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Performance of Monolithic and Veneered Zirconia Crowns After Endodontic Treatment and Different Repair Strategies

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Clinical Relevance

Two-step repair fillings with silica coating, silanization, and bonding provide improved fracture loads in monolithic and better marginal integrity in veneered zirconia restorations than one-step fillings. Monolithic restorations provide higher fracture loads but require more time for access preparation.

SUMMARY

Objectives: To investigate failure loads of monolithic and veneered all-ceramic crowns after root canal treatment and to analyze marginal integrity of repair fillings.

Methods and Materials: Seventy-two human molars were restored with monolithic (Zr-All) or veneered (Zr-Ven) zirconia crowns. Molars were assigned to six groups (n=12 per group) depending on restoration material, access type (no access cavity [control] or endodontic treatment [test]), and type of filling (one-step [1-st] or two-step [2-st]). For type of filling, molars were treated using a self-etch universal adhesive and cavities were either filled with layered composite (1-st) or filled until the crown material was reached, which was additionally conditioned and then filled (2-st). Scanning electron microscopic analysis of the restoration margins was performed before and after thermomechanical loading (TML), and the percentage of continuous margins was assessed. Crowns were then loaded to failure.

Results: Preparation of the access cavity required more time in monolithic (445 s) than in veneered crowns (342 s). Loads to failure were higher in control groups (Zr-All: 5814 N; Zr-Ven: 2133 N) and higher in monolithic test (2985 N) than in veneered test crowns (889 N). In monolithic crowns, 1-st had lower fracture

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loads than 2-st fillings (2149 N vs 3821 N). Continuous margins of 66% to 71% were achieved, which deteriorated after TML by 39% to 40% in Zr-All, by 34% in Zr-Ven-1-st, and by 24% in Zr-Ven-2-st.

Conclusions: Endodontic access and adhesive restorations resulted in reduced fracture load in monolithic and veneered zirconia crowns. Two-step fillings provided higher fracture loads in Zr-All and better marginal quality in Zr-Ven crowns.

INTRODUCTION

The need for root canal treatment (RCT) is one of the most common biological complications following reconstructive treatment and may lead to subsequent technical complications with veneering fractures after preparation of the endodontic access cavity.[1] Among abutment teeth initially positive for sensitivity testing, approximately 11% required RCT during an observation period of 10 years.[2] For single-crown abutments, the pulp survival rate reached 84.4% after 10 years and 81.2% after 15 years, while abutments in fixed dental prostheses (FDP) had a lower pulp survival rate of 70.8% after 10 years and 66.2% after 15 years.[3] The increased risk of pulpal necrosis following abutment preparation is related to an additive effect of several noxious agents, such as caries, repeated fillings, periodontal disease, and physical or restorative trauma.[4,5] Extensive reduction of the tooth structure to facilitate a similar path of insertion in long-span FDP or to provide sufficient space for all-ceramic restorations is another potential cofactor.[3,6]

In a recent review, factors influencing damage around endodontic access cavities and fracture resistance of all-ceramic crowns after access repair were investigated.[7] Although the authors were not able to provide a "best practice" clinical protocol, decisive factors were identified, such as the crown material and its adhesive potential, the cement material used, damage along the access cavity, and the ratio between cavity and crown size.[1,8-12] Further, the grit size of the diamond bur used for access preparation[9] and the filling technique to restore the access cavity[13] have been documented to influence fracture resistance of all-ceramic crowns. While glass ceramic crowns had lower fracture resistance than zirconia restorations,[14] veneered (bilayered) zirconia was not as resistant as monolithic zirconia.[8,15] In lithium disilicate glass ceramics, the use of larger-grit rotary diamonds (180 μm) reduced the failure load of bonded restorations to 2354 N as compared to small-grit diamond burs (126 μm, 3464 N).[9] In zirconia restorations, external stress from grinding induces a phase transformation from tetragonal to monoclinic and is associated with a 4% increase in volume. This volume increase results in compressive stresses and increased fracture toughness. Crack propagation occurs only when these clamping constraints are surpassed and stress factors exceed arresting factors.[16,17] Following RCT, an adhesive composite filling restoration should provide successful endodontic outcome, re-establish crown stability, and ensure crown retention.[13,18-21] To meet these requirements, a variety of techniques for pretreatment of the restoration have been examined, including etching or sandblasting of the surface as well as the application of special bonding agents.[20,22] While surface sandblasting with an aluminum oxide powder created microretention,[20,22] corundum particles coated with silicium oxide (CoJet, 3M ESPE, Rüschlikon, Switzerland) led to a retentive silicated surface and, in combination with a silane, enabled a chemical connection to the filling material.[23-25]

The aim of this experimental study was to investigate the fracture load of monolithic and veneered all-ceramic crowns following RCT and access cavity filling and to analyze the marginal integrity of one- or two-step repair fillings before and after thermomechanical loading (TML).

METHODS AND MATERIALS

Ethical approval was obtained for the use of extracted teeth for material testing of dental restorations. Seventy-two extracted human mandibular molars that had no caries, fractures, fillings, or restorations were selected. Teeth were kept in 0.1% thymol suspension for disinfection and to prevent dehydration.[26] The specimens were divided into six groups (n=12 per group) and labeled according to the intended crown restoration type and the filling procedure (group 1: Zr-All; 2: Zr-All-1-st; 3: Zr-All-2-st; 4: Zr-Ven; 5: Zr-Ven-1-st; 6: Zr-Ven-2-st; Figure 1).

Preparation of Specimens, Crown Fabrication, and Cementation

To simulate the periodontal ligament, a gum resin (Anti-Rutsch-Lack, Wenko-Wenselaar, Hilden, Germany) was applied in a thin layer on the root surface. To fix the specimens in the loading device, the roots were embedded in acrylic resin (Dermotec 20, Dermotec Siegfried Demel, Nidderau, Germany). Teeth were prepared for crown restoration by two

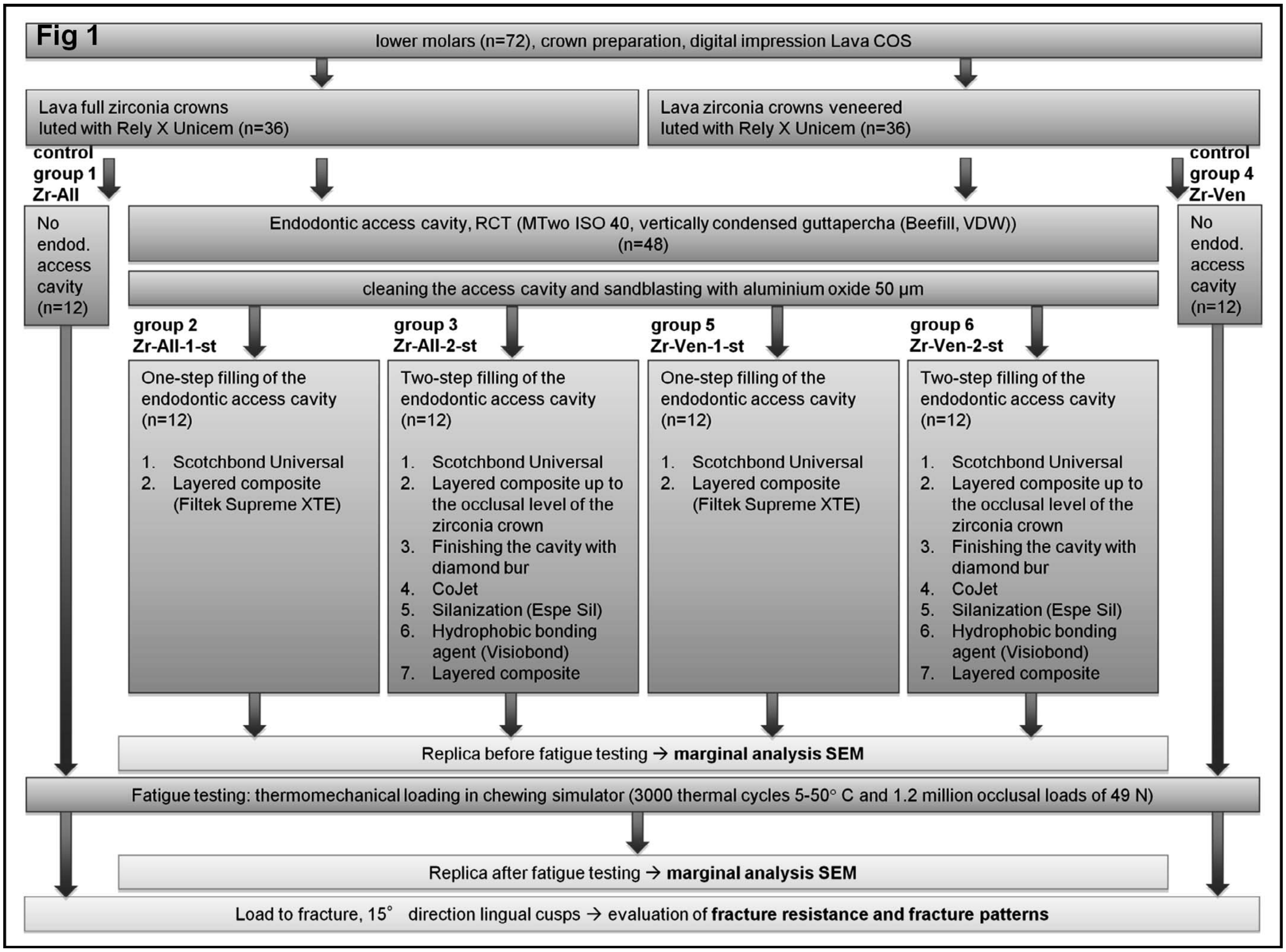

Figure 1. *Schematic overview of the study design and group treatment.*

operators (AS and AH) according to the guidelines for Lava All-Zirconia restoration (3M ESPE). A circular shoulder preparation of 1 mm (horizontally) was performed along the cemento-enamel junction using cylindrical burs (no. 307 [106-µm grit] and no. 4315 [40 µm-grit]; Intensiv, Grancia, Switzerland). Football-shaped diamonds were used for the preparation of the occlusal relief (no. 4250 [40-µm grit], no. 5250 [15-µm grit]; Intensiv). While the no. 307 bur was used only twice, the nos. 4315, 4250, and 5250 burs were used a maximum of four times. Standardization of a similar preparation was ensured using a silicon key (Affinis putty, Coltène, Whaldent, Altstätten, Switzerland) made from the original crown contour, which was sectioned and applied during substance reduction to illustrate sufficient clearance.

Digital impressions of all specimens were taken with the Lava scanner (3M ESPE). In groups 1 to 3, the monolithic zirconia crowns representing the anatomic contour of a mandibular molar were designed and computerized, ensuring a minimal crown thickness of 1 mm. Crowns were milled from ceramic blocks (Lava, 3M ESPE), and the surfaces were finally glazed. For groups 4 to 6, 3M zirconia copings of 0.5-mm thickness were manufactured (Lava, 3M ESPE). A professional dental technician (Diethard Schwarz, Dental Laboratory, Velden/Vils, Germany) conducted the feldspathic porcelain veneering at a minimal thickness of 0.5 mm with final glazing. Before cementation, the crown thickness of each specimen was measured in the area of the endodontic access with a thickness gauge (M&W Dental, Illnau, Switzerland). The prepared abutment surface was cleaned with pumice mixed with Ringer's solution (Ringer Ecotrainer Plus, B. Braun, Maria Enzersdorf, Austria), rinsed with water, and air-dried. The restorations were degreased with trichloroethylene (Merck KGaA, Darmstadt, Ger-

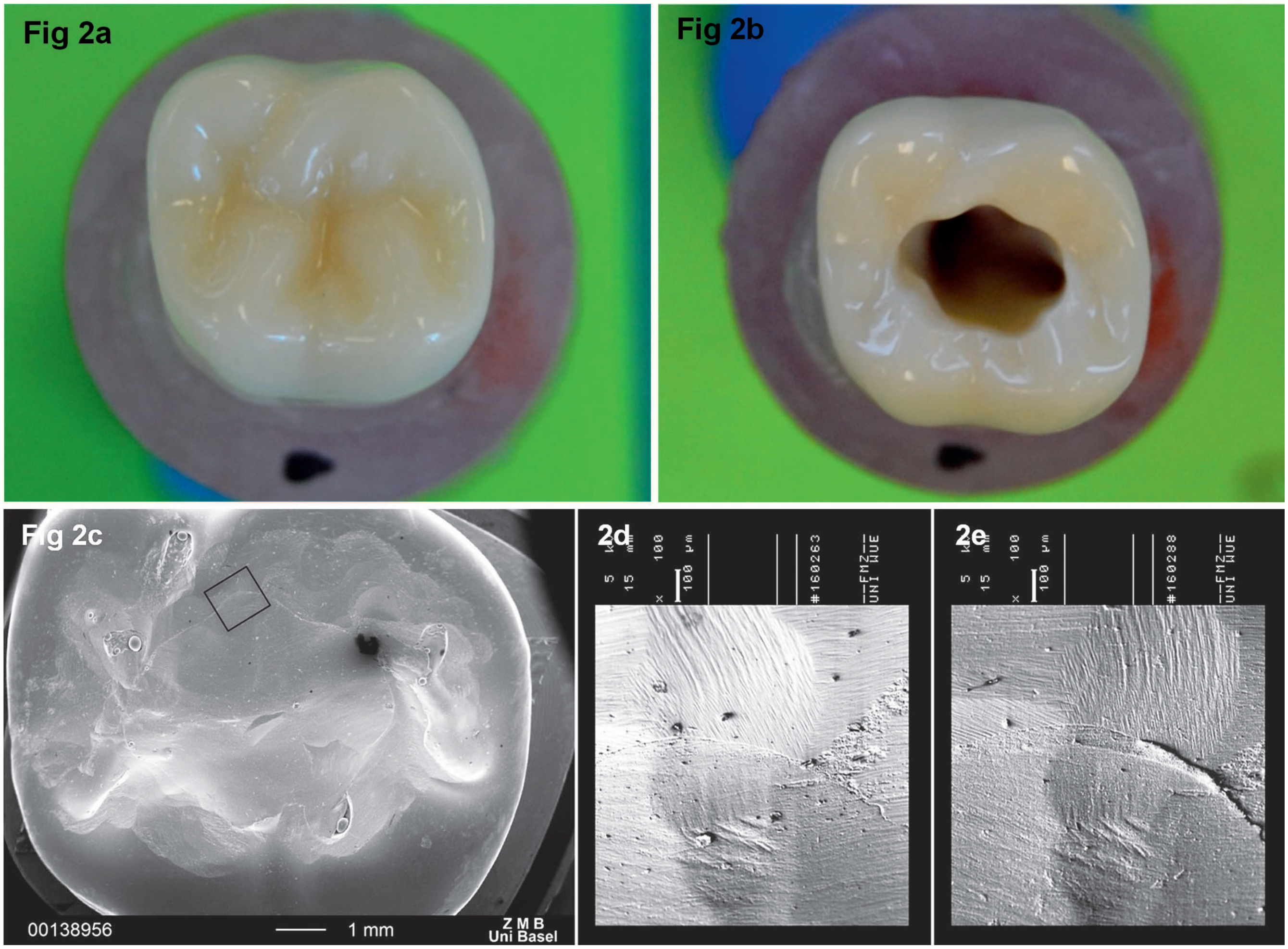

Figure 2. *(a): Sample (no. 3) of group 2 Zr-All-1-st crown after cementation. (b): Endodontic access and cavity preparation. (c): Overview with scanning electron microscope; detail indicated by square. (d): Detail of the restoration margin with 100% continuous margin before thermomechanical loading. (e): Same area after thermomechanical loading with proportion of continuous margin reduced to 53%.*

many) and cemented with a self-adhesive resin cement (RelyX Unicem, 3M ESPE).[1] After initial light curing for two seconds (Bluephase C8, Ivoclar Vivadent, Schaan, Liechtenstein), excess cement was removed, and final light curing was performed with 800-mW/cm^2 light intensity from four directions for 20 seconds each. Photographs and periapical radiographs (Insight Dental film, Kodak, Rochester, NY, USA) were taken, and after 10 minutes, the specimens were stored again in the 0.1% thymol suspension.

Endodontic Access, Root Canal Treatment, and Restoration of the Endodontic Access Cavity

The endodontic access preparation was performed by two operators (AS and AH) applying a standardized trapezoidal access shape for mandibular molars. A new cylindrical diamond (no. 307 [106-μm grit], Intensiv) was used for each specimen in a high-speed hand piece (40,000 min^{-1}) under water cooling (Figure 2a,b). The time required to penetrate the crown and complete the access cavity with all root canal entrances was recorded in seconds. Root length was defined based on the radiograph. Root canals were prepared using rotary instruments (Mtwo, VDW, Munich, Germany) up to a master apical file 40/04. Between the different instrument sizes the canals were flushed with 10 mL sodium hypochlorite (1%, Caelo, Hilden, Germany). The root canals were dried with paper points, coated with sealer (AH Plus, Dentsply De Trey GmbH, Konstanz, Germany), and filled with BeeFill 2 in 1 gutta-percha (BeeFill Gutta-percha cartridge, VDW) by the warm vertical compaction technique. The gutta-percha filling was then reduced with a round bur (0.9-1.4-mm diameter, Komet, Lemgo, Germany) up to 1 mm underneath the root canal orifice to increase the adhesive surface for the filling material. The access cavity was finished with cylindrical burs (no. 307 [106-μm grit] and no. 4315 [40-μm grit], Intensiv) and sandblasted with 50 μm Al_2O_3 particles (Dento-Prep, Ronvig, Daugaard, Denmark) to remove any remnant of sealer or gutta-percha and to increase adhesion. To generate adhesion to both dentin and the ceramic surface, a novel self-etch universal adhesive containing the functional monomer 10-methacryloyloxydecyl dihydrogen phosphate (10-MPD) and silane (Scotchbond Universal, 3M ESPE) was applied for 20 seconds, gently air-dried for five seconds, and light cured with Elipar S10 (3M ESPE) for 10 seconds. The endodontic access cavities were then filled with a one- or two-step filling procedure, applying 2-mm layers of a universal composite (Filtek Supreme XTE, 3M ESPE). With the one-step procedure, the cavity was filled with several layered increments. For the two-step procedure, composite layers were applied until the level of the ceramic material was reached. The remaining cavity was then conditioned with silica coating (CoJet Sand, 3M ESPE), water sprayed and air-dried, silanated (ESPE Sil, 3M ESPE), and air-dried after one minute. A light-cured adhesive (Bonding Visio Bond, 3M ESPE) was applied for 20 seconds and light cured for 20 seconds, and the filling was finished with two oblique layers. For both techniques, the surface was finished with a fine diamond bur (no. 4250 [40-μm grit], Intensiv) and polished with Occlubrush (Kerr, Bioggio, Switzerland) and a one-step diamond paste (Unigloss, Intensiv).

Replica Before and After Fatigue Testing, Load to Fracture

An impression of the sealed endodontic access cavity was taken with a polyvinyl siloxane impression material (Affinis Regular Body). Replicas were manufactured with epoxy resin (Stycast 1266 A & B 2 Part clear epoxy, Emerson & Cuming, Westerlo, Belgium). These replicas were controlled with an optical microscope (Wild M3B, Heerbrugg, Switzerland) to ensure that the entire filling margins were visible. All specimens underwent TML in a chewing simulator (CoCoM 2, OOK, Zürich, Switzerland). Stressing comprised 1.2 million occlusal loads of 49 N at 1.7 Hz and simultaneous thermal cycling (3000 thermal cycles between 5°C and 50°C) using antagonistic natural teeth. Following TML, the specimens were visually inspected, and the presence of any ceramic chipping or fracture was recorded. An additional set of replicas was manufactured as described above. All samples were then loaded to fracture in a universal testing machine (Allround-Line, Zwick GmbH& Co., Ulm, Germany) and a 20-kN-load cell. Specimens were fixed in a metal holder with the long axis of the roots at an angle of 15° to the direction of the load. A linear load (crosshead speed of 0.5 mm/min) was applied in the direction of the lingual cusp until fracture.

SEM Analysis of Marginal Quality

All replicas taken before and after TML were sputter coated with gold (EMITECH K550 Emitech, Taunus Stein, Germany) and numbered to facilitate a blinded analysis by one of the authors (SS) not involved in the restoration procedure. The restoration margins of the endodontic access cavities were examined with a scanning electron microscope (DSM 940, Zeiss, Oberkochen, Germany) at 100× to 1000× magnification and analyzed using dedicated measurement software (RaEm, programmer Peter Müller, Würzburg, Germany). Prior to all measurements, a measuring grid (copper mesh, item no. S150, Plano, Wetzlar, Germany) was scanned, and the measurement software was normalized at 100× magnification. Images of the restoration margins were saved and measured at 100× magnification. To investigate the margin quality of the restorations, criteria modified from the classification introduced by Blunck and Zaslansky[27] were applied to distinguish between 1) continuous margin (without any signs of gap formation), 2) noncontinuous margin (hairline crack or gap), and 3) not judgeable margin (due to excess composite material or fracture).[27] Finally, the proportion of continuous margin in each specimen was calculated and presented as a percentage of the individual judgeable margin (Figure 2c through e).

Statistical Analysis

The prediction variable fracture load was log transformed as verified by preliminary analysis, including a quantile comparison plot. Descriptive statistics included means (standard deviation) for metric variables and median (interquartile range) for fracture load. Linear models were performed to predict either thickness, time for access, or fracture load; these models provided estimates of slope values (for continuous variables) or difference of means as well as ratios (for categorical variables). For the percentage change of continuous margin (after vs before TML), linear regression models were performed to compare crown (Zr-All vs Zr-Ven) and access restoration (2-st vs 1-st). The corre-

Table 1. *Results of Different Parameters in the Six Groups With Crown Thickness, Time for Trepanation, Fracture Load, and Changes in Continuous Margin Before and After Loading, Mean (Standard Deviation), and Median (Interquartile Range) for Fracture Load*

Material	Zr-All (Monolithic)				Zr-Ven (Veneered)				*p*-Value (All Groups)
	Control	Test			Control	Test			
Parameter	1 Zr-All	2 Zr-All-1-st	3 Zr-All-2-st	2 and 3	4 Zr-Ven	5 Zr-Ven-1-st	6 Zr-Ven-2-st	5 and 6	
Crown thickness (μm)	1.38 (0.35)	1.46 (0.26)	1.5 (0.33)	1.48 (0.29)	1.34 (0.19)	1.44 (0.29)	1.55 (0.23)	1.50 (0.26)	0.474
Time for trepanation (s)	—	517 (80)	374 (73)	445 (105)	—	389 (131)	295 (89)	342 (120)	0.003
Fracture load (N)	5955 (5105-6603)	1975 (1480-2335)[b]	3265 (2718-4540)[b]	2705 (1983-3698)[a]	2200 (1855-2400)	923 (601-1274)	844 (568-1008)	844 (577-1141)[a]	<0.001
Continuous margin before load (%)	—	67 (13)	71 (21)	69 (17)	—	66 (10)	67 (12)	66 (11)	0.838
Continuous margin after load (%)	—	28 (19)	31 (22)	30 (20)	—	33 (10)[c]	43 (14)[c]	38 (13)	0.148
Change in continuous margin (%)	—	39 (16)	40 (29)	40 (23)[a]	—	34 (10)[c]	24 (12)[c]	29 (12)[a]	0.121

p-*values derived from analysis of variance (*F*-test) except for the following:*
[a] *Statistically significant differences between groups 2 3 and 5 and 6 (fracture load* p<*0.001; rank sum test; change in continuous margin* p=*0.042;* t*-test).*
[b] *Statistically significant differences between groups 2 and 3 (*p<*0.001; linear regression predicting log transformed fracture load values).*
[c] *Statistically significant difference between groups 5 and 6 after load (*p=*0.038) and changes (*p=*0.043;* t*-test).*

sponding 95% confidence intervals and *p*-values were calculated for all regressions. Nested model designs were performed to separately analyze selected study groups. The level of significance was set at $\alpha = 0.05$. Adjustment of significance level for multiple comparisons was omitted because of the descriptive nature of the study. All analyses were performed with the statistical program R version 3.1.2 (R Core Team 2014).[28]

RESULTS

The occlusal crown thickness in the area of the access varied between 1.34 and 1.55 mm without significant differences among the groups (Table 1). The time to complete the access cavity was significantly longer for Zr-All crowns (groups 2 and 3) with 445.3 ± 104.5 seconds than for Zr-Ven (groups 5 and 6) with 342.3 ± 119.5 seconds (p=0.003). Visual inspection following chewing simulation revealed that ceramic chippings had occurred in the Zr-Ven groups (two crowns in Zr-Ven-1-st, four crowns in Zr-Ven-2-st), while no ceramic chipping or fracture was observed in preserved Zr-Ven crowns (control group 4) or in any Zr-All specimens (groups 1 to 3).

Load to fracture varied between 5814 ± 1084 N for Zr-All and 806 ± 273 N for Zr-Ven-2-st (p<0.001). For both materials, fracture loads were significantly higher for preserved control groups than for the test groups (Table 1; Figure 3). Fracture loads were higher for Zr-All test specimens (groups 2 and 3; 2985 N) than for Zr-Ven specimens (groups 5 and 6; 889 N; p<0.001). The comparison of one-step and two-step filling restorations within the different crown materials revealed significantly higher fracture loads for Zr-All-2-st than for Zr-All-1-st, while no difference existed between the two procedures in the Zr-Ven groups 5 and 6 (Table 1).

The relative proportion of continuous margin along the endodontic access restoration varied between 66% and 71% before TML and was reduced to 28% to 43% after TML (Table 1; Figure 4). The deterioration of the marginal quality was greater in the Zr-All groups with 40% change compared with the Zr-Ven groups with 29% change of continuous margin (p=0.042; Table 1). The reduction in the proportion of continuous margin was significantly greater with the one-step procedure (Zr-Ven-1-st 34%) than with the two-step procedure (Zr-Ven-2-st 24%; p=0.043).

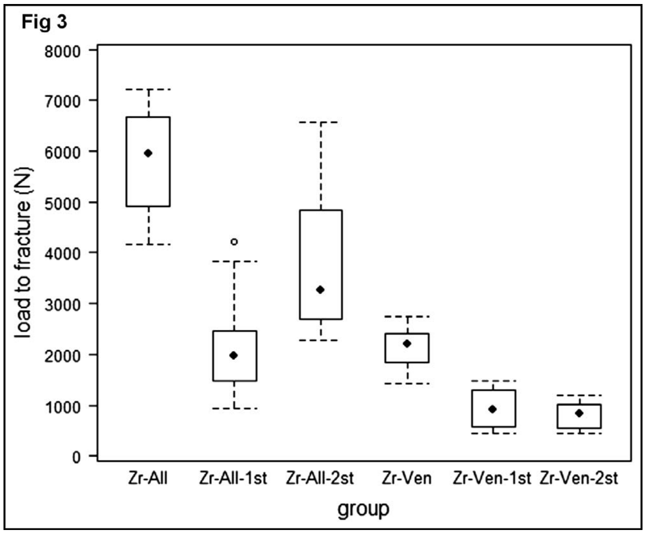

Figure 3. *Box plots of loads to fracture in groups 1 to 6.*

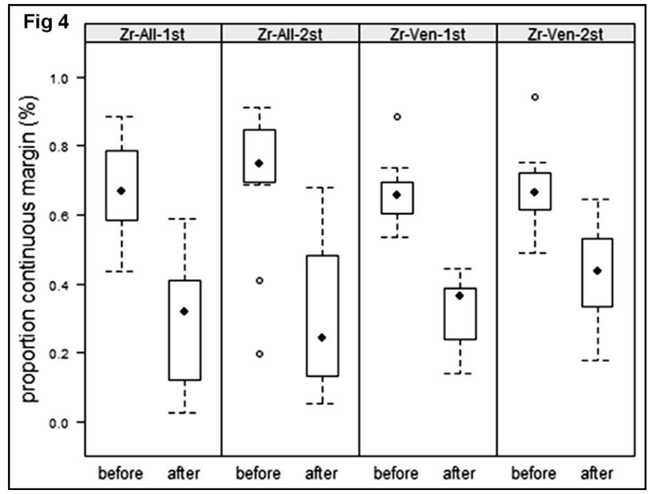

Figure 4. *Box plots of proportions of continuous margin before and after thermomechanical loading in groups with repair fillings (groups 2, 3, 5, and 6).*

DISCUSSION

The aim of this *in vitro* experiment was to compare monolithic and veneered zirconia crowns after access cavity preparation, RCT, and repair fillings. It was observed that preparation of the access cavity required more time in monolithic than in veneered crowns. Furthermore, loads to failure were significantly higher in monolithic crowns than in veneered crowns, and the two-step filling technique had a positive influence on fracture resistance with monolithic crowns. While an approximately two-thirds-perfect margin of the repair filling was initially achieved with either technique, thermomechanical load resulted in a deterioration of the marginal quality, particularly in the Zr-All groups, while the two-step filling procedure provided better marginal integrity in veneered crowns.

In the present *in vitro* study, extracted human teeth were used. Each tooth was individually prepared, and crown specimens were fabricated with computer-assisted design and manufacturing in accordance with the manufacturers' guidelines. A possible limitation of the current study protocol is that a certain variation in abutment dimensions and crown thickness existed. In other experimental studies, standardized epoxy or composite resin dyes with similar crown specimens were used and RCT was simulated.[1,9,10] In the present study, RCT was performed in groups 2 to 5 to ideally reflect the clinical situation. For the preparation of the endodontic access cavity, new burs were used for each specimen to ensure comparability, while repeated use of burs is common practice in the clinic. The coarse-grit diamonds of 106 μm that were used provided adequate access without weakening the ceramic integrity but may have resulted in marginal microfractures. However, the documented preparation time of 7.25 minutes for monolithic zirconia crowns and 5.42 minutes for veneered zirconia crowns would have been even more prolonged with the use of smaller grit sizes. To avoid heat-induced crack initiation and propagation in the ceramic material, the use of a diamond bur with sufficient water cooling has been recommended.[11,29-31] Carbide burs were found to be ineffective and associated with a higher risk of fractures and craze lines, particularly in glass-ceramic materials.[7,11,12] In an experimental study using lithium-disilicate crowns (IPS e.max CAD) cemented with dual-polymerizing resin cement (Multilink Implant, Ivoclar Vivadent), the use of a 126-μm-grit-size diamond rotary instrument and subsequent composite filling restoration did not affect fracture load (3464 N) as compared to the unprepared control (3316 N), while failure loads were reduced to 2915 and 2354 N when using coarse-grit diamonds of 150 and 180 μm, respectively.[32] In the study by Qeblawi and others,[32] destructive experimental testing was applied without any artificial aging, which is known to have a considerable impact on the values generated in load-to-fracture tests.[33] In the current experimental protocol, cyclic loading within physiological limits and simultaneous thermocycling was selected, and the periodontal ligament was simulated to mimic oral cavity conditions.[34] These factors may be responsible for the observed reduction in fracture loads among repair restorations, with none of them being able to restore the maximum load capability to the same level as was recorded for the specimens without endodontic access cavity.

In a recent review of *in vitro* studies, protocols were assessed with regard to fracture resistance of endodontically accessed and repaired all-ceramic crowns.[7] In addition to the initial baseline strength of the ceramic material, the application of adhesive cementation techniques, the size of the access cavity in relation to the crown size, and the residual tooth structure were discussed as potential key factors influencing fracture resistance.[7] In the current study, higher fracture resistance was found with monolithic compared to veneered all-ceramic crowns. Following endodontic access and cavity restoration, veneered crowns demonstrated reduced fracture values of 955 and 806 N, which is close to the maximal bite forces of 807 $\pm$ 140 N in the molar region of 20- to 24-year-old males[35] but exceeds normal chewing forces ranging from 70 to 150 N.[36] Previous studies have demonstrated favorable mechanical properties for monolithic crowns compared to veneered all-ceramic restoration.[14,15] Highest loads to fracture were documented for monolithic zirconia crowns (6517 N), while for the two veneered designs with or without a cervical collar of zirconia, average values of 4712 and 4091 N, respectively, were achieved.[15] For veneered Procera crowns cemented with Rely X Luting Plus cement (3M ESPE) on epoxy resin dies and provided with repair fillings, the endodontic access did not influence failure loads of alumina crowns (1459 N control, 1531 N with access restoration), while data for zirconia showed differences with 2514 N for the unprepared control and 2246 N for the repaired crowns.[1]

In the current study, ceramic chipping during TML occurred in six out of 24 veneered and prepared crown specimens, while no chipping fractures were observed in the unprepared control group Zr-Ven and in none of the monolithic crowns. Edge chipping around the endodontic access restoration was also observed when Procera crowns were loaded to failure.[1] In this experimental study, Procera crowns were fabricated based on alumina and zirconia copings with the veneering porcelain pressed over the copings.[1] In alumina crowns, core fractures and veneer shear were observed, while with zirconia copings, the veneering delaminated frequently from the core.[1] Analyzing the occlusal surface following endodontic access preparation in monolithic and veneered zirconia three-unit FDP also demonstrated that more microfractures and chippings occurred in veneered restorations.[8,11] Achieving durable bonding to zirconia restorations is challenging, and despite a wide variety of recommended surface conditioning methods, to date no universally accepted protocol exists.[37] In the present study, both repair methods applied for restoration of the access cavities of the monolithic zirconia crowns showed favorable results in terms of percentage of continuous margins. However, gap formation significantly increased under *in vitro* stress conditions, confirming previous studies that revealed that artificial aging affects the bonding effectiveness to zirconia.[38,39] For the one-step protocol, a universal adhesive containing the phosphate-based functional monomer 10-MDP was selected because of its proven chemical bonding capability to zirconia. However, since 10-MDP is one among many ingredients mixed into one solution, bond durability to zirconia is inferior compared to dedicated ceramic primers based on the same monomer.[38] These factors are possibly responsible for the rather low marginal quality achieved in group Zr-All-1-st after TML.

For the veneered zirconia crowns, both repair protocols used in the present study comprised silanization because there is consensus that application of a silane after mechanical conditioning of the veneering porcelain is crucial to achieve a chemical bond to the composite resin.[40] In the one-step protocol, the silane is incorporated into the formulation of the utilized adhesive Scotchbond Universal. In this group, marginal quality was inferior, though not statistically significant, compared to the two-step approach. These findings are comprehensible since there is recent evidence that the silane coupling agent in universal adhesives is less efficient compared to dedicated silanes.[41-44]

CONCLUSIONS

It can be concluded that the two-step repair filling with silica coating, silanization, and bonding of the marginal crown material led to improved fracture loads in monolithic zirconia crowns and better marginal integrity in veneered zirconia restorations as compared to the one-step filling. While monolithic restorations provided generally higher fracture loads and no chipping fractures, more time was required for preparing the endodontic access cavity than in veneered zirconia crowns.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of the Ethik beider Basel. The approval code for this study is EK 221/12.

Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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