Original Article

Traditional versus conservative endodontic access impact on fracture resistance of chairside CAD-CAM lithium disilicate anterior crowns: an in vitro study

Running title: INCISOR ENDODONTIC ACCESS FRACTURE RESISTANCE

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Abstract

Purpose: To evaluate the effect of traditional and conservative endodontic access hole preparation on fracture resistance of chairside computer-aided design and computer-aided manufacturing (CAD-CAM) lithium disilicate maxillary right central incisor crowns.

Materials and Methods: Fifty-seven milled lithium disilicate maxillary right central incisor crowns were designed and fabricated with a chairside CAD-CAM system (Planmeca Romexis, Planmeca). The abutment preparation had a 1.0 mm incisal reduction and 1.0 mm chamfer finish. The restorations were bonded with resin cement to printed resin dies (n = 19 per group) and were treated and divided into three groups, 1) no endodontic access, 2) traditional triangular endodontic access, and 3) conservative ovoidal endodontic access. The endodontic access of the crowns was sealed with flowable resin composite. Restorations were subjected to 10,000 cycles of thermal cycling between 5° and 55° C. Then, restorations were loaded and exposed to compressive loading force, and the crack initiation (CI) and complete fracture (CF) were recorded. SEM micrographs of broken specimens on the printed dies were captured. ANOVA test and Bonferroni's correction were used for statistical comparison.

Results: The fracture resistance among the three groups varied. Crowns with no endodontic access displayed significantly ($p < 0.001$) higher resistance [CI: 1025 (121) N; CF 1134 (127) N], followed by crowns with conservative ovoidal endodontic access [CI: 924 (60) N; CF: 1000 (72) N. Crowns with traditional triangular endodontic access showed the significantly ($p < 0.001$) lowest fracture resistance [CI: 635 (82) N; CF: 709 (75) N].

Conclusion: The fracture resistance of chairside CAD-CAM lithium disilicate maxillary anterior crowns is influenced by the type of endodontic access provided. Conservative ovoidal endodontic access provides crowns with higher fracture resistance than traditional triangular endodontic access. Crowns with no endodontic access provided the highest resistance than other types of endodontic access.

Keywords: endodontic access; fracture resistance; lithium disilicate; crown

Using computer-aided design and subtractive-computer-aided manufacturing (CAD-s-CAM) in dentistry can fabricate high-quality, accurate dental restorations.[1-4] Currently, chairside CAD-CAM dentistry allows the clinician to fabricate final crowns within a single visit, saving time and avoiding polyvinyl siloxane (PVS) impressions and provisional restoration.[5,6] Several ceramic materials are available to fabricate crowns with chairside CAD-CAM systems.[7] Clinicians can fabricate chairside CAD-CAM crowns from feldspathic, leucite, lithium disilicate, zirconia, and hybrid ceramics.[8]

All-ceramic crowns have become one of the first choices for clinicians. A report provided by one of the largest dental laboratories in North America reported that 80.2% of the restorations were fabricated out of all-ceramic in 2014, compared with 23.9% in 2008.[9] Moreover, a practice-based research study has reported that 52% of the posterior restorations provided in 2016 were all-ceramic, with 21% lithium disilicate.[10] Lithium disilicate ceramic has become very popular for crowns because of its high esthetic and mechanical properties. A recent systematic review found that the survival rate of single lithium disilicate crowns had a 100% rate at 2 years and 97.8% at 5 years.[11]

Endodontic therapy consists of removing the pulpal tissue of the tooth followed by placing an obturating material in the root canal space.[12] Full coverage crown has been recommended after endodontic treatment for teeth with significant tooth loss by caries, trauma, and pulpal necrosis.[13,14] A university study evaluating the influence of coronal restoration type on the survival of endodontically treated teeth found that teeth that received full coverage crown had a 91.7% success rate after a mean of 38 months, followed by amalgam restorations with 86.5%, composite restorations 83.0% and temporary restorations 34.5%, thus supporting full coverage crown treatment for endodontically treated teeth.[15]

Endodontic therapy through crowns is a common procedure for clinicians. An estimated 20 – 50% of nonsurgical endodontic treatments are provided through the crown,[16] and a survey of clinicians reported that 72% of practitioners prefer to keep the crown after the endodontic procedure.[17,18] Retrospective studies have also reported that all-ceramic crowns required endodontic therapy in 2.5% to 8.6% of cases.[19-21] The effect of endodontic access to all-ceramic crowns has been the subject of many in vitro studies.[22-27] It has been suggested that endodontic access initiates catastrophic failure for complete crowns.[28,29] New conservative endodontic access has been proposed for maxillary central incisors; traditionally, the access was triangular, and the novel access is more ovoidal in shape to remove less amount of the tooth or crown structure.[30] To the authors' knowledge, no studies have been performed comparing the fracture resistance of traditional versus conservative endodontic access. Therefore, this study aimed to evaluate the fracture resistance of crowns with no endodontic access, traditional triangular endodontic access, and novel, conservative ovoidal endodontic access. The first hypothesis was that there is no difference in fracture resistance of chairside CAD-CAM lithium disilicate maxillary right central incisor crowns with traditional triangular endodontic access and conservative ovoidal endodontic access. The second hypothesis was that crowns with no endodontic access and crowns with the two different types of endodontic accesses are different.

Materials and methods

Specimen preparation

A typodont (1560 Dentoform; Columbia Dentoform, Lancaster, PA, USA) maxillary right central incisor was prepared for an all-ceramic crown with 1.0 mm circumferential chamfer located 1.0 mm above the gingival margin and 1.0 mm uniform axial and incisal reduction. The final prepared tooth had a height of 9 mm. The thickness of the restoration was 1.0 mm uniform. The prepared tooth and typodont were scanned with a chair-side scanner (Emerald, Planmeca, Helsinki, Finland). The software provided the digital design with ideal contours (PlanCAD Easy, Planmeca, Helsinki, Finland). A total of 57 maxillary right central incisor crowns were milled out (PlanMill 30S, Planmeca, Helsinki, Finland) of lithium disilicate (E.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein). The typodont tooth was scanned with a laboratory scanner (Degree of Freedom HD, DOF, Seoul, Korea) to digitally design the die matching the tooth preparation. Fifty-seven dies were printed out of resin model (Model Resin, Formlabs 3, Formlabs, Somerville, MA, USA) with an in-lab 3D printer (FormLab 3, Formlabs).

Crowns were treated following the manufacturer's recommendation, first with hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar Vivadent) for 20 seconds and rinsed with water for 20 seconds. Then, primer (Monobond Plus, Ivoclar Vivadent) was applied for 60 seconds. All the crowns were cemented to the printed resin dies with conventional resin luting cement (Multilink Automix, Ivoclar Vivadent) and photo-cured (Elipar 2500, 3M Oral Care, St. Paul, MN, USA; > 750 mW/cm^2) on the mesial, distal, buccal, lingual and occlusal surfaces for 20 seconds each, then allowed to self-cure for 6 minutes with 200 grams of applied weight.

The crowns were divided into 3 groups (n = 19 / group) and treated as follows: (1) full crowns with no endodontic access; (2) full crowns with traditional triangular endodontic access and; (3) full crowns with conservative ovoidal endodontic access (Fig 1). Endodontic access for groups 2 and 3 was provided with a round diamond bur (6801 DC, ESX Modern Access Kit, Brasseler USA, Savannah, Georgia, USA) specialized for endodontic access following specialized measurements with water coolant. For group 2, two horizontal lines were drawn on the lingual surface, with the first one 3 mm above the cervical CEJ and the second 2 mm below the incisal edge, and 2 vertical lines were drawn 2 mm from mesial and distal to guide for preparation. For group 3, two similar lines were drawn but 4 mm away from the crown’s cervical CEJ, incisal edge, and mesial and distal borders. After endodontic access was completed, the restorations were repaired with a ceramic repair system (Intraoral Repair Kit, BISCO Inc., Schaumburg, IL, USA) following the manufacturer’s instructions, including the application of ceramic etchant (9.5%) on the ceramic surface for 90 seconds, rinsing, and drying. Then the porcelain primer was placed on the ceramic for 30 seconds and dried with an air syringe. The porcelain bonding resin was applied, and the access was sealed with flowable resin composite (Filtek Supreme Flowable Restorative, 3M Oral Care) and light cured (Elipar 2500, 3M Oral Care) for 20 seconds. All cemented crowns were kept at 37°C distilled water for 24 hours.

Fracture strength test

All restorations were subjected to 10,000 cycles of thermal cycling between 5°C and 55°C (dwell time 20 seconds). Then samples were fixed on a jig at a 40-degree inclination between tooth axis and direction of load and then exposed to compressive loading force until fracture in a universal testing machine (858 Mini Bionix II, Eden Prairie, MN, USA) at a crosshead speed of 1.0 mm/min. The load was applied with a tapered cone-shaped (2.0 mm at the tip) applicator centered on the lingual surface approximately 2.0 mm from the incisal edge. The load at crack initiation and load for complete fracture were both recorded in Newtons.

Fractographic analysis

Fractographic analysis of fractured specimens of each crown on the 3D printed teeth was performed with a scanning electron microscope (TM3000, Hitachi, Tokyo, Japan; 5 kV). The number of cracks, and length, was quantified in the micrograph based on the 40x magnification and ImageJ software (NIH, USA).

Statistical analysis

The sample size was determined by a power analysis that showed 11-40 specimens were needed for each group for the test; therefore, 19 specimens per group were used (G*Power). A one-way ANOVA test was performed, and a pairwise comparison was performed using Bonferroni's correction. A p-value less than 0.05 was considered statistically significant.

Results

Fracture strength test

The force at crack initiation (CI) and force at complete fracture (CF) of the chairside CAD-CAM lithium disilicate maxillary right central incisor crowns without and with traditional triangular and conservative ovoidal endodontic access are shown in Table 1. The CI and CF were influenced by the treatment of the crown. Crowns without endodontic access displayed higher fracture resistance, with 1025.81 N for CI and 1134.13 N for CF, followed by crowns with conservative ovoidal endodontic access, with 924.49 N for CI and 1000.09 N for CF. Crowns with traditional triangular endodontics access displayed the lowest fracture resistance, with 635.02 N for CI and 709.38 N for CF. All three groups were statistically significantly different ($p < 0.001$) for both CI and CF.

Fractographic analysis

Representative SEM observations of the fracture surfaces of the chairside CAD-CAM lithium disilicate crowns without and with different endodontic access are shown in Figure 2 (without access; averaged 13.4 cracks with an average length of 0.82 mm), Figure 3 (traditional triangular; averaged 5.6 cracks with an average length of 1.6 mm), and Figure 4 (conservative ovoidal; averaged 4.4 cracks with an average length of 1.4 mm). It should be noted that the varying location of the fracture in the restoration can obscure the differences between the specimens. Traditional endodontic accesses showed more vertical cracks than conservative ones, which showed more horizontal cracks. Crowns without access had more, but smaller, cracks than endodontically accessed crowns.

Discussion

Chairside CAD-CAM lithium disilicate crowns for anterior and posterior teeth have become a widespread option for clinical dentistry.[31,32] In fact, a recent practice-based study indicated that this ceramic was the second most commonly used material for single restorations.[10] The purpose of this study was to determine whether crowns without and with different endodontic accesses display different fracture resistance. Based on the results, the first null hypothesis that there was no difference in fracture resistance of chairside CAD-CAM lithium disilicate maxillary right central incisor crowns with traditional triangular endodontic access and conservative ovoidal endodontic access was rejected because crowns with conservative ovoidal endodontic access displayed higher fracture resistance (CI 924.49 N and CF 1000.09 N) than traditional triangular endodontic access (CI 635.02 N and CF 709.38 N). Furthermore, the second null hypothesis that there was a difference between crowns with no endodontic access and crowns with the two different types of endodontic accesses was accepted because the control group of crowns with no endodontic access displayed the highest fracture resistance values (CI 1025.81 N and CF 1134.13 N) than crowns with traditional and conservative accesses.

Conservative dentistry aims to provide the least invasive treatment possible.[33] In endodontics, access design involving minimum tooth tissue removal has been developed to provide root canal therapy with less removal of tissue structure.[34] A recent study using cone-beam computed tomography evaluated traditional and conservative access; it concluded that traditional access requires the removal of 9.61 mm^2 of tissue for males and 8.91 mm^2 for females, and conservative access made the removal of 3.4 mm^2 for males and 3.1 mm^2 for females. Therefore, conservative access results in significantly less structure removal.[35] The controversy between traditional and conservative access relies on whether the clinician completely removes the pulp with conservative access; but this is also related to the skill of the clinician, tooth anatomy, and materials and methods utilized to open the access, clean, shape and obturate the root canal.[36-38] The literature offers several successful cases reporting conservative endodontic accesses for anterior and posterior natural teeth and crowns.[39-44] A study comparing the fracture resistance of conservative endodontic cavity (CEC) preparations versus traditional endodontic cavity (TEC) for posterior teeth concluded that fracture resistance was higher for mandibular premolars (CEC 586.8 N and TEC 328.4 N) and molars (CEC 1586.9 N and TEC 641.7 N).[45] Furthermore, a recent finite element analysis study evaluating the stress distribution in teeth treated with minimally invasive access compared to traditional access demonstrated that traditional access presented higher stress values than minimally invasive access, and higher stress values indicate higher susceptibility to fracture.[46] To the best of the authors' knowledge, there is a gap in the literature as no publication has ever compared the traditional and minimally invasive access through crowns. However, the present study agrees with the data available on natural teeth where conservative endodontic access provides higher fracture resistance and lower stress values than teeth with traditional endodontic access.

Traditional endodontic access provided in this study followed the Commission on Dental Competency Assessment by the American Board of Dental Examiners (CDCA ADEX), which provides the licensure exam in most states in the USA.[47] The measurements for the traditional endodontic access with a triangular shape required in the examinations state to have the incisal aspect of the opening at ≥ 2.0 mm, the cervical access opening ≥ 3.0 mm from the lingual cementum enamel junction (CEJ) and mesiodistally ≤ ½ of the lingual surface to provide fully supported marginal ridges.[47] The conservative ovoidal shape endodontic access in this study was significantly smaller, and it followed previous case reports where the access is 4 mm from mesial, distal, incisal, and lingual CEJ aspects.[48-50] Other access, such as on the incisal edge, has been reported in the literature;[51] however, few other reports are available at this time. Therefore, this type of access was not evaluated in the present study.

Further studies should compare other endodontic access designs for maxillary right central incisors. However, it would be interesting to see the performance of those access types in other teeth, such as canines. Replicate studies are required to compare traditional and conservative endodontic access to verify their fracture resistance. A limitation of the study is the use of printed resin dies instead of natural teeth; however, the selection of printed resin dies as a dentin substitute decreases the variables caused by collecting natural teeth without caries, doing similar hand-prepping for crowns, and storage of natural teeth. As a result, the data obtained from each measurement were acceptably consistent (standard deviation was about 20% of the mean value). Another limitation is the lack of a control group that did not undergo thermal cycling. More SEM micrographs could have been collected to enhance the fractographic analysis for statistical analysis. Longer aging and fatigue cycling may also help better predict the restorations' performance.

Conclusion

The fracture resistance of chairside CAD-CAM lithium disilicate maxillary right central incisor varies according to the type of endodontic access. Conservative ovoidal endodontic access provided higher fracture resistance than traditional triangular endodontic access. Crowns with no endodontic access provided higher fracture resistance than crowns with any type of endodontic access. Based on the present results, it can be recommended to avoid a triangular endodontic access in incisors with all-ceramic full crowns - whenever possible

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Table 1 Mean fracture resistance of chairside CAD-CAM lithium disilicate maxillary right central incisor crowns without and with traditional and conservative endodontic access.

Type of restoration	Number of specimens	Force at Crack Initiation (CI) in Newtons	Force at Complete Fracture (CF) in Newtons
Crowns with no endodontic access	19	1025.81 (121.06)[a]	1134.13 (127.28)[a]
Crowns with traditional triangular endodontic access	19	635.02 (82.12)[b]	709.38 (75.24)[b]
Crowns with conservative ovoidal endodontic access	19	924.49 (59.59)[c]	1000.09 (72.28)[c]

Values in parenthesis are standard deviations. The same lowercase letter in the same vertical column indicates no significant difference ($p > 0.05$).

Figure Captions

Figure 1 Summary of three types of restorations. (a) Crowns with no endodontic access (Group 1), (b) crowns with traditional triangular endodontic access (Group 2), and (c) crowns with conservative ovoidal endodontic access (Group 3).

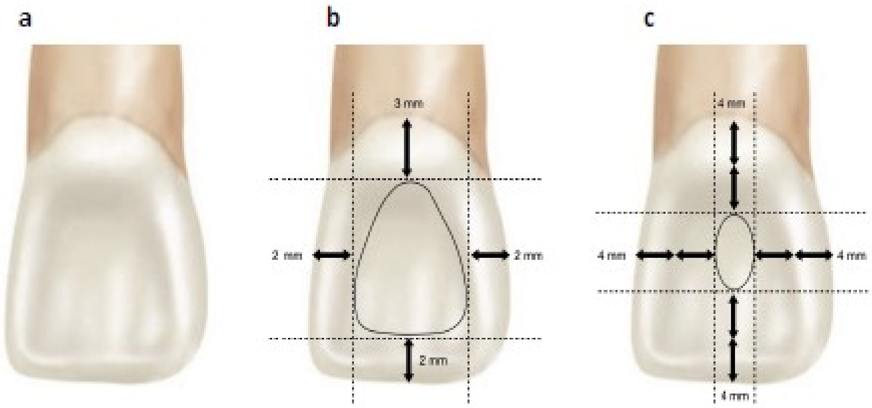

Figure 2 Micrographs of a crown with no endodontic access (Group 1). (a) Micrographs with 40x magnification and (b) 100x magnification. Scale bar is 1 mm in 2a and 2 mm in 2b.

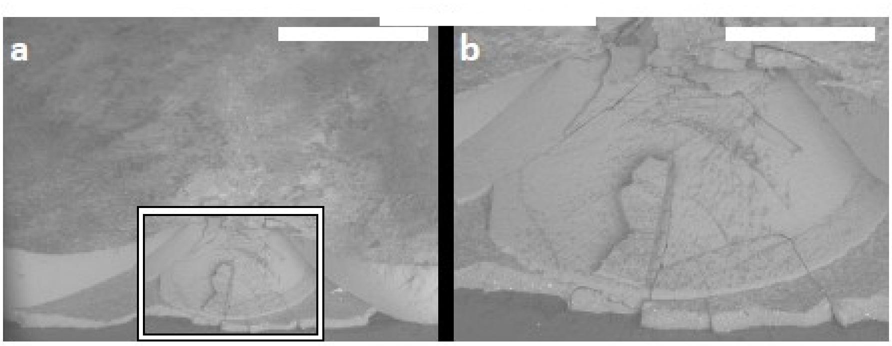

Figure 3 Micrographs of a crown with traditional triangular endodontic access (Group 2). (a) Micrographs with 40x magnification and (b) 100x magnification. Scale bar is 1 mm in 3a and 2 mm in 3b.

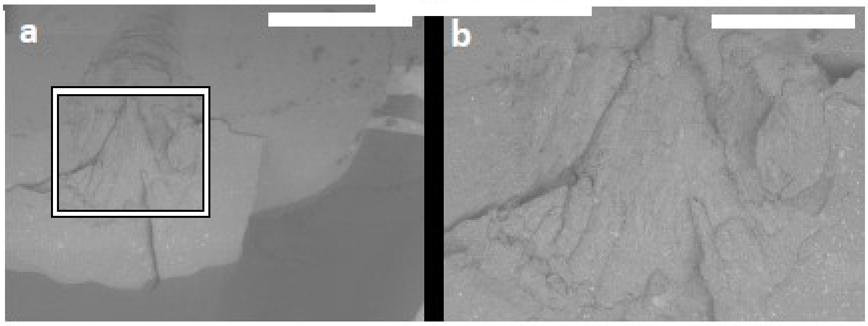

Figure 4 Micrographs of a crown with conservative ovoidal endodontic access (Group 3). (a) Micrographs with 40x magnification and (b) 100x magnification. Scale bar is 1 mm in 4a and 2 mm in 4b.