Effect of Preparation Design on the Fracture Resistance of Zirconia Crown Copings

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The aim of this *in vitro* study was to evaluate the effects of different preparation designs on the fracture resistance of single-crown zirconia frameworks. To this end, maxillary molar dies of CrCo alloy were fabricated with five different preparation designs: shoulderless, slight and pronounced deep chamfer, beveled and non-beveled shoulder. Ten zirconia copings with a wall thickness of 0.4 mm were fabricated for each type of preparation. After cementation by glass ionomer cement, they were loaded until fracture.

There were significant differences in the breaking load of the experimental groups (ANOVA, p<0.01). The shoulder preparation had a mean breaking load of 2286 N, the shoulderless preparation 2041 N, the beveled shoulder 1722 N, the pronounced deep chamfer 1752 N, and the slight chamfer 1624 N.

Based on the results of this study, a shoulder preparation is highly recommended whenever possible. Moreover, for endodontically treated teeth that are structurally compromised or which have anatomically limited areas, the slight chamfer preparation is an optimal recommendation.

Key words: Preparation, Zirconia, CAD/CAM

INTRODUCTION

All-ceramic restorations offer excellent esthetics and have been successfully used for restoring anterior and posterior teeth[1-6]. Pressable glass-ceramic and glass-infiltrated ceramic materials are used as adhesively retained inlays, partial crowns, single crowns, and small bridges in the anterior region[2,4]. In particular for zirconia, it can be used for virtually any type of fixed restoration and high-performance applications due to its superior mechanical properties[7-10]. Similar to the technique employed in the construction of metal-ceramic restorations, zirconia-based restorations use high-strength ceramic material for the framework in order to provide sufficient resistance against cyclic loading.

The strength of an all-ceramic restoration depends not only on the fracture resistance of the material, but also on a suitable preparation design with adequate material thickness. The assumption that increased material thickness automatically produces greater strength was disproved by an *in vitro* study. Crowns made from pressable leucite-reinforced ceramic (IPS Empress, Ivoclar Vivadent, FL-Schaan) were tested for fracture resistance as a function of shoulder width. An increase in Weibull modulus was found for the more delicate preparations[11]. Friedlander and Doyle also investigated the influence of different preparation designs on the fracture resistance of glass-ceramic crowns[12-14]. Highest values were observed for

the following preparation design: total occlusal convergence angle of 10 degrees and a 1.2 mm shoulder finish line with sharp axiogingival line angle. On the other hand, other authors preferred a shoulder preparation with a round axiogingival line angle, which might be more suitable for all-ceramic restorations from a theoretical point of view[15]. As for the manufacturers, most would advise a pronounced deep chamfer preparation for all-ceramic materials. In the same vein, there was evidence that chamfer finish lines, like shoulder finish lines, affected the mechanical stability of crowns[16].

On leucite-reinforced ceramic or glass-infiltrated alumina molar crowns, an *in vitro* study reported that their resistance to fracture was irrespective of preparation design[17]. However, on zirconia-based restorations, there is a lack of scientific data. The aim of this study, therefore, was to evaluate if fracture resistance of yttria tetragonal zirconia polycrystal (Y-TZP)-based single crowns in the molar region was influenced by the standard types of preparation designs.

MATERIALS AND METHODS

Tooth preparation

Five acrylic maxillary right molars (Frasaco, Tettnang, Germany) were prepared using the different preparation finishing lines to be tested: shoulderless, slight chamfer, pronounced deep chamfer, shoulder, and shoulder with bevel (Fig. 1).
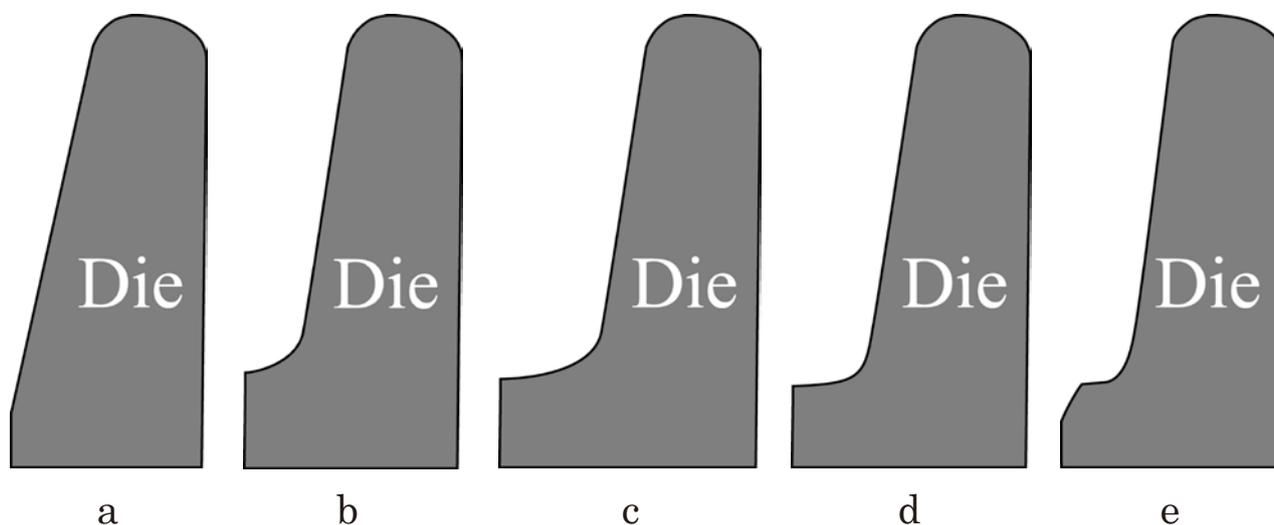
Fig. 1   Schema of tooth preparations
(a; shoulderless, b; slight chamfer, c; pronounced deep chamfer, d; shoulder, e; beveled shoulder)

As recommended by the manufacturer, the circumferential preparation depth was 1.0 mm — except for the shoulderless preparation and the slight chamfer preparation which had 0.5 mm removed. The anatomical shape of the occlusal surface was reduced by 1.5 mm. Preparation angle of the axial walls was set to 10 degrees with a parallel milling machine (Degussa F1, DeguDent, Hanau, Germany). For the beveled shoulder preparation, the margin was beveled to 1.5 mm.

Duplicate molds of the prepared teeth were made. Wax (Nawax Compact, Yeti Dental, Engen, Germany) was poured into the molds, and then 10 tooth dies were cast in CrCo alloy (Remanium 800, Dentaurum, Ispringen, Germany) for each type of preparation. Metal dies were embedded in an auto-polymerizing resin (Paladur, Heraeus Kulzer, Hanau, Germany). Preparations on the metals dies were then retrimmed on the parallel milling unit with tungsten carbide finishers (Komet H 356 RGE 103.031, Brasseler, Lemgo, Germany) to smooth out sharp edges and junctions. Thereafter, casting blows and flashes were removed.

Zirconia framework fabrication
Impressions of the test models were taken using a polyether impression material (Impregum, 3M ESPE, Seefeld, Germany), and a stone definitive cast (Everest Rock, KaVo, Biberach, Germany) of each tooth die was fabricated for scanning. This special scannable die stone material (Everest Rock, KaVo, Biberach, Germany) was used to achieve the best possible scan results. Scanning was done using a multi-lightband projector scanner (Everest Scan, KaVo, Biberach, Germany). Settings for the copings were: wall thickness of 0.4 mm and virtual cement layer of 35 μm.

Hot isostatic pressed (HIP) zirconia blanks (Everest ZH 16; KaVo, Biberach, Germany) were milled and then ground by diamond tools (Diamond Grinding Pin 1 ZH/Pin 2 ZH, KaVo, Biberach, Germany). The frameworks were fitted to stone dies. Frameworks which could not be adapted within five minutes were rejected. Adaptation was performed by an experienced dental technician under original magnification ×8 (Stemi DV4, Zeiss, Gottingen, Germany) according to published literature[18-20]. Adaptation was considered accomplished when two or more investigators determined — by visual inspection — that no marginal gaps were visible and that retention would be lost if further adjustment were made.

To identify areas that needed correction, a lipstick (Shine Délicieux, L'Oréal, Paris, France) was applied to the definitive die and the coping was placed without force. Red lipstick markings inside the framework were then removed with a diamond rotary cutting instrument (Komet 8801014, Gebr. Brasseler, Lemgo, Germany) under water spray to protect the zirconia framework from heat damage. This procedure was repeated until the indicated markings disappeared, and a uniform and even contact of the coping on the die was achieved. After each refinement, color was removed from the die using a steam cleaner.

All copings were adapted by the same dental

technician. Two dental technician investigators would then determine if more correction was needed to improve the fit. In the event of a failed consensus, a supervising dentist would make the final decision. The investigators were two experienced dental technicians with more than 25 years of experience in producing copings and with more than nine years of experience in fabricating zirconia restorations. Both investigators were calibrated before the present study by dividing 50 crowns with different defined marginal openings into two groups (clinically acceptable and clinically unacceptable). Inter-examiner agreement factor was 90%. If the dental technician investigators could not reach an agreement, then an experienced dentist with more than 10 years in clinical practice would make the final decision.

Cementation with glass ionomer cement
In the present study, the zirconia copings were tested without any veneering material. This was because several studies have indicated that neither the veneering porcelain nor the thickness of the veneering porcelain had a significant effect on the compressive load to failure of bilayered crowns[21,22].

The copings were cemented conventionally with a glass ionomer cement (Ketac Cem, 3M ESPE, Seefeld, Germany) on the metal dies, which had been cleaned with steam and alcohol. All copings were filled with an excess of luting cement and then loaded with a vertical force of 50 N for 10 minutes in a cementation device to ensure the results were not affected by the different cement gap sizes[23]. All cementation was done by the same team comprising an experienced dentist, who sat the coping onto the metal die, and a dental assistant, who activated the capsule of cement and started the mixing procedure.

All restorations were stored in distilled water at a temperature of 37℃ for at least 48 hours before loading.
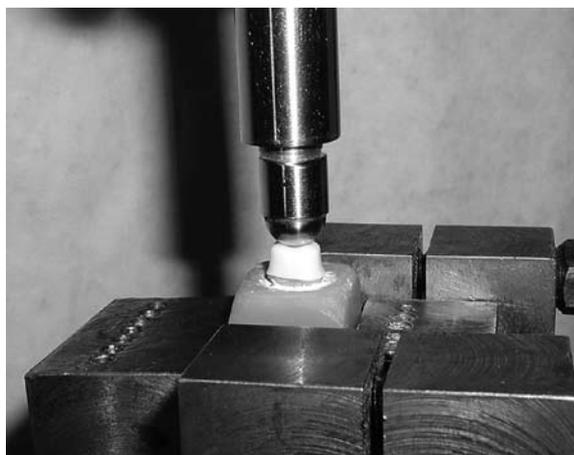
Fig. 2   Placing the loading piston on the coping in the universal testing machine.

Fracture load test
A total of 50 specimens were loaded in a universal testing machine (Type 1445, Zwick, Ulm, Germany) until total fracture occurred. The specimens were clamped in the holder of the machine and loaded vertically on the occlusal surface. As the position of the applied force has a significant influence on fracture strength results, the loading piston was positioned at the center of the occlusal surface (Fig. 2). To make sure the position was correct, it was checked by at least three examiners.

The loading piston was a vertically movable rod with a semi-spherical head 10 mm in diameter. To distribute the applied force over a larger area and to avoid loading stress peaks on the ceramic surface, a piece of 1-mm-thin polyethylene vacuum-forming foil (Copyplast 1.0, Scheu-Dental, Iserlohn, Germany) was placed between the test piston and the specimen. Thrust speed of the machine was 0.5 mm/min according to previous studies[24-26]. The universal testing machine was controlled *via* a computer software system (TestXpert program, Zwick, Ulm, Germany), which also completed the stress-strain diagram and recorded the breaking load.

Statistical analysis
Statistical analysis was carried out using a computer program (SPSS 14.0, SPSS Inc., Chicago, IL) whereby the mean, minimum, maximum, and standard deviation values were calculated. One-way analysis (ANOVA) was done to detect statistical differences between group medians based on a significance level of 5%. A *post hoc* multiple comparison test (Student−Newman−Keuls) was performed to evaluate differences between the individual groups. A qualitative analysis of the fractured copings was done using a scanning electron microscope at ×50 and ×1,000 magnification.

RESULTS

Fracture strength
The highest mean breaking force of 2286 N was observed with the shoulder preparation without a bevel, although this type of preparation also exhibited the highest standard deviation of 536 N. The beveled shoulder preparation showed a mean (SD) value of 1722 (262) N. For the shoulderless preparation, the mean (SD) value was 2041 (355) N. The pronounced deep chamfer preparation exhibited a mean (SD) value of 1752 (261) N, while the lowest mean breaking load was observed in slight chamfer preparation with a mean (SD) value of 1624 (150) N (Fig. 3).

One-way ANOVA indicated significant differences (p<0.01) between the different preparation designs at a significance level of 5% (Table 1). Student−

Table 1   One-way ANOVA of different preparation designs (level of significance: 5%)

Source	Df	Sum of squares	Mean square	F value	P value
Preparation	4	2977812	744453.8	6.5	0.000*

*: Significant difference

Table 2   *Post hoc* multiple comparison test (Student−Newman−Keuls) on fracture loads: test indicated three homogeneous subgroups (level of significance: 5%)

Preparation	Subgroup 1	Subgroup 2	Subgroup 3
Slight chamfer	1624.43		
Shoulder with bevel	1722.69	1722.69	
Pronounced deep chamfer	1752.13	1752.13	
Shoulderless		2041.77	2041.77
Shoulder			2286.64
Significance (p-value)	0.678	0.100	0.113
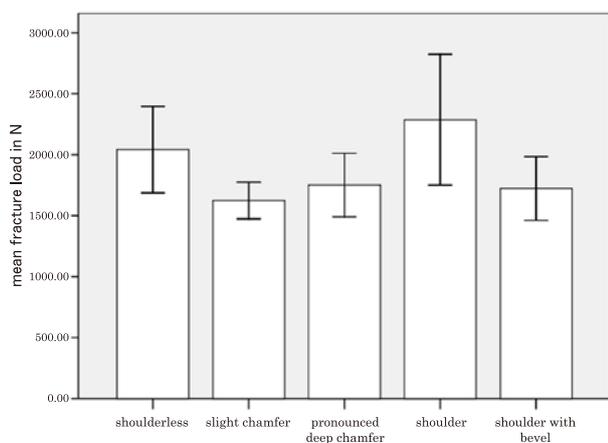
Fig. 3   Means and standard deviations of the fracture load of five different preparation designs.
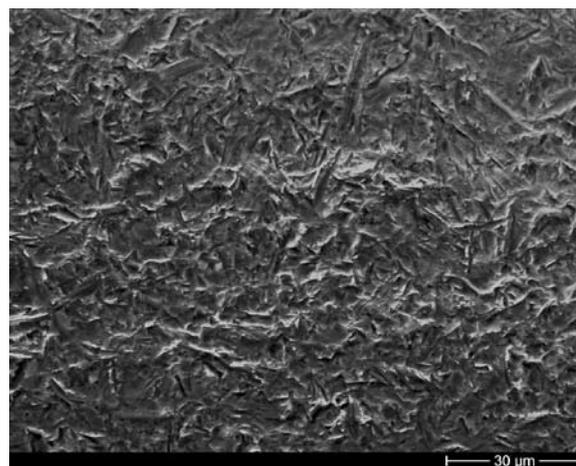
Fig. 4   SEM picture of defects caused by the milling process (magnification factor: 1000).

Newman−Keuls test indicated three homogeneous subgroups (Table 2).

Fracture analysis by SEM
By means of SEM, it was observed that fracture gaps — without exception — ran from the center of loading at the middle of the occlusal surface to the preparation margin.

SEM pictures also showed grinding-induced surface flaws which were caused by the CAD/CAM milling process as well as microcracks (Fig. 4).

DISCUSSION

The fracture strength of a clinical crown is influenced by several factors, such as cementation, loading condition, and the elastic modulus of the supporting die[27,28]. According to Scherrer and de Rijk[27], increasing the elastic modulus of the supporting material resulted in increased fracture strength[27]. In the present study, the elastic modulus of the supporting metal die was 200 GPa, which was superior to that of dentin at 12 GPa[29]. If natural teeth were used as the supporting model, the fracture strength of the copings might have been lower. As for the other factors of loading condition and cementation, they were the same for all the specimens in this study.

Milling zirconia in its dense state can cause surface defects (Fig. 4), and thus exerts an adverse influence on fracture loads[30]. In the present study, all specimens were fabricated in this way. Therefore, in the context of this study, the machining effect of zirconia might have no impact on the results between the different preparation finish lines.

This *in vitro* study demonstrated that in single molar crown frameworks fabricated from yttria-stabilized zirconia, a significantly higher fracture strength was attained with a shoulder preparation. A possible reason for this was that the occlusal forces

were also borne by the circumferential shoulder, and there was less stress concentration on the axial walls compared to other preparation designs. However, according to Student－Newman－Keuls test, the shoulderless preparation was not significantly different from the shoulder preparation. The favorable results of the shoulderless preparation might be explained by the stress distribution pattern during loading. When load on the coping was increased, the coping could slide down the axial wall of the die without being limited by the margin. This then resulted in a stress concentration on the occlusal surface of the coping. However, from periodontal point of view, the shoulderless preparation is obsolete[31].

The slight chamfer, pronounced deep chamfer, and beveled shoulder preparations did not differ significantly with regard to breaking load. This could be attributed to the adequate strength attained with preparation designs that require minimal removal of sound tooth structure, such as slight chamfer preparation. In light of this result, consideration should be given to these designs from a prophylactic point of view with emphasis on conserving tooth structure and preventing preparation trauma.

The mean breaking loads for all the herein-examined preparation designs were well above the clinically required strength of 1000 N for zirconia. This load value is based on the observation that zirconia loses up to 50% of its initial strength in the milieu of the oral cavity and on the assumption that the mean masticatory force in the posterior region is 300 N with an added safety margin of 200 N[9,30].

In this study, zirconia frameworks without porcelain veneering were loaded until fracture. As the effect of the veneering material on the breaking strength of zirconia-based restorations is still debatable, the copings were not veneered with porcelain[21,22]. Additionally, it is noteworthy that while it is possible to achieve equal frameworks with standardized dimensions, it is almost impractical to harbor such an expectation for veneered crowns. This is because veneering porcelain is applied by dental technicians, and therefore human errors are inevitable at this step in the working procedure.

Results of the present study concurred with another study which found that the breaking load for zirconia-based three-unit fixed dental prosthesis (FDP) with shoulder preparation was significantly higher than the deep chamfer preparation[32]. Conversely, a study on glass-ceramic crowns, which have a lower fracture resistance than zirconia, did not demonstrate any differences in loading capacity in relation to the preparation widths tested[11]. In other words, since increased material thickness did not have any positive impact on loading capacity, a less invasive preparation design should be the obvious, optimal choice.

CONCLUSIONS

Within the limitations of the present study, the shoulder preparation emerged as the recommended preparation design from both mechanical and periodontal points of view. As for a less invasive preparation design, the slight chamfer preparation would be the recommended option. For zirconia-based restorations, the deep pronounced chamfer preparation design is not recommended.

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