Direct composite versus glass-ceramic endocrowns for mechanically compromised molar teeth
de Kuijper, Maurits

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Cyclic loading and load to failure of lithium disilicate endocrowns: influence of the restoration extension in the pulp chamber and the enamel outline.

This chapter is based on the following paper:
ABSTRACT

Objectives: The objective of this study was to investigate the influence of the extension of the restoration in the pulp chamber and the enamel outline on the fracture resistance of lithium disilicate endocrowns after dynamic loading.

Materials and methods: 105Extracted sound molars were endodontically treated and randomly assigned to 1 control group (endodontic access cavity only) and 6 (endocrown groups (n=15 each): no extension in the pulp chamber, outline in Enamel (0/E) or Dentin (0/D) with a 2mm (2/E, 2/D) and 4mm extension (4/E, 4/D). Immediate Dentin Sealing was applied and the indirect restorations were luted using a direct composite resin. Specimens were thermomechanically aged in a chewing simulator (1.2x10^6 cycles at 1.7 Hz/50N, 8000 cycles 5-55°C). Surviving specimens were loaded at a 45 degree angle until failure. Data were analyzed using a two-way ANOVA and Freeman-Halton Exact test (α = 0.05).

Results: All specimens survived the thermomechanically aging process. There was no significant main effect of the restoration extension or type of outline on the fracture strength, F(1, 6)=2.42, p=0.12 and F(2, 6)=2.88, p=0.06 respectively. There was no significant interaction effect between the restoration extension and the outline on the fracture strength F(2, 6)=0.41, p=0.67. The control group had significantly more repairable failures compared to the experimental groups (p=0.01).

Conclusions: The amount of extension and the type of outline did not influence the fracture strength of glass-ceramic endocrown restorations after thermomechanical aging. Specimens from all experimental groups predominantly failed catastrophically.

1. INTRODUCTION

Indirect restorations can be divided on the basis of the mode of cementation in retentive and nonretentive techniques. Retentive techniques rely heavily upon the macroretention for clinical success, whereas nonretentive techniques rely mainly on adhesion to the tooth tissue. In the past decade, there is a shift in the clinical field from retentive toward nonretentive restoration of endodontically treated teeth, for which indirect resin composites or glass-ceramics are employed.

In case of severe amount of tissue loss of an endodontically treated tooth, the use of adhesively bonded restorations allows for a minimal preparation and thus preservation of tooth structure. Endocrowns could be a conservative treatment option. Endocrowns are adhesively bonded restorations with an extension into the pulp chamber. Guidelines concerning the optimal dimensions are lacking. The influence of a 2, 3 and 4mm extension on the load to failure was studied in vitro. Specimens were loaded at a 45 degree angle. It was concluded that all endocrown configurations demonstrated fracture loads higher than the normal reported human bite force, but that the 2mm extension resulted in more repairable failures. In this study, the specimens were not aged and the effect of the outline was not taken into account.

In vitro and in vivo studies show that a durable adhesion to dentin remains a challenge. An outline in dentin may lead to a higher risk of failure, as was demonstrated in vivo for ceramic inlays and onlays. Immediate Dentin Sealing (IDS) improves the bond to dentin in indirect restorations and might therefore contribute to the clinical performance, especially when the outline is situated in dentin. In the case of endocrowns, any undercuts present in the pulp chamber can be blocked out during the IDS procedure using composite resin, so tooth tissue can be preserved as well.

In a systematic review, 76.2% of the included studies reported fracture of the ceramic or tooth. Also, nonvital teeth appear to be more prone to fracture, probably due to loss of tooth tissue, which negatively influences survival. The challenge in restoring an endodontically treated tooth is therefore to obtain a tooth-restoration complex that is resistant to fracture. Modifying factors need to be investigated. With respect to endocrowns, the extension into the pulp chamber and the preparation outline seem important determinants. The objective of this in vitro study therefore is to investigate the influence of the extension of the restoration in the pulp chamber and the type of outline (enamel or dentin) on the load to failure of lithium disilicate endocrowns after extensive cyclic loading in a chewing simulator.

The null hypothesis tested, was that there would be no influence of the restoration extension and outline on the load to failure of lithium disilicate endocrowns after...
extensive cyclic loading. The second hypothesis is that there would be no difference in the mode of failure between the control and treatment groups.

2. MATERIAL AND METHODS

An overview of the materials used in this study is presented in Table 1. A total of 105 sound, freshly extracted third molars similar in size were included (n=15 per group). Presence of caries or cracks, restorations or root canal treatment, abnormal morphology and roots <10mm were exclusion criteria. All specimens were embedded 1mm below the cemento-enamel junction (CEJ) in polyvinylchloride tubes (height: 10mm; diameter: 12mm) using auto-polymerizing acrylic resin (Autoplast; Condular; Wager, Switzerland). Teeth were stored in distilled water before preparation.

Table 1. Overview of the materials used in the study.

<table>
<thead>
<tr>
<th>BRAND</th>
<th>TYPE</th>
<th>CHEMICAL COMPOSITION</th>
<th>MANUFACTURER</th>
<th>BATCH NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultra-etch A3</td>
<td>Etching agent</td>
<td>35% H₃PO₄</td>
<td>Ultradent, St. Louis, USA</td>
<td>D080, L090, K021, F080, T031</td>
</tr>
<tr>
<td>Optibond FL Bonding agent</td>
<td>Primer: HEMA, GPDM, PAMM, ethanol, water, photo-initiator</td>
<td>Adhesive: TEGDMA, UDMA, GPDM, HEMA, bis-GMA, filler, photo initiator</td>
<td>Kerr, Orange, CA, USA</td>
<td>6286025, 6113545</td>
</tr>
<tr>
<td>Clearfil AP-X Pit Microhybrid composite resin</td>
<td>bis-GMA, triethyleneglycol dimethacrylate, silanated barium glass filler, silanated colloidal silica, di-camphorquinone</td>
<td>Kuraray, Okayama, Japan</td>
<td>2E0706</td>
<td></td>
</tr>
<tr>
<td>Tetric EvoFlow A3 Flowable composite resin</td>
<td>Dimethacrylates, barium glass fillers, ytterbium trifluoride, silicon dioxide, mixed oxide and copolymer, additives, catalysts, stabilizers, pigments</td>
<td>Ivoclar Vivadent, Schaan, Liechtenstein</td>
<td>W05639</td>
<td></td>
</tr>
<tr>
<td>Cojet sand Blasting particles</td>
<td>Aluminum trioxide particles coated with silica, particle size: 30µm</td>
<td>3M ESPE, Saint Paul, MN, USA</td>
<td>442859</td>
<td></td>
</tr>
<tr>
<td>IPS Ceramic Etching Gel Ceramic etching gel</td>
<td>&lt;5% hydrofluoric acid</td>
<td>Ivoclar Vivadent</td>
<td>V23918</td>
<td></td>
</tr>
<tr>
<td>Monobond Plus Silane coupling agent</td>
<td>Ethanol, 3-trimethoxysilylpropymethylacrylate, methacrylated phosphoric acid ester</td>
<td>Ivoclar Vivadent</td>
<td>T45804</td>
<td></td>
</tr>
</tbody>
</table>

Table 1 (continued). Overview of the materials used in the study.

<table>
<thead>
<tr>
<th>BRAND</th>
<th>TYPE</th>
<th>CHEMICAL COMPOSITION</th>
<th>MANUFACTURER</th>
<th>BATCH NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPS e.max CAD HT A3</td>
<td>Lithium disilicate Glass-ceramic</td>
<td>97% SiO₂, Al₂O₃, P₂O₅, K₂O, Na₂O, CaO, F, 3% TiO₂, and pigments, water, alcohol, chloride</td>
<td>Ivoclar Vivadent</td>
<td>V31667</td>
</tr>
<tr>
<td>Enamel HFO UD3 Microhybrid composite resin</td>
<td>Monomer matrix, diurethandimethacrylate, bisphenol-A glycidyldimethacrylate, 1,4'-Butanedioldimethacrylate. Fillers: glass filler (68%), nano zirconium oxide particles (12%)</td>
<td>Micrurium, Avegno, Italy</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.1. Endodontic treatment

Endodontic treatment was carried out using a rotary file system (WaveOne Primary/ISO 25, taper 8%; Dentsply Sirona; Milford, USA). Gutta-percha cones were cemented using a root canal sealer (AH Plus; Dentsply Sirona) and covered with a glass ionomer cement (Vitrebond; 3M ESPE; St. Paul, USA). The access cavity was restored using a three step etch-and-rinse adhesive (Optibond FL; Kerr; Orange, USA) and a microhybrid composite (Clearfil AP-X Posterior A3; Kuraray; Okayama, Japan). The composite was layered and each increment light-cured for 20 seconds using a high-power curing unit (Bluephase 20i; Ivoclar Vivadent; Liechtenstein, Schaan). The output of the curing unit was >1100 mw/cm² throughout the experiment (Bluephasemeter; Ivoclar Vivadent). After endodontic treatment, specimens were stored in distilled water for a maximum of four months.

2.2. Randomization and specimen preparation

After endodontic treatment all teeth were randomly assigned via block randomization (block size=7) using an online randomization generator (www.sealedenvelope.com) to the control group (Control; no further treatment) or six experimental groups (n=15; Figs. 1 and 2). The original morphology was scanned and saved using an intraoral scanning device (Cerec Omnicam; Dentsply Sirona; Bensheim, Germany) to serve as a reference for the indirect restoration. All teeth in the treatment groups were decapitated using a coarse diamond wheel bur (5909FG; Komet Dental; Lengo, Germany) 1mm above the cemento-enamel junction and subsequently restored.

2.3. Enamel groups

For the tabletop restorations (0/E), no further preparation was performed. The composite sealing the pulp chamber was pretreated using silica-coated particle abrasion (CoJet System; 3M ESPE; St. Paul, USA). Thereafter, Immediate Dentin Sealing (IDS) was applied to the freshly cut dentin. Dentin was etched with 35% phosphoric acid (Ultra-etch; Ultradent; St. Louis, USA) for 15 seconds, rinsed and dried. A silane coupling agent
(Monobond Plus; Ivoclar Vivadent) was rubbed on the composite for 60 seconds. A primer (Optibond FL Primer; Kerr; Orange, USA) was applied on the etched dentin and scrubbed in for 20 seconds, followed by suction drying. A filled adhesive (Optibond FL Adhesive; Kerr) covering only the dentin and the pulp chamber composite was light-cured during 20 seconds and covered with a layer of flowable composite resin (Tetric Evoflow A3; Ivoclar Vivadent). Final light-curing was performed through glycerin gel for 40 seconds. When present, adhesive excess on enamel was removed using a red ring shoulder bur in low speed (15,000 rpm). A provisional restoration (ProTemp 4; 3M ESPE; Seefeld, Germany) was cemented for two weeks using polycarboxylate cement (Durelon; 3M ESPE). For the other enamel groups, the pulp chamber was prepared to a depth of 2mm and 4mm (2/E and 4/E respectively; Figure 1A) using a red ring bur. For the subsequent surface treatment and restoration, the same protocol was followed as described for group 0/E.

2.4. Dentin groups

After decapitation, the outer enamel was removed using coarse abrasive discs (Sof-Lex disc; 3M ESPE) and subsequently polished (brownie/greenie; Shofu Dental; Ratingen, Germany), thus creating an outline situated in dentin only (Figure 1B). The dentin specimens received either no further preparation (0/D) or preparation of the pulp chamber to a depth of 2mm (2/D) or 4mm (4/D). The same IDS protocol as described for the enamel groups was followed.

Figure 1. Representative specimens of the enamel (A) and dentin outlines (B), different types of endocrown configurations (C) and fracture testing (D).

A B C D

2.5. Scanning and milling of the restorations

Using a digital impression (Cerec Omnicam; Dentsply Sirona), the indirect restoration was designed from the previously saved scan. In order to standardize the ceramic thickness, the occlusal table was adjusted to ensure a 5mm and 6mm thickness of the ceramic in the

Figure 2. Overview of the study groups (n= 15 per group) and flow chart showing the experimental sequence. 1, 2 and 4: restoration extension in the pulp chamber of 0, 2 or 4mm. Outline in enamel (E) and dentin (D).
central groove and cusps respectively. Lithium disilicate restorations (IPS e.max CAD HT A3; Ivoclar Vivadent) were milled (InLab MC XL; Dentsply Sirona; Figure 1C). After two weeks, the provisional was removed and the preparation cleaned using a pumice slurry. The IDS layer was treated using silica-coated particle abrasion until the surface appeared matte, followed by phosphoric acid etching of the enamel (15 seconds). The IDS layer was silanized for 60 seconds (Monobond Plus; Ivoclar Vivadent). The preparation was covered with a filled adhesive (Optibond FL Adhesive; Kerr), but not light-polymerized. The intaglio surface of the indirect restoration was etched (20 seconds) using 4.9%-hydrofluoric acid (IPS Ceramic Etching gel; Ivoclar Vivadent), thoroughly rinsed and ultrasonically cleaned for 5 minutes. The etched surface was silanized for 60 seconds. The same filled adhesive was applied on the intaglio surface of the indirect restoration and subsequently luted to the preparation using a heated microhybrid composite (Enamel Plus HFO U63; Micerium, Avegno, Italy). Light-polymerization was performed through glycerin gel for 90 seconds per side (occlusal, buccal and lingual) and the restoration was polished (brownie/greenie; Shofu Dental). The digital impression was exported to stereolithography-files (STL-files) and the surface available for adhesion was determined using engineering software (Geomagic Control X; Morrisville, USA) in mm².

2.6. Thermomechanical aging, fracture test and analysis
All specimens were thermomechanically aged (SD Mechatronik CS4.8 Chewing Simulator; Feldkirchen-Westerham, Germany) using an axial 50N load (1.2x10⁶ cycles; 1.7 Hz) and thermal cycling (8000 cycles, 5-55 °C, dwelling time 30 seconds) simultaneously. The load was placed on all cusps at the increase of the slopes, just below the summit, using a ceramic antagonistic sphere. After aging, the specimens were checked for wear and fractures under an optical microscope (x10, OPMI pico; Zeiss; Jena, Germany). The presence of a fracture or chipping was defined as a failure. Surviving specimens were mounted in a jig and the lingual cusps were loaded under a 45 degree angle using an 5mm diameter hardend, stainless steel sphere until failure (MTS810; 1mm/min; Figure 1D). All fractures were visually analyzed at x40 magnification (Wild Heerbrugg M3Z Schott; Zeiss; Switzerland) and classified. Repairable failures were defined as failures that would not result in tooth loss and further specified as follows: a) fracture within the restoration, b) fracture of the restoration and adhesive failure and c) combined fracture, with a maximum of 3mm below the original outline. Non-repairable failures result in extraction of the tooth and were classified as 1) a fracture more than 1mm below the original outline or 2) root fracture. Representative failures of each category were sputter-coated with a 3nm thick layer of gold (80%)/ palladium (20%) (90s, 45mA; Balzers SCD, O30 Balztes, Liechtenstein). specimens were analyzed using cold field emission Scanning Electron Microscope (SEM) (LyraTC; Tescan; Brno, Czech Republic) under magnification varying between 50X – 4000X. The unit operated at 20 kV, WD range of 5-15mm, and with a spotsize range of 25pA-100pA.

2.7. Statistical analysis
Results were analyzed using IBM SPSS 24 statistic software package (SPSS Inc.; Chicago, USA). Data was visually inspected for outliers using box plots. Two extreme outliers were identified, with values more than 3 times greater than the interquartile range (1 in group 0/E; 1 in group 2/D). Upon reviewing the recordings of the experiment, movement of the specimens was detected during fracture testing. Therefore these outliers were removed. After removal of these outliers, assumptions of normality and homogeneity of variance were checked. A two-way ANOVA test was conducted, with the fracture load as the dependent variable and the outline (control/enamel/dentin) and pulp extension (control/0mm/2mm/4mm) as independent variables. To compare the mode of failure between groups a Fisher-Freeman-Halton Exact test was performed. In order to assess if the preparation dimensions within the same extension group (0/E versus 0/D, 2/E versus 2/D and 4/E and 4/D) were the same, the surface area was evaluated. A Kruskal-Wallis test was performed with the surface area as the dependent and the treatment group as the independent variable, since the data did not meet the assumptions for normality and homogeneity of variance. Post hoc tests were done using the Bonferroni correction. A p-value of less than 0.05 was considered significant in all aforementioned tests.

3. RESULTS
All specimens survived the thermomechanical aging process. Slight wear facets were present on the cusps of the ceramic restorations. Subsequently, all specimens were subjected to load to failure testing. An overview of the results is presented in Table 2. There was no significant main effect of pulp extension or outline on the fracture load, F (1, 6)=2.42, p=0.123, ω=0.06 and F (2, 6)=2.88, p=0.06, ω=0.21 respectively. There was no significant interaction between groups a Fisher-Freeman-Halton Exact test was performed. In order to assess if the preparation dimensions within the same extension group (0/E versus 0/D, 2/E versus 2/D and 4/E and 4/D) were the same, the surface area was evaluated. A Kruskal-Wallis test was performed with the surface area as the dependent and the treatment group as the independent variable, since the data did not meet the assumptions for normality and homogeneity of variance. Post hoc tests were done using the Bonferroni correction. A p-value of less than 0.05 was considered significant in all aforementioned tests.

<table>
<thead>
<tr>
<th>GROUP</th>
<th>N</th>
<th>MEAN±SD</th>
<th>MINIMUM</th>
<th>MAXIMUM</th>
<th>95% CONFIDENCE INTERVAL</th>
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<tr>
<td></td>
<td></td>
<td>LOWER BOUND</td>
<td>UPPER BOUND</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>15</td>
<td>1080±27</td>
<td>699</td>
<td>1501</td>
<td>925</td>
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<tr>
<td>0/D</td>
<td>15</td>
<td>782±353</td>
<td>357</td>
<td>1326</td>
<td>587</td>
</tr>
<tr>
<td>0/E</td>
<td>14</td>
<td>812±235</td>
<td>384</td>
<td>1399</td>
<td>677</td>
</tr>
<tr>
<td>2/D</td>
<td>14</td>
<td>884±394</td>
<td>325</td>
<td>1856</td>
<td>656</td>
</tr>
<tr>
<td>2/E</td>
<td>15</td>
<td>1071±408</td>
<td>326</td>
<td>1974</td>
<td>846</td>
</tr>
<tr>
<td>4/D</td>
<td>15</td>
<td>923±345</td>
<td>239</td>
<td>923</td>
<td>732</td>
</tr>
<tr>
<td>4/E</td>
<td>15</td>
<td>1036±278</td>
<td>553</td>
<td>1408</td>
<td>882</td>
</tr>
</tbody>
</table>

Table 2. Mean fracture loads (N) per group. 0, 2 and 4: restoration extension in the pulp chamber of 0, 2 or 4mm. Outline in enamel (E) and dentin (D).
Figure 3 depicts the failure modes per group. There was a significant association between the treatment group and mode of failure (p=0.00; two-sided). The odds for a repairable failure in the control group were 5.5 times higher as compared to group 2/D, 9 times higher as compared to group 0/E, 9.8 times higher as compared to group 4/D and 4/E and 21 times higher for groups 0/D and 2/E. All experiment groups failed predominantly catastrophic. The location of the failures was almost exclusively located in tooth tissue at the point of loading, irrespective of the extension in the pulp chamber. Upon SEM-analysis, all representative specimens showed radial cracks arising from the pulp chamber and mixed substrate failures, irrespective of the extension of the restoration (see Figure 4). A good integrity between the adhesive layers was present (Figure 4B).

There was a significant difference in the surface area between groups, H(5)=67.77, p=0.00. Pairwise comparisons with adjusted p-values showed that group 0/D had a significant lower surface area as compared to groups 4/E, 4/D and 2/E (all p=0.00). Group 0/E had a significant lower surface area compared to group 4/D (p=0.00) and 4/E (p=0.00). The surface area of group 2/D differed significantly from group 4/D (p=0.01) and 4/E (p=0.00). Within the same extension group, there was no significant difference in surface area (see figure 5).

Figure 3. Failure modes per group. 0, 2 and 4: restoration extension in the pulp chamber of 0, 2 or 4mm. Outline in enamel (E) and dentin (D). Numbers in the bar represent the number of failures of that specific type of failure.

Figure 4. SEM-images of representative specimens. A) cracks in the pulp chamber, B) close-up of image 4A, showing the integrity between the ceramic (Cer), composite (Comp), IDS and dentin (D). C) Crown fragment after failure. D) Close-up of 4C showing the detached dentin to the inner surface of the endocrown.
4. DISCUSSION

The objective of this study was to investigate the influence of the extension of the restoration in the pulp chamber and the type of outline on the load to failure of severely compromised endodontically treated molars after extensive cyclic loading. No significant effect of the depth of extension in the pulp chamber or the outline on the load to failure could be demonstrated, hence the first hypothesis cannot be rejected. The second hypothesis, that there would be no difference in mode of failure between the control and treatment groups, has to be rejected. The specimens from the control group fractured more often favorably compared to those in the experimental groups, with almost exclusively catastrophic failures. Few studies investigated the influence of the endocrown extension on fracture or fatigue loading in the posterior region. One study performed no aging of the specimens, while the other studies aged the specimens by thermomechanical aging using a chewing simulator. Of the studies concerning load to fracture, three studies could demonstrate an influence of the endocrown extension. A 3mm extension of lithium disilicate molar endocrowns resulted in a significant lower load to fracture, as compared to a 2mm and 4mm extension (762.8±240N, 843.4±106N and 943.5±110N respectively) when loaded at a 45 degree angle. The odds for a repairable fracture in the 2mm group were respectively 2.5 times and 5.5 times higher as compared to the 4mm and 3mm extensions. This suggests a more favorable outcome when the endocrown is only extended 2mm in the pulp chamber. However, in the present study, no difference in terms of fracture load between the extensions was found. This could be due the effect of aging, the application of IDS or the use of a direct composite as a luting agent.

Thermomechanical aging contributes to slow crack propagation and stress corrosion in the brittle restorative material and results in lower fracture loads for glass-ceramics. Since the high number of cycles (1,2x10^6), subcritical crack growth might be a contributing factor for the lack of a significant effect. As for the IDS, it is shown that it results in a higher bond strength compared to a procedure where dentin bonding is applied during the cementation of the indirect restoration (delayed dentin sealing). IDS also contributed to a higher fracture load of lithium disilicate restorations on molars. Additionally, a direct microhybrid composite was used to bond the endocrowns to the prepared molars. The microtensile bond strength of glass-ceramic inlays bonded to dentin with a direct composite resin was significantly higher compared to luting with a dual-curing composite cement. Ceramic laminate veneers also performed with higher load to failure and longer survival times in accelerated fatigue testing when luted with a direct composite instead of a dual-polymerizing composite resin cement. It was shown in vitro that photopolymerisation of a direct composite under 9mm thick glass-ceramic endocrowns was feasible with an extended curing time (90 seconds per side), as was done in the current study.

In the study of Dartora, lithium disilicate molar endocrowns with an extension of 5mm (2008.6±427.9N) performed significantly better compared to an extension of 1mm (1268.2±551.2N) when loaded occlusally. No significant difference existed between a 3mm (1795.4±761.7N) or 5mm extension. A possible explanation for this difference, is the use of a glass ionomer to fill the pulp chamber. Glass ionomers have less mechanical strength than direct composite. When used as a base for indirect restorations on endodontically treated molars, it can result in significant lower loads to fracture than when direct composite is used within the pulp chamber.

All specimens predominantly exhibited catastrophic failure. For premolars, a 5mm deep lithium disilicate endocrown performed with significantly higher fracture loads than a 2.5mm deep endocrown. However, 2.5mm endocrowns resulted in more repairable failures, while the 5mm group exclusively failed unfavorable. In contrast, in the same study, CAD/CAM composite endocrowns performed significantly better with a 2.5mm extension as compared to a 5mm extension. The mean loads to fracture were very low for all groups (ranging between 90 and 300N). The authors acknowledged the general low values and attributed this to the vigorous aging protocol (1.2x10^6 cycles; 1.6 Hz), the 45 degree oblique load and the lack of ferrule. All outlines were located exclusively in dentin and no IDS was applied. In the current study, the O/D group performed not significantly different as compared to the other experiment groups. Apart from the difference in adhesive protocol, this is probably accounted for by the smaller pulp chamber dimensions and thinner walls of premolars as compared to molars.

Stepwise fatigue loading might be a more valid test method than static load to failure tests to predict the in vivo performance of indirect restorations. However, Rosentritt et al.
Compared in vivo survival rates with in vitro simulations for lithium disilicate fixed partial dentures. The authors concluded that thermomechanical aging by 1,200,000 cycles with a load of 35N in a chewing simulator provided a sufficient prognosis of probable clinical failures during five years of function. All specimens in this study survived the aging process, even though the load applied in this study was higher (50N). On the other hand, maximum whole tooth load can vary between 70.6 and 146N during normal function.17

One study19 investigated the influence of the endocrown extension on the survival during stepwise fatigue loading. Endodontically treated premolars were restored with lithium disilicate overlays (no retention in the pulp chamber), endocrowns with an extension of 2mm and 4mm and classical crowns with a post and core build-up. No ferrule was obtained and all restorative margins were in dentin. Dentin was sealed prior to impression taking using IDS. After restoration, specimens were thermomechanically aged using a chewing simulator (600,000 cycles, 49N, 1.7Hz; 1500 thermo-cycles, 5–55 °C) and subsequently subjected to stepwise fatigue loading. Four out of twelve overlays debonded during aging in the chewing simulator, whereas the other experiment groups all survived. During stepwise fatigue loading, no difference in survival was found between groups. The authors concluded that the use of flat overlays should be discouraged on endodontically treated premolars but that 2mm and 4mm endocrowns and classical crowns perform equally well in terms of fatigue resistance. All specimens failed exclusively unrestorable.

Among the same extension groups (0/E versus 0/D, 2/E versus 2/D and 4/E versus 4/D) there was no significant difference in the mean surface area for adhesion. This indicates a fairly uniform sample per extension, with only the type of outline (enamel or dentin) varying. Although there is an increasing trend in the mean surface area when the extension in the pulp chamber increases (see Figure 5), only significant differences existed between the 0mm and 4mm groups. This suggest a limited increase in surface area when the pulp chamber is incrementally prepared 2mm in depth and might be a contributing factor that no difference in load to fracture was found between the varying extensions. On the other hand, no significant differences in load to fracture were found between the 0/D (worst case scenario for extension and outline) and 4/E (best case scenario for extension and outline), even though the latter had significant more area available for adhesion. When taking the unfavorable loading angle (45 degree), the thermomechanical aging and the lack of ferrule into account, the performance of the 0/D group is remarkable.

The angle of 45 degree was chosen to concentrate the stress more on the cervical area of the tooth, which might aid in a better discrimination between the different extensions.16,30 A possible explanation is the use of IDS. This finding is corroborated by the difference in clinical performance of glass-ceramic endocrowns with2 and without1 IDS. When no IDS was used, 14 (16%) out of the 87 endocrowns debonded in an up to 7.5-year clinical study.2 A direct composite was used to lute all indirect restorations. In order to ensure a sufficient polymerization, an extended curing time of 6 minutes was used. The authors noted that these adhesive failures occurred between the composite and the dentin and that the cured composite remained on the intaglio surface of the endocrowns. In contrast, only 2 (2%) out of the 99 endocrowns cemented in conjunction with IDS debonded in an up to 10-year clinical study.2

From a clinical point of view, it is important to realize that a 4mm extension might not be possible in a number of cases, without the risk of perforating the furcation area. Moreover, when no rubberdam is used during the preparation, gutta-percha might be exposed resulting in reinfection of the root canal system. On the other hand, preparation of the pulp chamber aids in a clear path of insertion of the restoration during cementation which makes the bonding easier. Also, preparation is sometimes dictated by esthetic demands and previous crowns, where a chamfer preparation is necessary. A ferrule might aid in a higher load to failure, but can compromise the internal fit of the final restoration.21

Within the limitations of this in vitro study, the extension in the pulp chamber does not seem to contribute to fracture resistance of lithium disilicate endocrowns. One must take into account that the clinical situation is far more complex and that the prognosis of an adhesive restoration is influenced by a number of variables, including patient risk factors and operator variables.22,23 These might be more important than tooth level variables. Future clinical studies should take these risk factors into account.

5. CONCLUSIONS

Within the limitations of this in vitro study, the following could be concluded:

- Extension of the restoration in the pulp chamber did not significantly influence the load to fracture of glass-ceramic (endoc)crowns after extensive thermomechanical aging;
- The type of outline did no significantly influence the load to fracture of glass-ceramic (endocrowns) after extensive thermomechanical aging;
- There was no significant difference in failure mode between the experiment groups, all failures were predominantly catastrophic.
REFERENCES


