Effect of incisal preparation design on the fracture strength of monolithic zirconia-reinforced lithium silicate laminate veneers

Running title: PREPARATION DESIGN ON STRENGTH OF LAMINATES

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Abstract

Purpose: This study aimed to assess the fracture resistance of monolithic zirconia reinforced-lithium silicate laminate veneers (LV) fabricated on various incisal preparation designs.

Materials and Methods: Sixty maxillary central incisors with various preparation designs were 3D-printed, 15 each,

including preparation for: 1) LV with feathered edge design; 2) LV with butt joint design; 3) LV with palatal chamfer; and 4) full-coverage crown. Restorations were then designed and manufactured from zirconia-reinforced lithium silicate (ZLS) following the contour of a pre-operation scan. Restorations were bonded to the assigned preparation using resin cement and following the manufacturer's instructions. Specimens were then subjected to 10,000 thermocycles at 5 °C to 55 °C with a dwell time of 30 seconds. The fracture strength of specimens was then assessed using a universal testing machine at a crosshead speed of 1.0 mm/min. One-way ANOVA and Bonferroni correction multiple comparisons were used to assess the fracture strength differences between the test groups (α = 0.001). Descriptive fractographic analysis of specimens was carried out with SEM images.

Results: Complete coverage crown and LV with palatal chamfer design had the highest fracture resistance values (781.4 ± 151.4 N and 618.2 ± 112.6 N, respectively). Single crown and LV with palatal chamfer had no significant

difference in fracture strength ($p>.05$). LV with feathered edge and butt joint designs provided significantly ($p<.05$)

lower fracture resistance than complete coverage crown and LV with palatal chamfer design.

Conclusion: The fracture resistance of chairside milled ZLS veneers was significantly influenced by the incisal

preparation designs tested. Within the limitation of this study, when excessive occlusal forces are expected, LV with

palatal chamfer display is the most conservative method of fabricating an indirect restoration.

Keywords: Silicates, Flexural Strength, Computer-Aided Design, Subtractive Computer-Aided Manufacturing

Chairside computer-aided design and computer-assisted manufacture (CAD-CAM) permits clinicians to precisely manufacture a wide array of materials, for provisional or definitive restorations, faster than the traditional methods.[1-

7] Recent studies have demonstrated that CAD-CAM restorations have a better marginal adaptation than conventionally

fabricated indirect restorations.[8,9] Similar to CAD-CAM complete coverage restorations, laminate veneers (LV) can

be fabricated using CAD-CAM technology where an intraoral scanner (IOS) is used to register the preparation, designed, then milled from a material of choice.[10,11] These restorations have shown to provide high esthetic results to fulfill patient demands.[12,13] LV fabricated using digital workflow have shown a satisfactory survival rate of 94% after 9 years.[14]

Various materials are used to fabricate chairside CAD-CAM veneers, such as glass ceramics (lithium disilicate, leucite-reinforced feldspathic, and feldspathic porcelain), zirconia, resin composite, resilient (hybrid) ceramics, polymer-infiltrated ceramics, and zirconia-reinforced lithium silicate (ZLS).[15,16] Dental glass-ceramics have become one of the first choice for clinicians because they provide excellent physical properties such as translucency, low thermal conductivity, adequate strength biocompatibility, wear resistance, and great esthetic results.[17,18] Companies continuously try to develop higher-strength glass ceramics by modifying the composition and simplifying the steps for fabrication and delivery.[19,20] A novel material is zirconia-reinforced lithium disilicate developed by Vita (Vita Zahnfabrik, Baden-Württemberg, Germany) and Dentsply (Dentsply Sirona, Charlotte, NC, USA) in conjunction with the Fraunhofer Institute for Silicate Research in Wurzburg, Germany; they are separately marketed as two products: Vita Suprinity PC and Celtra Duo.[21-23] This novel material has a similar microstructure as traditional glass ceramics with lithium metasilicate crystallites ($Li_2Si_2O_3$) and lithium orthophosphates crystallites (Li_3PO_4). However, tetragonal zirconia fillers were added in order to increase the strength. A sintering process is provided so the crystals increase their size, and the lithium disilicate crystals ($Li_2Si_2O_5$) are formed.[24] Several studies evaluating the properties and success of chairside CAD-CAM LV focus on lithium disilicate and feldspathic porcelain are available in current literature. However, research is lacking on recently developed materials.[14,25] In addition to the variety of material choice, tooth preparation with various incisal preparation designs is recommended for LV, including feathered-edge, butt-joint, and palatal chamfer (Fig 1).[26] Tooth preparation with feathered-edge preparation design avoid incisal overlap of LV on the incisal edge; however, LVs are overlapped on the incisal edge in butt-joint and palatal chamfer preparation designs.[27,28] The use of different preparation designs is based on the clinical experience and potential esthetic outcomes; however, there is no consensus on the impact of preparation design on the success and survival of the LV.[29-32]

The present comparative in-vitro study aimed to assess the fracture resistance of chairside LV manufactured from a recently developed ceramic (zirconia-reinforced lithium silicate) for tooth preparations with feathered-edge, butt-joint, and palatal chamfer designs. A full-coverage crown manufactured from the same material and fabrication technique was used as the control group. This study hypothesized that 'there is no difference in fracture resistance among the three different preparation designs of LV' and 'complete coverage crowns have higher fracture resistance than tested LV.'

Materials and Methods

The sample size for this study was calculated from a previous study[33] using G*Power (α =0.05, power=0.8). It was determined that 9–35 samples were needed for each group. Fifteen samples were used per group, similar to previous studies. Four maxillary right central incisors (1560 Series, Columbia Dentoform, Lancaster, PA, USA) were used to prepare teeth for (1) feathered-edge LV, (2) butt-joint LV, (3) palatal chamfer LV, and (4) complete coverage crown

(Fig. 1). Tooth preparations followed the manufacturer's recommendation for veneer with 0.4 mm chamfer, 0.6 facial reduction, and 1.0 mm incisal reduction. The full coverage crown was 1.0 mm chamfer with 1.5 mm facial reduction and 1.5 mm incisal reduction. The preparations were then digitally scanned using an intraoral scanner (Omnicam, Dentsply Sirona, Charlotte, NC, USA) to design LV and crowns following the anatomy of a preparation. Designed

restorations were then used to manufacture zirconia-reinforced lithium disilicate (Celtra Duo, Dentsply Sirona) restorations using a 5-axis milling machine (inLab MC-X5, Dentsply Sirona); 15 per group. Milled restorations were crystalized (Universal Spray Glaze Fluo, Dentsply Sirona, Charlotte, NC, USA) following the manufacturer's recommendations using a sintering oven (Programat CS2, Ivoclar Vivadent), and then the restorations were polished with a lithium disilicate polishing kit (Dialite LD, Brasseler USA, Savannah, GA, USA) following the manufacturers' recommendations. In addition, prepared typodont teeth were scanned using a desktop scanner (Freedom HD, DOF, Seoul, Korea), and virtual models were created a design software. STL files of virtual models were used to manufacture 60 dies using a 3D printer (Formlabs 3B, Formlabs Inc. Somerville, MA) from a resin for dental models (Model Resin, FormLabs, Somerville, MA, USA).

Restorations were ultrasonically cleaned in a bath (5300 Sweep Ultrasonic Cleaner, Quala Dental Products) with 90% isopropyl alcohol for 5 minutes. They were allowed to dry at room temperature; then, their intaglio surface was treated with 5% hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar Vivadent) for 30 seconds. Restorations were then rinsed with water spray and dried with an air syringe before the application of silane (Calibra Silane Coupling Agent, Dentsply Sirona) for 60 seconds. Restorations were then luted to their assigned 3D-printed teeth with resin cement (Calibra Ceram, Dentsply Sirona), following the manufacturer's instructions and using a light curing unit (Elipar 2500, 3M Oral Care, St Paul, MN, USA) with 200 g of applied weight. A single experienced prosthodontist performed all cementation procedures. After 48 hours, the specimens were subjected to artificial aging using a thermocycling machine (Thermo-cycler The-1100, SD Machatronik, Feldkirchen-Westerham, Germany) for 10,000 cycles between 5 °C and 55 °C with a dwell time of 30 seconds

(Figure 2). Specimens were then subjected to a compressive load at a crosshead of 1.0 mm/min until failure using a universal testing machine (858 Mini Bionix II, Eden Prairie, MN, USA). The fracture load was applied while specimens were mounted in a jig at a 40-degree inclination with a tapered cone-shaped indenter with 2.0 mm at the tip. The indenter centered on the lingual side of the sample was 2.0 mm from the incisal edge. A 1.5 mm thick piece of high-temperature silicone rubber was placed between the indenter and the veneer. The load at complete fracture was recorded in Newtons.

A scanning electron microscope (TM3000 Hitachi, Tokyo, Japan) was used to perform a fractographic analysis of the broken specimens with an accelerating voltage of 5 kV. Individual images were stitched together using Affinity Designer (Serif Ltd., UK).

Fractographic analysis was assessed descriptively. A Kolmogorov-Smirnov test was used to assess the normal distribution of data. One-way ANOVA test and Bonferroni correction multiple comparisons were used to assess the impact of preparation design on the fracture strength of restorations at a significant level of 0.001.

Results

Fracture Resistance

The fracture strength of zirconia-reinforced lithium silicate restorations assessed in this study is shown in Table 1. The type of restoration influenced the fracture strength. The Kolmogorov-Smirnov test showed normal distribution of data. One-way ANOVA indicated a significant ($p<0.001$) effect of restoration type on fracture strength. Complete coverage crown displayed the highest fracture resistance (781.4 ± 151.1 N), followed by LV with palatal chamfer design (618.2 ± 112.6 N); however, the Bonferroni correction test showed that there was no significant difference between the groups ($p=0.449$). The fracture strength of LV with butt-joint design (385.2 ± 119.7 N) was significantly higher than LV with feathered-edge design (194.8 ± 174.4 N) ($p<0.001$); however, its fracture strength was significantly lower than LV with palatal chamfer design and complete coverage crown ($p<0.001$).

Fractographic Analysis

Representative scanning electron microscopy (SEM) images of the fracture surfaces of zirconia-reinforced lithium silicate restorations are shown in Figures 3-6. The feathered-edge LV presented cracks on the sides of the veneer (mesial and distal) and predominately failed due to adhesive failure, unlike all other groups. In contrast, the butt joint fractured along the incisal edge. Finally, palatal chamfer and full crowns presented similar fracture patterns to butt-joint, but full crown cracks were slightly smoother along the fractured surface.

Discussion

Chairside CAD-CAM ceramic restorations have become very common in daily practice for their high accuracy, fast fabrication methods, and a wide variety of materials available.[34,35] This wide choice of materials enables LV to fulfill patients' esthetic demands.[36,37] LV can also be used to treat worn, malformed, fractured, and spaces between teeth (diastemas).[38] Clinicians have options with different preparation designs for ceramic LV, including feathered edge, butt joint (incisal bevel), and palatal chamfer (overlapped).[39] The present in vitro study included load-to-failure and fractographic failure analysis to compare the fracture resistance of feathered edge, butt joint, and palatal chamfer LV, as well as full crowns. Based on the results, the first null hypothesis was rejected because there were significant differences in the fracture resistance values among the groups. For instance, the butt joint LV with 385.2 (±119.7) N was significantly higher than the feathered edge LV with 194.9 (±174.4) N, whereas the palatal chamfer LV with 618.2 (±112.6) N was significantly higher than any other LV. Furthermore, the second hypothesis was "partially" rejected because there was one type of ZLS LV (palatal chamfer) that showed no significant difference compared to full-coverage crowns with 781.4 (±151.1) N.

The maxillary right central incisor was selected in this study because central incisors are the most noticeable teeth in the mouth and, therefore, can cause the most esthetic concerns addressed by clinicians.[40] However, anterior teeth are commonly treated with ceramic LV.[41,42] The restoration preparations followed the guidelines provided by Celtra Duo (Dentsply Sirona) for veneers: 1.5 mm incisal reduction, 0.4 mm incisal, and 0.6 middle third reduction, whereas for full-coverage crowns: 1.5 mm incisal reduction, 1.0 mm chamfer margin, and 1.5 mm middle third reduction.[43] According to the manufacturer, LV with ZLS can be fabricated with thicknesses from 1.0 to 1.5 mm. However, due to the standardization of this study, the authors decided to have it a 1.5 mm to match the full coverage crown recommendation.

The present study evaluated the most common LV preparations: feathered edge, butt joint, and palatal chamfer. The feathered edge LV only need to remove the unsupported enamel on the incisal edge and are widely recommended for patients with stable occlusion and normal vertical overlap.[44,45] Butt joint LV only include the incisal overlap design and are indicated in patients with malocclusion such as anterior reverse articulation or excessive vertical overlap.[46] Palatal chamfer LV includes reduction and chamfer margin on the palatal surface and are indicated if the buccolingual incisal edge is thin or when the length of the restoration needs to be considerably increased.[29,47] Other types of veneer preparations have also been described, such as window preparation and 'prepless veneers.' However, the window preparation design is not a common treatment because it does not mask the ceramic finish line, causing chipping of unsupported enamel with compromised esthetics due to the partial coverage of facial surfaces.[48-50] Additionally, the 'prepless veneer' approach is still controversial because it lacks long-term clinical studies without clear protocols for finish design or margin, and laboratory fabrication is more complex than other types.[51,52] Therefore, those types of LV were not included in this study.

The results of this investigation showed the palatal chamfer veneers had the highest fracture resistance across veneer preparations. These results agreed with previous studies using different ceramics and methodologies. Another in-vitro study compared the fracture resistance of LV with no incisal reduction with bucco-incisal bevel, 1 mm incisal reduction with butt joint, and a 1 mm incisal reduction with 1 mm height of palatal chamfer LV fabricated with porcelain ceramic.[53] They found that palatal chamfer veneers bonded to natural teeth showed the highest value.[53]

Another study comparing pressable lithium disilicate ceramic for LV with incisal shoulder finish line with and without palatal chamfer cemented to natural teeth concluded that using the palatal chamfer design significantly increased the fatigue failure cycle count.[54] Moreover, a 3-dimensional finite element study comparing maxillary incisors restored with a butt joint and palatal chamfer ceramic LV demonstrated different mechanic behaviors.[55] It concluded that incisal overlap design with palatal chamfer tolerated stress better.[55] To the best of the authors' knowledge, this is the first study that evaluates different veneer designs with the ZLS ceramic. Full coverage crowns displayed the highest fracture resistance (781.4 ±151.1 N); this may be due to the ceramic veneer with Celtra Duo being thinner on the facial surface with 0.6 mm in middle-third and 0.4 mm at the chamfer while the full coverage crown is 1.5 mm at the middle third and 1.0 mm at the chamfer margin. This result concurs with other studies showing that the thicker the ceramic restoration the higher fracture resistance is displayed.[33,56]

Further studies should evaluate the fracture resistance of other teeth restored with LV, especially the canines. A limitation of this study was using printed resin dies instead of natural teeth, but resin dies have been utilized in previously published studies, providing reliable results. Furthermore, the resin dies decrease the variability and

challenges caused by natural teeth, such as collecting natural anterior teeth without caries, performing similar hand-prepping LV and crown preparations, and storing natural teeth. In addition, longer aging and fatigue cycling may also provide better performance evaluation for the restorations. More detailed fractography would contribute to a more precise determination of failure modes. Another limitation of this study is using only one type of novel ceramic (zirconia-reinforced lithium disilicate). The market offers other novel ceramics, such as polymer-infiltrated ceramics, so future studies should also compare more novel CAD-CAM dental ceramics. Lastly, this study only evaluated maxillary central incisor veneers. This is a limitation because other anterior teeth, such as canines, should be evaluated to obtain broader data on the behavior of this novel ceramic in anterior teeth.

Conclusion

The incisal edge design influences the fracture resistance of chairside CAD-CAM ZLS LV. Palatal chamfer veneers provided higher fracture strength than butt joint veneers, and feathered edge veneers displayed the lowest values. Palatal chamfer veneers displayed no statistically significant difference compared to veneers with a palatal chamfer in fracture strength.

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Figures

Figure 1. Schematic drawing of the four types of restorations prepared. (1) Veneers with feathered edge; (2) Veneers with butt joint; (3) Veneers with palatal chamfer; and (4) Full-coverage single crowns.

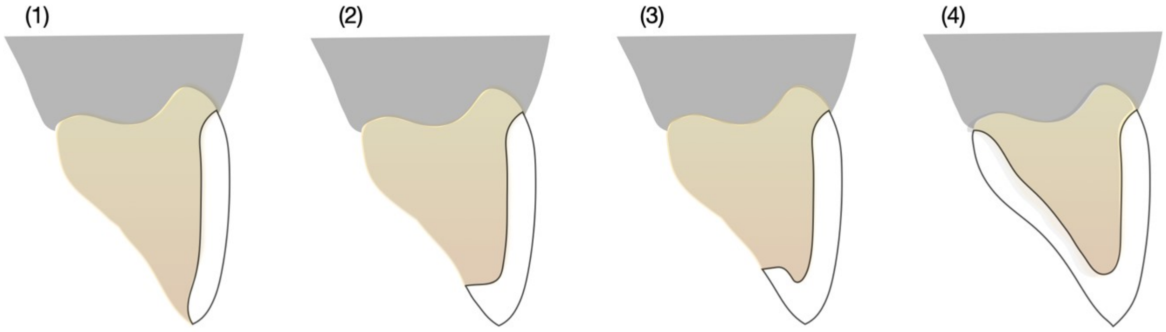


Figure 2. The bonded restorations were subjected to 10,000 thermocycles at 5 °C to 55 °C with a dwell time of 30 seconds.

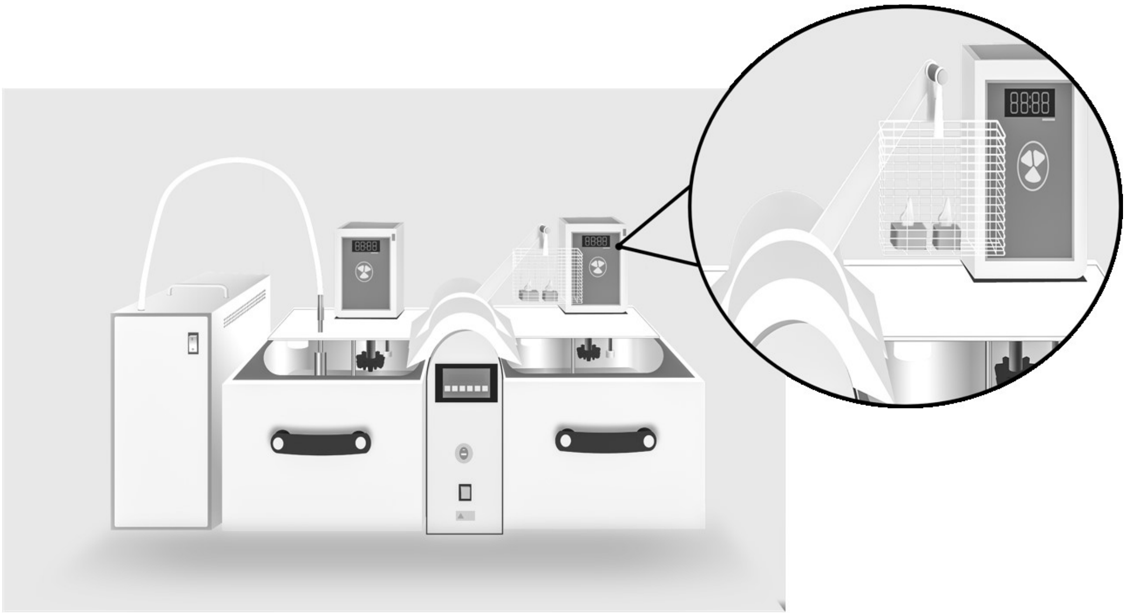


Figure 3. SEM image of a fractured veneer with feathered edge. Feathered-edge LV presented cracks on the sides of the veneer (mesial and distal) and predominately failed due to adhesive failure. Scale bar is 2 mm.

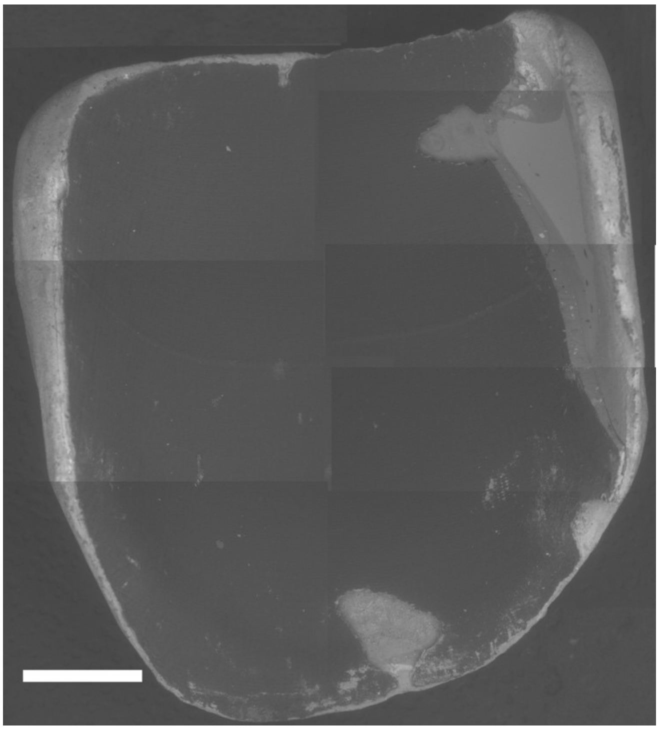


Figure 4. SEM image of fractured veneer with butt joint. Butt-joint LV fractured along the incisal edge. Scale bar is 2 mm.

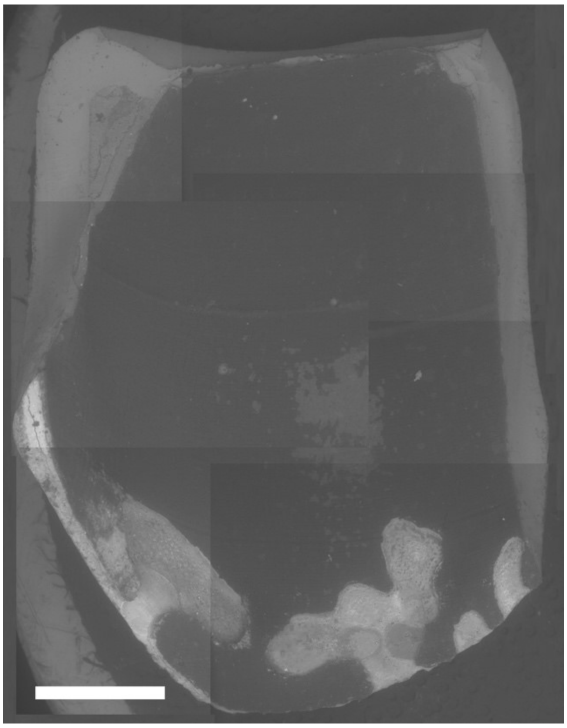


Figure 5. SEM image of a fractured veneer with palatal chamfer. Palatal chamfer LVs fractured along the incisal edge. Scale bar is 2 mm.

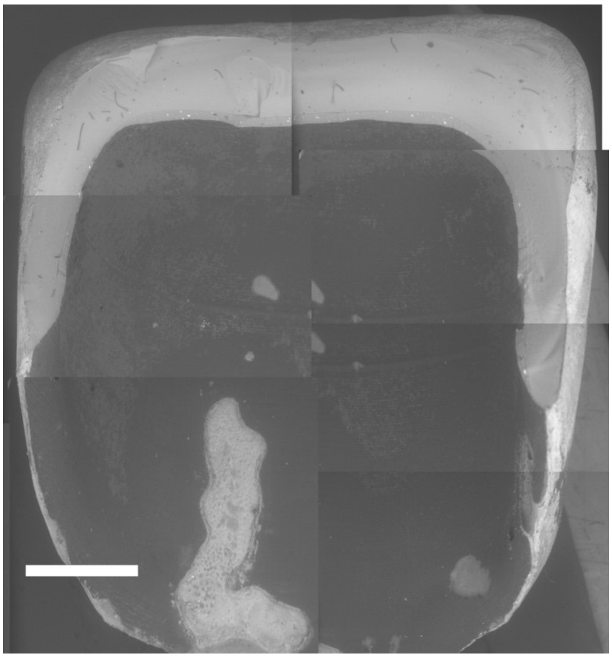
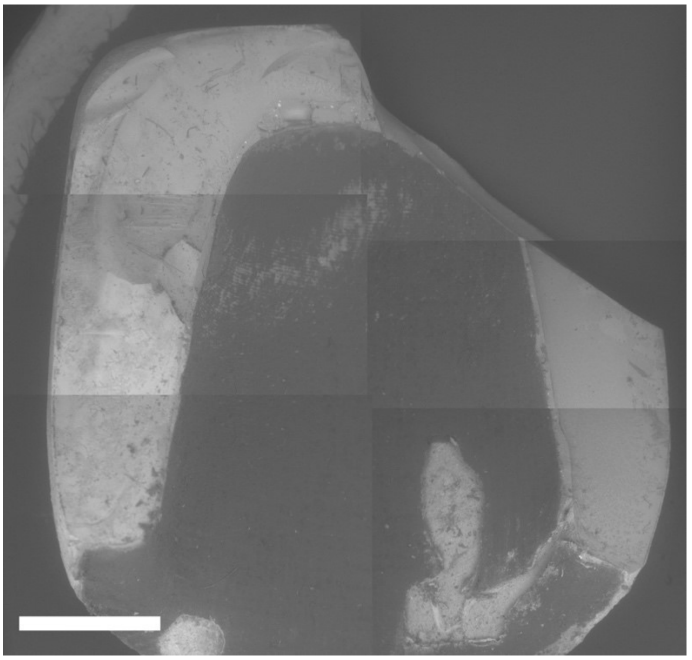


Figure 6. SEM image of a fractured traditional crown. Traditional crowns fractured along the incisal edge with smoother cracks than other groups along the fractures surface. Scale bar is 2mm.



Tables

Table 1. Fracture strength of zirconia-reinforced lithium silicate restorations.

Type of Restoration	**Mean ± SD (N)**
Feathered-Edge Laminate Veneer	194.9 ± 174.4^{a}
Butt-Joint Laminate Veneer	385.2 ± 119.7^{b}
Palatal Chamfer Laminate Veneer	618.2 ± 112.6^{c}
Complete Coverage Single Crown	781.4 ± 151.1^{c}

The same superscript letter in the right column indicates no significant difference ($p<0.001$).

Abbreviation: SD, standard deviation.