once the stress accumulated in the composite becomes higher than its strength, surface cracks can occur. The cracks will penetrate deeper into composites under further loading and lead to the final fracture. Cracks in resin composites always propagate through the resin matrix around inorganic filler particles [34-36] or penetrating organic fillers [37]. The fracture resistance of resin composites is more related to their inherent properties, such as granule size or material of fillers [34, 37, 38]. Our FEA showed a higher compressive stress at the contact interface, and for the deformed surface models, the Solid von Mises Stress was around 340 MPa, which was close to the provided compressive strength 383 MPa from the manufacturer. This suggested a compressive damage for the RNC discs. This permanent compressive surface deformation was also observed by in our SEM study later on.

Nakamura et al. showed that there are rather high tensile stresses in composite crowns around the loading points and that the occlusal surface might be a critical factor for the success of composite crowns [32]. However, in our FEA study, the Lava Ultimate CAD/CAM showed much lower tensile stresses in this area, when compared
to the ceramic model. This might be caused by the ceramic particles in the resin matrix working as ‘supporting bricks’ restraining the elastic deformation under the loading area. In this respect, the material has both ceramic and composite properties, being a so called ‘Resin Nano Ceramic’.

The fracture resistance of Group L was always lower than that of Group LS at the same thickness. This can be explained by the better bonding caused by sandblasting in Group LS. Although we did not test the quantitative bond strength in this study, we found that some Lava Ultimate fragments still remained on the epoxy substrate after fracture in Group LS, but that all the fractured fragments debonded from epoxy substrates in Group L. This indicated that better bonding can lead to higher fracture resistance. This was proved by our FEA results. Since the sandblasting of the specimens resulted to a better bonding between the testing disc and the substrate epoxy, the deformation of the testing disc under the loading area was restraint, which was reflected by the ‘no contact surface’ model. The results showed that for this sandblasting model, the same stress was distributed at a higher load compared to the polished model, which could be explained that the better bonding can restrain the stress distribution, by giving a sound support and making the multilayered restorations function better as a whole. The phenomenon confirmed that better bonding could lead to higher fracture resistance.

Previous studies showed that the dentin bond strength was important for the fracture resistance of indirect resin composites [18, 39], and that ceramic or composite crowns luted with resin cement had higher fracture resistance than those luted with other luting agent [16, 33]. It is reported that the dentin/resin adhesive interface was more sensitive to crack growth than either dentin or resin composite [40]. Furthermore, Finite Element studies predicted that failure of the tooth-restoration interface is more likely to happen than failure of the composite material [10, 41], the possible bridging effect by the adhesive resin cement may contribute to the interfacial surface [17]. The stiffness of the substrate including the luting cement also plays a role in the fracture resistance [3, 18], as the failure triggered by the development of tensile stresses is much more sensitive to the ratios of elastic moduli between the restorative material and the luting material and substrate than to the thickness of the material [8, 42]. Therefore, in order to improve clinical performance, it is important to increase the resin cement modulus and assure good bonding [18].

As occlusal thickness affects the fracture resistance of the composite and ceramic crowns [10, 33], the recommended thickness of occlusal reduction ranges from 1.3 mm to 2.0 mm for composite or ceramic restorations [3, 10, 33, 43, 44]. The
normal occlusal load ranges between 100 N to 200 N at the molar region [3], becoming as high as 965 N [3, 45-53] on occasions such as trauma or an accidental bite of hard foreign bodies. As a result, a fracture resistance above 1,000 N is required to ensure good clinical performance [54]. This criteria was met by all the testing specimens tested in this study, even at the thickness of 0.5 mm or 1.0 mm.

Restorations with a thickness less than 1.0 mm are clinically used. When these ultrathin restorations are applied, the RNC ones seemed to have a better performance than the ceramic ones. Similar results were reported about the resin composites and ceramics in a fatigue test [8, 55], in which the resin composite ultrathin restorations showed a better survival rate. It is also reported that the composite inlays had better fracture resistance than ceramic inlays [56, 57]. However, clinicians sometimes recognized that restorations developed so called ‘wear facets’ after a period of functional loading. These ‘wear facets’ were not real contact points but some contact areas with dimensions of approximately 3 mm in diameter. Our FEA study suggested that the formation of these so called ‘wear facets’ might not be caused by wear, but were some permanent deformations.

However, the results of this study can only be used to interpret initial performances of the restorations. Previous study showed that fatigue can affect the performance of both composite [58] and ceramic restorations [35]. In addition, thermal cycling can influence the performance of cement layer and further influence the fracture resistance of composite restorations [59]. So the thermal or mechanical cycling study can be considered in the future.

5.6 Conclusion

Within the limitation of this study, we can conclude that there was a linear relation between restoration thickness and fracture resistance for IPS e.max CAD, but not for Lava Ultimate CAD/CAM. The restorations with the thickness above 0.5 mm can be clinically used for both materials. However, when apply the ultrathin restoration, such as of a thickness of 0.5 mm, Lava Ultimate CAD/CAM material is recommended. When Lava Ultimate CAD/CAM is used, the surface treatment of sandblasting is suggested.
5.7 Reference


