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Influence of substructure design and spacer settings on the in vitro performance of molar zirconia crowns

Martin Rosentritt *, Daniela Steiger, Michael Behr, Gerhard Handel, Carola Kolbeck

Department of Prosthetic Dentistry, Regensburg University Medical Center, Franz-Josef Strauss Allee 11, D-93042 Regensburg, Germany

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Objectives: The aim of this study was to evaluate the in vitro behaviour of all-ceramic zirconia molar crowns in regard to different core designs and marginal fit.

Methods: Identically shaped methacrylate molars were prepared according to the ceramic restoration directives resulting in a 1-mm deep circular shoulder preparation. They were embedded in polymethylmethacrylate resin after covering their roots with a polyether layer to simulate periodontal mobility. The crown cores were made of yttria-stabilized zirconia veneered with a corresponding veneering ceramic. The crowns were divided into 5 groups ($n = 8$) which differed in core design and cement gap thickness: #1: simple core, 40 μm cement; #2: core with minimal occlusal support, 40 μm cement; #3: core with optimized cusp support, 40 μm cement; #4: core with optimized cusp support, 30 μm cement; #5: core with optimized cusp support, 10 μm cement. All crowns were cemented with zinc oxide phosphate cement and thermo mechanically loaded ($1.2 \times 10^6 \times 50$ N; 6000×5 °C/55 °C) with identical metal ceramic restorations as antagonists. Crown failures were monitored and described. Area and direction of the chipping failures of the veneering ceramic were documented by means of scanning electron micrographs.

Results: All core designs showed chipping during chewing simulation with different numbers (defect areas). #1: 6 chippings (8.1 mm^2); #2: 2 chippings (3.5 mm^2); #3: 2 chippings (2.1 mm^2); #4: 3 chippings (5.7 mm^2); #5: 3 chippings (7.3 mm^2).

Conclusions: An optimized core design reduced number and surface area of occurring chippings. A variation of the gap thickness showed no significant influence on the in vitro performance.

1. Introduction

To fabricate highly aesthetic restorations without metal substructures numerous all-ceramic materials with different clinical application modes are available. For the restoration of molar teeth with single crowns yttria-stabilized zirconia ceramic can be used. These materials can be processed in CAD/CAM (computer aided design/computer aided manufacturing) or CAM technologies and have been investigated thoroughly in the past years under in vivo conditions.[1–3] If substructures for crowns or fixed dental prostheses are made of partially stabilized zirconia they provide high fracture strength, a small range of strength variation and high structural reliability compared to glass-ceramics.[4,5] Number and sequence of fabrication steps (e.g. wax modelling versus CAD-design) depend on the chosen system and material. But all zirconia substructures have to be fabricated in the particular CAM processing. Afterwards most of them have to be veneered with conventional ceramics in layering or press technique. These veneering materials show low strength

* *Corresponding author*. Tel.: +49 941 944 6054; fax: +49 941 944 6171.
E-mail address: Martin.Rosentritt@klinik.uni-regensburg.de (M. Rosentritt).
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Table 1 – Description of examination groups.

Group	Substructure design	Substructure thickness [mm]	Spacer area [%]	Cement gap [μm]
1	Simple	0.5	90	40
2	Modified Minimal occlusal support Small cusp support	0.6–0.8	90	40
3	Optimized	0.7–1.3	90	40
4	Optimized occlusal support		80	30
5	Optimized cusp design		70	10

compared to the high strength zirconia substructure material.[6] Furthermore the veneering porcelain is directly exposed to chewing, clenching and moisture which might weaken the veneering and result in cracks or chipping.[7,8]

These brittle break downs are typical failures of ceramic materials. Although chippings have as well been reported with porcelain fused to metal (PFM) restorations,[9,10] especially the chipping problems with all-ceramic zirconia restorations are examined and discussed at the moment.[1–3,11,12] Various factors that might have an influence on chipping occurrence have been reported, such as veneering thickness,[13] morphology of the circular finishing line, adhesive forces between substructure and veneering [14] or negative effects because of the combined different material layers.[15–17] Internal fit of zirconia CAD-/CAM-fabricated restorations can be characterized as satisfactory in most cases.[18] It has not been cleared yet, whether internal fit and corresponding cement thickness do have an influence on the occurring chipping incidents of these restorations.

Laboratory tests such as finite element analysis may help to predict fracture behaviour of specific material combinations. But failure types and pattern are mainly influenced by clinically relevant reasons such as preparation angle and finishing line design, internal fit and cement thickness or the individual crowns design with its occlusal variations and therefore different effects on loading and force distribution. Chewing simulations[19] imitating the clinical situation with dynamic loading and thermal cycling may help to examine specimen behaviour under clinically approximated conditions.[20,21] The failures appearing during simulation can be compared with clinically observed failures. Fractographic methods[22,23] can be used to describe ceramic failures. These are in most cases initiated by flaws inside the material or defects in marginal areas or the occlusal surface.[24] The methods contribute to the evaluation of all-ceramic restoration failures during chewing simulation.

The hypothesis tested in this study was that different substructure designs, but not the internal cement thickness, do significantly decrease the number and area of chippings in zirconia based all-ceramic crowns after simulated oral service.

2. Materials and methods

The tooth 46 (Morita, Dietzenbach, Germany) was prepared for a single crown according to the directives for zirconia all-ceramic restorations. A circular and occlusal anatomical reduction of 1–1.5 mm was carried out with a preparation angle of 4°. The finishing line resulted in a 1-mm deep circular shoulder with rounded inner angles at an isogingival height of the tooth cervix. Sharp inner edges and undercuts were eliminated. This prepared tooth was then multiplied resulting in 40 identical polymethylmethacrylate teeth which were positioned in resin blocks (Palapress Vario, Heraeaus-Kulzer, Germany). Beforehand their roots were covered with a 0.75-mm layer of polyether material (Impregum: 3 M Espe, Seefeld, Germany) to simulate periodontal tooth mobility.[19,25] Polyether impressions (Permadyne: 3M Espe) and working dyes were made of class IV dental stone (Fuji Rock: GC-Corporation, Tokyo, Japan). Then the substructures for the molar crowns were fabricated of the yttria-stabilized zirconia Cercon Base (Degudent, Hanau, Germany) according to the manufacturer's instructions in CAD–CAM-technique.

Five examination groups were defined ($n = 8$) which differed in substructure design and thickness as well as internal fit (Table 1): #1 = simple 0.5 mm substructure and 40 μm cement gap; #2 = modified 0.6–0.8 mm substructure with minimal occlusal support and 40 μm cement gap; #3–#5 = 0.7–1.3 mm substructure with optimized occlusal support and cusp design and 40 μm (#3), 30 μm (#4), 10 μm (#5) cement thickness. The different internal adaptation modes were reached by different CAD parameters for ‘‘cement thickness’’ and ‘‘spacer area’’ (Table 1). The substructures were veneered with Cercon Kiss (DeguDent, Hanau, Germany). Thickness of the entire restoration was 2.5 ± 0.1 mm. Thus the veneering thickness depended on the substructure design and varied between 1.2 and 2.0 mm. All crowns were cemented using zinc-phosphate cement (Harvard: Hoffman&Richter, Berlin, Germany). Forty identical crowns were fabricated for teeth 26 (Morita, Dietzenbach, Germany) of Co–Cr alloy (Wirobond LFC: Bego, Bremen, Germany) and a veneering porcelain (Duceram Kiss: Degudent) which ought to serve as antagonists during chewing simulation. The all-ceramic crowns and antagonists were adjusted in a dental articulator (Artex CN: Amann-Girrbach, Pforzheim, Germany) and transferred to the chewing simulator (EGO, Regensburg, Germany).

Thermal cycling (6000×5 °C/55 °C; 2 min each cycle) and mechanical loading ($1.2 \times 10^6 \times 50$ N) were performed with parameters based on the literature data which are supposed to simulate 5 years of oral service.[20,21] During simulation time all crowns were monitored, appearing failures were documented and failed crowns were excluded from further simulation process. Location (mesial, distal, buccal or lingual direction) and extension (width, height and area) of the occurring failure modes were determined. Statistical analysis was performed using One-way ANOVA (Bonferroni post hoc) and χ^2 tests.