Durability and Weibull Characteristics of Lithium Disilicate Crowns Bonded on Abutments with Knife-Edge and Large Chamfer Finish Lines after Cyclic Loading

Davide Cortellini, DDS, PhD,[1] Angelo Canale, DDT,[2] Rodrigo O.A. Souza, DDS, PhD,[3] Fernanda Campos, DDS,[4] Julia C. Lima, DDS,[4] & Mutlu Özcan, DDS, DMD, PhD[5]

[1]Private Practice, Riccione, Italy
[2]Dental Laboratory, Rimini, Italy
[3]Department of Dentistry, Division of Prosthodontics, Federal University of Rio Grande do Norte, Natal, RN, Brazil
[4]São Jose dos Campos Dental School, Department of Prosthodontics and Dental Materials, São Paulo State University, São José dos Campos, Brazil
[5]Dental Materials Unit, Center for Dental and Oral Medicine, Clinic for Fixed and Removable Prosthodontics and Dental Materials Science, University of Zurich, Zurich, Switzerland

Keywords
Crowns; cyclic loading; finish line; fracture strength; lithium disilicate ceramic; load-bearing capacity.

Correspondence
Mutlu Özcan, Dental Materials Unit, Center for Dental and Oral Medicine, Clinic for Fixed and Removable Prosthodontics and Dental Materials Science, University of Zurich, Plattenstrasse 11, Zurich CH 8032, Switzerland.
E-mail:mutluozcan@hotmail.com

The authors deny any conflicts of interest.

Accepted June 26, 2014

doi: 10.1111/jopr.12237

Abstract

Purpose: The aim of this study was to evaluate the durability of lithium disilicate crowns bonded on abutments prepared with two types of finish lines after long-term cyclic loading.
Materials and Methods: Pressed lithium disilicate all-ceramic molar crowns were bonded (Variolink II) to epoxy abutments (height: 5.5 mm, Ø: 7.5 mm, conicity: 6°) (N = 20) with either knife-edge (KE) or large chamfer (LC) finish lines. Each assembly was submitted to cyclic loading (1,200,000×; 200 N; 1 Hz) in water and then tested until fracture in a universal testing machine (1 mm/min). Failure types were classified and further evaluated under stereomicroscope and SEM. The data (N) were analyzed using one-way ANOVA. Weibull distribution values including the Weibull modulus (m), characteristic strength (0), probability of failure at 5% (0.05), 1% (0.01), and correlation coefficient were calculated.
Results: Type of finish line did not significantly influence the mean fracture strength of pressed ceramic crowns (KE: 1655 ± 353 N; LC: 1618 ± 263 N) ($p = 0.7898$). Weibull distribution presented lower shape value (m) of KE (m = 5.48; CI: 3.5 to 8.6) compared to LC (m = 7.68; CI: 5.2 to 11.3). Characteristic strengths (0) (KE: 1784.9 N; LC: 1712.1 N) were higher than probability of failure at 5% (0.05) (KE: 1038.1 N; LC: 1163.4 N) followed by 1% (0.01) (KE: 771 N; LC: 941.1 N), with a correlation coefficient of 0.966 for KE and 0.924 for LC. Type V failures (severe fracture of the crown and/or tooth) were more common in both groups. SEM findings showed that fractures occurred mainly from the cement/ceramic interface at the occlusal side of the crowns.
Conclusion: Lithium disilicate ceramic crowns bonded onto abutment teeth with KE preparation resulted in similar fracture strength to those bonded on abutments with LC finish line.
Clinical Significance: Pressed lithium disilicate ceramic crowns may not require invasive finish line preparations since finish line type did not impair the strength after aging conditions.

Stresses at the marginal areas of fixed dental prostheses (FDPs) can be compensated for by increasing the crown thickness dictated by the depth of the finish line. This becomes a more important issue for the durability of all-ceramic restorations due to their brittle nature as opposed to metal ones, which present ductility at the marginal areas.[1,2] This allows for the indication of metal FDPs not only for large chamfer (LC), but also for knife-edge (KE), or the so-called tilted chamfer (TC) tooth preparations. Recently, due to its high fracture strength, yttria-stabilized zirconia in its monolithic or bilayered form

Table 1 Mean fracture strength and standard deviation (SD) (N), Weibull distribution values including the Weibull modulus (m), characteristic strength (0), probability of failure at 5% (0.05), 1% (0.01), correlation coefficient (CC), and confidence interval (CI) for each experimental group

Groups	Mean (SD)	m	CI (95%)	σ_0	0.05	0.01	CC	CI (95%)
KE	1655 (353)	5.48	3.5–8.6	1784.9	1038.1	771	0.966	1582.6–2013.1
LC	1618 (263)	7.68	5.2–11.3	1712.1	1163.4	941.1	0.924	1569.2–1867.9

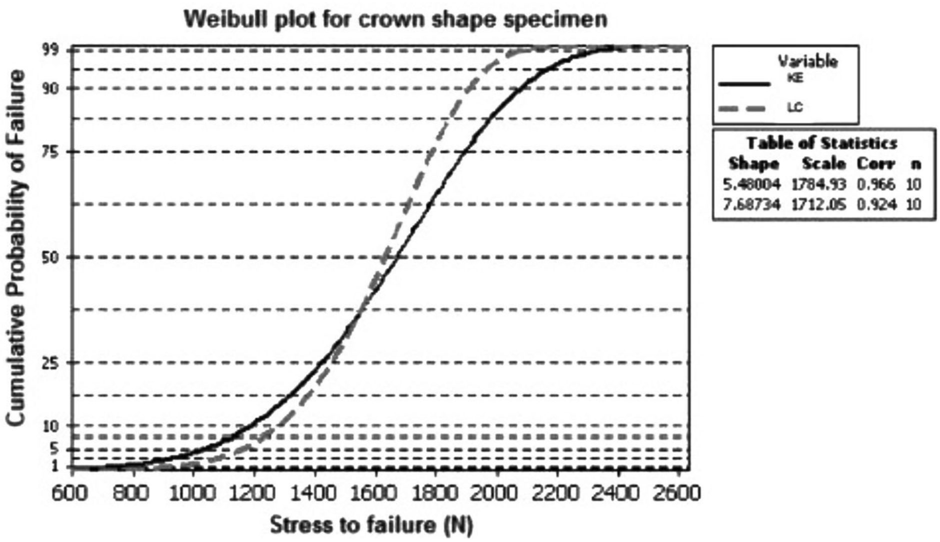

Figure 1 Weibull plot for the tested groups.

as indicated for FDPs,[3-7] demonstrated favorable in vitro[6] and clinical results on KE preparations.[8] Limited information is available in this respect for glassy matrix ceramics.[9]

Therefore, the objective of this study was to evaluate the durability of lithium disilicate crowns bonded on abutments prepared with two types of finish lines after long-term cyclic loading. The null hypothesis tested was that the finish line type would not affect the fracture strength of lithium disilicate crowns.

Materials and methods

Specimen preparation

One dental technician prepared standard epoxy resin (Zeiser Blue Star, Zeiser I und II; Demetec, Mittelbiberach, Germany) abutments by mixing the two components in a syringe (mixing ratio: 45.8-g paste and 5.5-g hardener), polymerizing in a pressure pot at room temperature for 8 hours, and then duplicating in silicone (Wieland AGC Dubli Gum Haerter; Wieland Dental, Pforzheim, Germany). The abutments represented tooth preparations on the mandibular first molar (height: 5.5 mm, Ø: 7.5 mm, conicity: 6°) ($N = 20$) with finish lines of either KE or LC both with a radius of 1.2 mm. Pressed lithium disilicate all-ceramic molar crowns (e.max Press; Ivoclar Vivadent, Schaan, Liechtenstein) were fabricated according to the manufacturer's recommendations. The dimensions of the crowns in each group were as follows: KE—occlusal: 1.5 mm; axial, buccal, and lingual: 0.8 mm; axial, mesial, and distal: 1.0 mm; margin buccal/lingual/mesial/distal depth: 0.3 mm; LC—occlusal: 1.5 mm; axial, buccal, and lingual: 1.4 mm; axial, mesial, and distal: 1.5 mm; margin buccal/mesial/distal depth: 0.9 mm; margin lingual: 0.8 mm.

Table 2 Distribution of failure modes in percentage, according to Refs. (11) and (12) for each experimental group. Type I: minimal fracture or crack in the crown; Type II: less than half of the crown lost; Type III: crown fracture through midline or half of the crown displaced or lost; Type IV: more than half of the crown lost; Type V: severe fracture of the crown and/or tooth, and cracking: veneer ceramic cracked at the interface; chipping: fracture in the veneer ceramic surface without exposure of the framework; delamination: veneer ceramic was damaged and the framework exposed; catastrophic failure: fracture in both the veneer ceramic and the framework

Failure modes		Groups	
	Burke's classification[11]	KE (%)	LC (%)
Cracking/chipping[12]	I	0	0
Delamination[12]	II	0	20
	III	10	10
	IV	20	0
Catastrophic fracture[12]	V	70	70

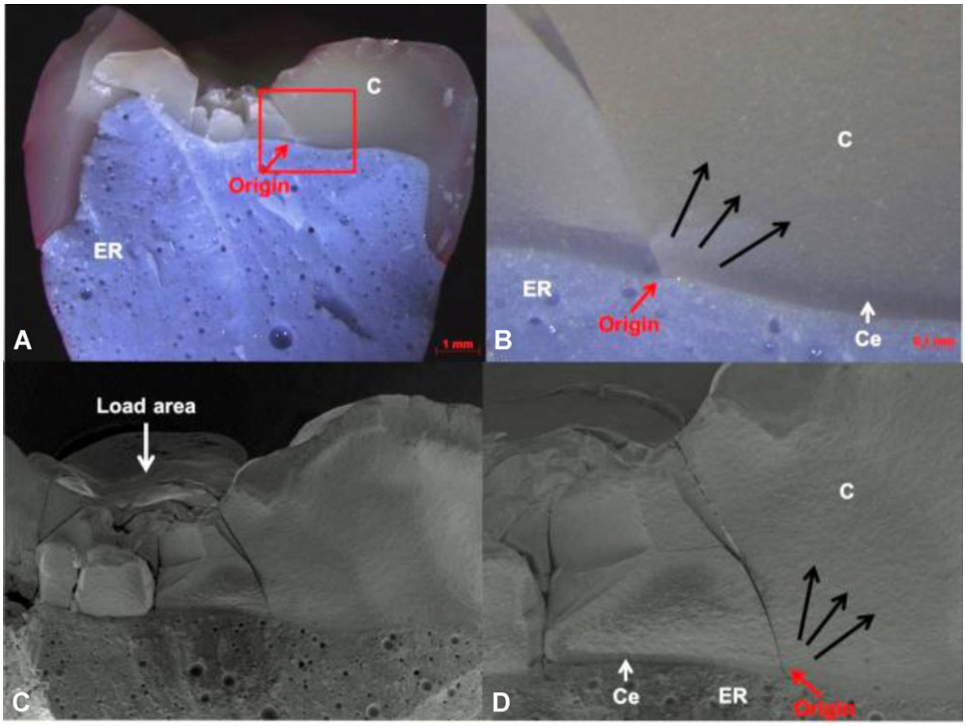

Figure 2 (A) Stereomicroscopy image (10×) of a representative crown from LC group with catastrophic fracture. Overview of the fractured crown. (B) Stereomicroscopy image (80×) corresponding to the area of crack origin, marked in red. (C) SEM image of the crown after fracture at 60× showing the load area. (D) SEM image at 150×. The black arrows indicate the direction of the crack propagation, evidenced by the presence of wake hackles; the red arrow indicates the possible origin of the flaw. C, ceramic; Ce, cement; ER, epoxy resin. KE: margin buccal/lingual/mesial/distal depth: 0.3 mm; LC: margin buccal/mesial/distal depth: 0.9 mm.

Cementation

The cementation surfaces of the crowns were etched with hydrofluoric acid 5% (Ivoclar Vivadent) for 20 seconds. One coat of silane coupling agent (Monobond Plus; Ivoclar Vivadent) was applied. After 5 minutes waiting for reaction, adhesive resin (Heliobond; Ivoclar Vivadent) was applied using a microbrush.

The abutments were air-abraded with alumina particles coated with silica (CoJet Sand; 3M ESPE, Seefeld, Germany) for 20 seconds (2.5 bar, distance: 10 mm). One coat of silane (Monobond Plus) was applied, we waited for its reaction for 5 minutes, and then adhesive resin (Heliobond; Ivoclar Vivadent) was applied. The crowns were cemented to their corresponding abutments with dual-polymerized resin cement (Variolink II; Ivoclar Vivadent) and polymerized with an LED polymerization device (Radii-Cal; SDI, Bayswater, Australia) for 40 seconds at each direction from a distance of 2 mm (light intensity: 1200 mw/cm^2). The abutment/crown assemblies were embedded in acrylic resin using a modified parallelometer.

Cyclic loading and fracture tests

Each assembly was submitted to cyclic loading (Model: ER-11000; ERIOS, São Paulo, Brazil) (1,200,000×, 200 N, 1 Hz)[10] in water and then tested until fracture in a universal testing machine (Emic DL-1000; Emic, São José dos Pinhais, Brazil) with a 1000 Kgf load cell (1 mm/min).

Failure type analysis

After fracture tests, failure types were categorized according to Burke's classification:[11] Type I: minimal fracture or crack in the crown; Type II: less than half of the crown lost; Type III: crown fracture through midline or half of the crown displaced or lost; Type IV: more than half of the crown lost; Type V: severe fracture of the crown and/or tooth. In addition, cracks, chipping, delaminations, and catastrophic total failures were noted.[12] Fractured specimens were further evaluated under stereomicroscope (Stereomicroscope; Wild M3B, Heerburg, Switzerland) at 10× to 80× and scanning electron microscopy (SEM) (JSM-5500; JEOL Ltd., Akishima, Tokyo, Japan) at 20× to 150× magnification.

Statistical analysis

Statistical analysis was performed with SPSS Statistics for Windows v.20 (SPSS, Chicago, IL, USA). Shapiro–Wilk test indicated normal distribution of the data. Data (N) were analyzed using one-way ANOVA. Weibull analysis was performed using Minitab Version 14 (Minitab, State College, PA, USA). Weibull distribution values including the Weibull modulus (m), characteristic strength (0), probability of failure at 5% (0.05), 1% (0.01), and correlation coefficient were calculated:

$$\ln\ln\frac{1}{1-F_{\sigma_c}} = m\ \ln\ \sigma_c - m\ln\sigma_0$$

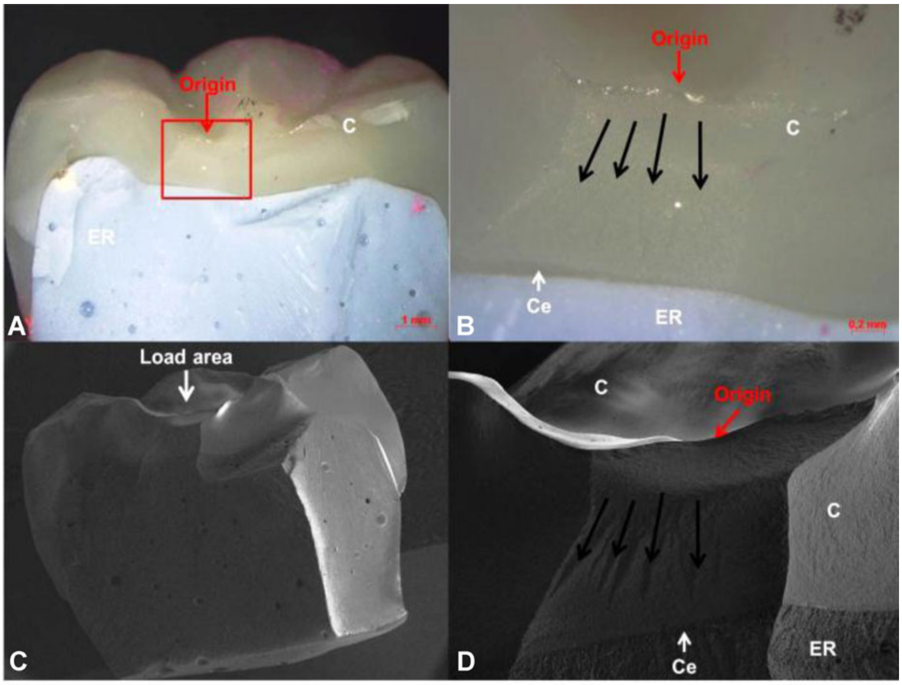

Figure 3 (A) Stereomicroscopy image (10×) of a representative crown from KE group with catastrophic fracture. Overview of the fractured crown. (B) Stereomicroscopy image (40×) corresponding to the area of crack origin, marked in red. (C) SEM image of the crown after fracture at 20× showing the load area. (D) SEM image at 100×. The black arrows indicate the direction of the crack propagation, evidenced by the presence of wake hackles; the red arrow indicates the possible origin of the flaw. C, ceramic; Ce, cement; ER, epoxy resin.

The characteristic strength was considered to be the strength at a failure probability of approximately 63%.

Results

Type of finish line did not significantly influence the mean fracture strength of pressed lithium disilicate ceramic crowns ($p = 0.7898$) (Table 1). Weibull distribution presented lower shape value (m) of KE compared to LC. Characteristic strengths (0) were higher than probability of failure at 5% (0.05) followed by 1% (0.01), with a correlation coefficient of 0.966 for KE and 0.924 for LC (Table 1, Fig 1).

Cracks and chipping were not observed. Type V failures (severe fracture of the crown and/or tooth) were more common in both groups (Table 2). SEM findings showed that fractures occurred mainly from the cement/ceramic interface at the occlusal side of the crowns (Figs 2 and 3).

Discussion

Since the finish line type did not affect the fracture strength of lithium disilicate crowns significantly after long-term cyclic loading, the null hypothesis tested could be accepted. As in one similar study,[9] where fracture strength of glass ceramic (Dicor) crowns was tested, no significant effect of finish line was noted; however, in that study no fatigue conditions were simulated, and ceramic restorations were bonded to human teeth. Also, a KE finish line was not even considered, as this type of finish line was not indicated for this ceramic type. Confirming these in vitro findings, in a clinical study,[13] the type of finish line (chamfer or shoulder) did not influence the clinical performance of glass-ceramic crowns (Dicor), a finding attributed to adhesive cementation of the crowns. With the use of alumina ceramics (In-Ceram), shoulder or chamfer finish line type also did not show significant differences in terms of immediate mean fracture strength.[14] In contrast, in another study where metal dies were used, ceramic optimized crowns with chamfer finish line presented significantly higher fracture strength than those with shoulder finish line.[15] It is notable that in previous studies focusing on the fracture strength of glass ceramic crowns, the experimental design did not involve a KE finish line as a comparison group, most probably due to the general conviction that this type of finish line would not allow sufficient strength to the brittle nature of the glass-based ceramics.

In this study, the nonsignificant effect of finish line type on the fracture strength results even after long-term fatigue conditions indicates that lithium disilicate ceramics may not require invasive preparations. Although slightly lower m values were observed with KE compared to LC, the results were not significant. Type V failures were more commonly observed in both groups and could be considered catastrophic failures that cannot be repaired. Similarly, in a recent in vitro study, complete fractures but no chippings were observed for lithium disilicate crowns where the abutment material was natural tooth.[16] These findings are supported in a clinical study in which up to 4 years of findings were reported, and one fracture but no chippings were observed out of 29 single crowns.[17] In another clinical study, out of 74 crowns, 5 fractures and 3 minor chippings of the veneering ceramic were observed after a mean observation period of 79.5 months.[18] The authors reported that all teeth received a 1-mm wide chamfer or rounded shoulder preparation with an occlusal/incisal reduction of 1.5 to 2.0 mm. The study did not mention on which kind of finish lines the fractures happened, but chipping was attributed to occlusal adjustments and as a consequence, roughening of the veneering ceramic. In this study, we did not make any adjustments to the crowns using burs.

Epoxy resin abutments were used instead of human teeth, as it would be difficult to standardize the dimensions of the latter. Epoxy resin abutments were air-abraded to achieve micromechanical retention between the epoxy resin and the resin cement since adhesion of the cement to the abutment may play a role in fracture propagation at this interface. The situation in this experimental set-up in terms of abutment material may clinically represent the situation where the crowns are cemented on the resin composite cores or large composite restorations on prepared teeth. It is assumed that air-abrasion increased the interfacial strength. Thus, cracks initiated from the tensile side of the crown material, namely the intaglio surfaces. The effect of abutment material type on the fracture strength of glass ceramic materials needs to be explored in future studies.

At present, mechanical testing parameters and cyclic loading protocols show a great variation in the literature. The cyclic loading of 1,200,000× is considered to correspond to 5 years of clinical service.[10] In our preliminary studies, 50 and 100 N did not result in any crack formation with the ceramic material tested, but with 200 N, we started observing hairline crack formation. Thus, loading was performed under 200 N. Clinical studies on the longevity of lithium disilicate FDPs should report on the association between the incidence of failure and finish line types employed.

Conclusions

Pressed lithium disilicate ceramic crowns bonded onto teeth with a KE finish line resulted in nonsignificant fracture strength and Weibull moduli compared to those bonded on teeth with a LC finish line after long-term cyclic loading. Accordingly, such ceramic crowns may not necessitate invasive finish line preparations to ensure their adhesion on enamel.

Acknowledgments

The authors greatly acknowledge CDTs Angela Giordano, Daniela Bergantini, and Barbara Bergantini for their contribution to specimen creation.

References

1. Nakamura T, Dei N, Kojima T, et al: Marginal and internal fit of Cerec 3 CAD/CAM all-ceramic crowns. Int J Prosthodont 2003;16:244-248.
2. Souza RO, Özcan M, Pavanelli CA, et al: Marginal and internal discrepancies related to margin design of ceramic crowns fabricated by a CAD/CAM system. J Prosthodont 2012;21:94-100.
3. Komine F, Iwai T, Kobayashi K, et al: Marginal and internal adaptation of zirconium dioxide ceramic copings and crowns with different finish line designs. Dent Mater 2007;26:659-664.
4. Beuer F, Aggstaller H, Edelhoff D, et al: Effect of preparation design on the fracture resistance of zirconia crown copings. Dent Mater J 2008;27:362-367.
5. Reich S, Petschelt A, Lohbauer U: The effect of finish line preparation and layer thickness on the failure load and fractography of ZrO2 copings. J Prosthet Dent 2008;99:369-376.
6. Comlekoglu M, Dundar M, Özcan M, et al: Influence of cervical finish line type on the marginal adaptation of zirconia ceramic crowns. Oper Dent 2009;34:586-592.
7. Aboushelib MN: Fatigue and fracture resistance of zirconia crowns prepared with different finish line designs. J Prosthodont 2012;21:22-27.
8. Poggio CE, Dosoli R, Ercoli C: A retrospective analysis of 102 zirconia single crowns with knife-edge margins. J Prosthet Dent 2012;107:316-321.
9. Bernal G, Jones RM, Brown DT, et al: The effect of finish line form and luting agent on the breaking strength of Dicor crowns. Int J Prosthodont 1993;6:286-290.
10. Rosentritt M, Behr M, van der Zel J, et al: Approach for valuating the influence of laboratory simulation. Dent Mater 2009;25:348-352.
11. Burke FJ: Fracture resistance of teeth restored with dentin-bonded crowns: the effect of increased tooth preparation. Quintessence Int 1996;27:115-121.
12. Aboushelib MN, Feilzer AJ, Kleverlaan CJ: Bridging the gap between clinical failure and laboratory fracture strength tests using a fractographic approach. Dent Mater 2009;25:383-391.
13. Malament KA, Socransky SS: Survival of Dicor glass-ceramic dental restorations over 14 years. Part II: effect of thickness of Dicor material and design of tooth preparation. J Prosthet Dent 1999;81:662-667.
14. Jalalian E, Aletaha NS: The effect of two marginal designs (chamfer and shoulder) on the fracture resistance of all ceramic restorations, Inceram: an in vitro study. J Prosthodont Res 2011;55:121-125.
15. Cho L, Choi J, Yi YJ: Effect of finish line variants on marginal accuracy and fracture strength of ceramic optimized polymer/fiber-reinforced composite crowns. J Prosthet Dent 2004;91:554-560.
16. Seydler B, Rues S, Müller D, et al: In vitro fracture load of monolithic lithium disilicate ceramic molar crowns with different wall thicknesses. Clin Oral Investig 2014;18:1165-1167.
17. Reich S, Schierz O: Chair-side generated posterior lithium disilicate crowns after 4 years. Clin Oral Investig 2013;17:1765-1772.
18. Gehrt M, Wolfart S, Rafai N, et al: Clinical results of lithium-disilicate crowns after up to 9 years of service. Clin Oral Investig 2013;17:275-284.