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ORIGINAL ARTICLE

Fracture characteristics of anterior resin-bonded zirconia-fixed partial dentures

Martin Rosentritt · Stefan Ries · Carola Kolbeck · Maria Westphal · Ernst-Jürgen Richter · Gerhard Handel

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Abstract Resin-bonded fixed partial dentures (RBFPD) are used as a minimal invasive, tooth-preventing alternative for replacing anterior teeth. Zirconia cantilever restorations were supposed to show sufficient strength for a clinical application. The aim of this investigation was to determine the fracture characteristics of cantilever and two-retainer RBFPD, which are fabricated by computer-manufactured high-strength zirconia. Human incisors and canines were used to form three groups of 14 RBFPDs with different types of preparation: group 1, an invasive cantilever; group 2, a minimal-invasive cantilever and group 3, a two-retainer RBFPD control. After thermal cycling and mechanical loading, which was performed to simulate oral service, all restorations were loaded to fracture in a universal testing machine. One half of the specimens were investigated as a control without simulated service. Mode of failure was determined for the three designs. Both cantilever groups showed comparable fracture resistance of 227 N (no. 1) and 210 N (no. 2) before thermal cycling and mechanical loading. The resistance after aging was reduced to 210 N for the invasive cantilever RBFPD and to 179 N for the minimal invasive group. Three-unit RBFPDs showed a significantly higher ($p<0.02$) fracture resistance than cantilever bridges before (426 N) as well as after aging (360 N). Predominant failure was FPD and retainer fracture for the invasive cantilever design, debonding for the minimal cantilever design and RBFPD fracture for the two-retainer design. The present study revealed a significantly higher fracture resistance for two-retainer RBFPDs than for cantilever RBFPDs. The frequency of adhesive debonding increased for non-retentive prepared cantilever RBFPDs.

Keywords Zirconia · Anterior FPDs · Single retainer · Fracture characteristics

M. Rosentritt (✉) · C. Kolbeck · G. Handel
Department of Prosthetic Dentistry,
Regensburg University Medical Center,
Regensburg, Germany
e-mail: martin.rosentritt@klinik.uni-regensburg.de

S. Ries · M. Westphal · E.-J. Richter
Department of Prosthodontics, School of Dental Medicine,
University of Wurzburg,
Wurzburg, Germany

Introduction

In contrast to a conventional preparation, with a reduction of tooth substance between 63% and 72%, a resin-bonded fixed partial denture (RBFPD) design may be prepared with a maximum tooth hard tissue loss of 3–30% [1]. This substance-conserving procedure is particularly advantageous in young patients with caries-free adjacent teeth and extensive pulpal cavities. Initially, high failure rates of RBFPDs were caused by hydrolytic weakening of the adhesive bond between cement and metal framework. Debonding might be minimized by using a retentive preparation design with slots and boxes [2]. The survival rates of these restorations, which were investigated up to 20 years now, vary between 60% (11 years) [3], 66% (20 years) [4], 83% (in 13 years) [5] and 95% (10 years) [2]. A non-precious metal framework may show corrosion, and different thermal expansion coefficients of tooth and metal may lead to stress in the adhesive bond and ultimate adhesive failure. This may be associated with the development of recurrent caries if the patient does not notice the defect in time. Aesthetic considerations preventing the natural translucency of the teeth led to the application of all-ceramic frameworks. High failure rates with aluminium oxide framework provide the impetus for a fundamental redesigning and the search for alternative high-strength ceramic materials. A cantilever design with just one retainer was reported to improve the survival probability of RBFPDs [6–10]. Thus, cantilever RBFPD would be preferred since this treatment modality would preserve sounder tooth substance if it has higher probability of survival as stated. Koutayas et al. [11] reported high fracture rates for two-retainer all-ceramic RBFPDs in contrast to comparable cantilever versions when cyclically loaded at 25 N. Clinical reports of a single-retainer RBFPDs showed promising results [8, 9, 12–14], and Kern [12] stated a 5-year survival rate of two-retainer alumina ceramic RBFPDs of about 74% and for the single retainer bridges of 92%.

The question arises whether cantilever or two-retainer RBFPDs, which are fabricated by computer-aided and manufactured (CAD/CAM) high-strength zirconia, may show improved fracture resistance for clinical application. Two-retainer RBFPDs were compared to cantilever RBFPDs with invasive or minimal-invasive preparation.

Materials and methods

Forty-two caries-free central maxillary incisors and 12 caries-free maxillary canines were cleaned and stored in a 1% chloramine solution. The roots were covered with an artificial periodontal membrane (anti-slip polish; Wenko-Wenselar, Hilden, Germany) in order to imitate the periodontal mobility of the abutment teeth. The teeth were embedded in composite blocks (Technovit 4000; Heraeus Kulzer, Wehrheim, Germany) to a level 2 mm below the enamel–dentin junction at an inter-incisal angle of 135° to the horizontal plane. The roots of the teeth were pierced and equipped with a 1-mm-thick metal pin to prevent rotation. All teeth were randomly divided in three groups of 14 RBFPDs each group: an invasive cantilever group (no. 1), a minimal-invasive cantilever group (no. 2) and a two-retainer RBFPD control (no. 3). All three groups provided a palatal 0.2- to 0.3-mm-deep veneer preparation exclusively in enamel. The invasive cantilever preparation (no. 1) had an additional palatal pit in the cingulum area (depth, 0.5 mm; diameter, 1 mm) and an approximal box facing the pontic (2 mm bucco-orally and inciso-cervical; 0.5 mm mesiodistal). The two-retainer group was additionally prepared with an oral guidance plane connecting the two approximal surfaces via the oral circumference of the tooth and a palatal pit in the area of the cingulum (depth, 0.5 mm; diameter, 1 mm). This preparation was finished with four parallel 0.5-mm-deep retention grooves—one on each approximal surface and two in the tuberculum on the oral guidance plane. All preparations were conducted using a parallelometer (Parallel-a-prep; Fig. 1).

All teeth were restored according to the manufacturer's instructions using zirconia RDFPDs (Cercon Base) with a glass-ceramic veneering (Cercon Ceram S (both Degudent, Hanau, Germany). The surfaces of the teeth were cleaned with a rubber cup and pumice and etched for 60 s with 37% orthophosphoric acid. The wings of the RBFPDs were pretreated with the tribochemical treatment (Rocatec, 3M ESPE, Seefeld, Germany). This procedure is a method for silicatizing surfaces. In the first step, the surface is cleaned and activated by air abrading (110 μm aluminium oxide, 10 s; Rocatec Pre). In the second step, a tribochemical treatment with silica-modified aluminium oxide (110 μm aluminium oxide, 13 s; Rocatec Plus) is performed. All abrading is carried out at a distance of 10 mm with a pressure of 2.8 bar. Finally, the surface is silanised (3M Espe Sil) in order to achieve a chemical bond between the inorganic silicatised surface and the composite cement. All RBFPDs were adhesively bonded with Panavia21 EX (Kuraray, Osaka, Japan). Seven RBFPDs of each group were subjected to thermal cycling and mechanical loading (TCML) and seven specimens without TCML served as a control. TCML (6,000 thermal cycles with distilled water at 5°C/55°C and 1.2×10^{6} times 25-N force applied at an angle of 135° with a human antagonist) was performed for simulating a 5-year oral service [15]. After

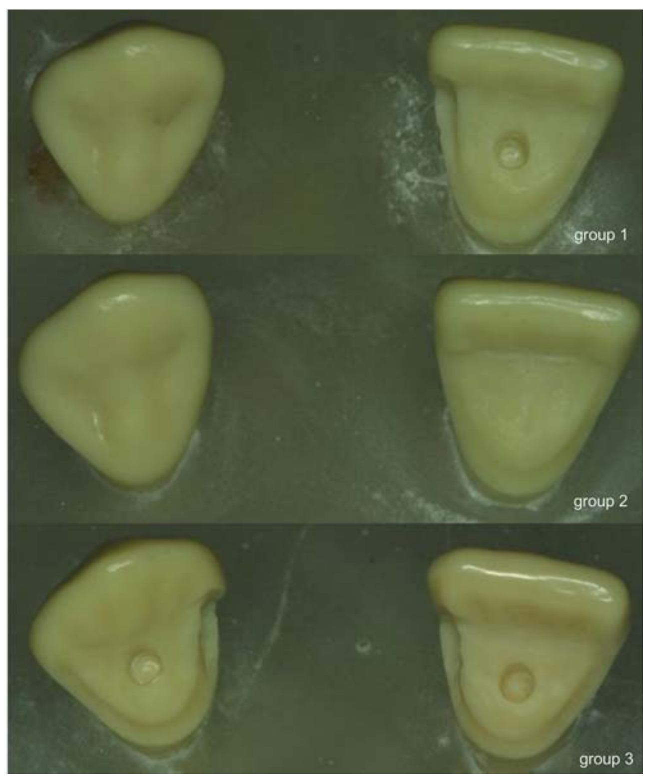

Fig. 1 Preparation design (from above): invasive cantilever group (no. 1), minimal-invasive cantilever group (no. 2) and two-retainer RBFPD control (no. 3)

TCML, all RBFPDs were loaded to fracture in a universal testing machine (v=1 mm/min, Zwick 1445; Zwick, Ulm, Germany) 3 mm apical to the incisal edge of the pontic (angle, 135°). For achieving uniform force distribution, a 1-mm-thick tin foil was placed between the loading die and the tooth. The failure type of each fracture was assessed under a light microscope (SV8; Olympus, Germany) and classified according to the following criteria: (1) fracture of the restoration, (2) fracture of the abutment and (3) failure of the adhesive bond. Medians and 25%/75% were calculated and statistically analyzed using the Mann–Whitney U test and Kruskal–Wallis test (α=0.05).

Results

Both cantilever groups (no. 1 and no. 2) showed comparable median fracture resistance of 227 N (no. 1) and 210 N (no. 2) before TCML. During TCML, two samples of each group failed due to debonding (no. 2) or tooth fracture (no. 1). The fracture resistance after aging was reduced to 210 N for the invasive cantilever RBFPD and to 179 N for the minimal invasive group. No significant differences were found between both cantilever groups before (p=0.41) or after aging (p=0.35). The three-unit RBFPDs showed a significantly higher (p<0.02) fracture resistance than the cantilever bridges. The results of 426 N before aging reduced non-significantly to 360 N after aging. One RBFPD failed during aging due to tooth fracture. The results of the fracture test are depicted in Fig 2.

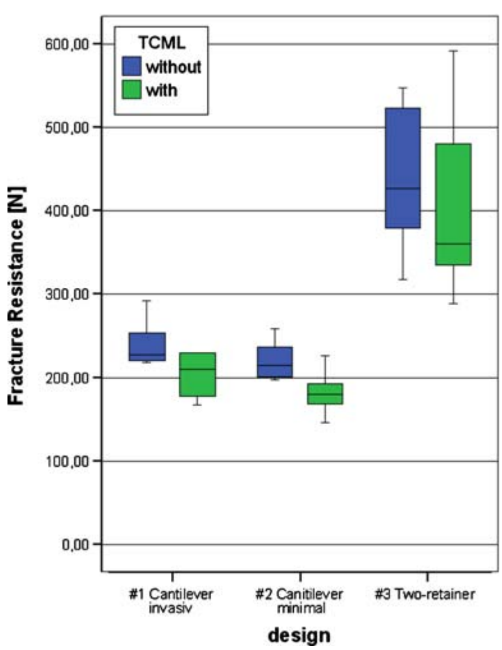

Fig. 2 Fracture resistance (N) of RBFPDs with two-retainer or cantilever design (with/without TCML)

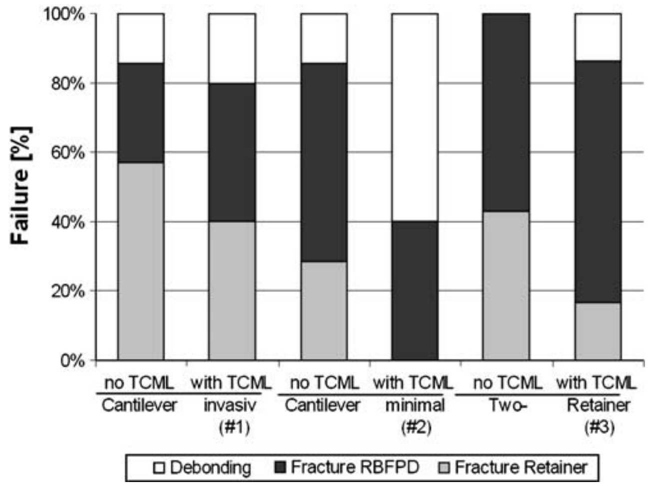

Fig. 3 Fracture pattern of RBFPDs with two-retainer or cantilever design (with/without TCML)

Figure 3 shows the distribution of the failure types during fracture testing. In the invasive prepared group (no. 1) without TCML, 14.3% of the RBFPDs debonded, 28.6% failed due to fracture of the retainer and 57.1% due to fracture of the RBFPD. After TCML, fracture of the retainer and fracture of the RBFPDs was found each in 40% of the cases. Twenty percent of the cases surviving bridges showed debonding. In the non-retentive cantilever group (no. 2) without TCML, 14.3% of the RBFPDs debonded, 28.6% failed due to fracture of the RBFPD, and in 57.1% of the cases, the retainer fractured. After TCML, the number of debonding increased to 60% and the number of RBFPD fractures reduced to 40% of the surviving specimens. No RBFPD of group 2 debonded after TCML. The two-retainer group (no. 3) showed no debonding, 42.9% retainer fractures and 57.1% RBFPD fractures before TCML. After TCML, debonding was found in 14.3% of the specimens. The number of retainer fractures reduced to 14.3% and the number of FPD fractures increased to 71.4%. All specimens of this group survived TCML.

Discussion

The RBFPD is a minimal invasive therapy particularly in young patients with extensive pulpal cavities and relatively wide dentinal tubules. It has been shown that a retentive preparation of the teeth is regarded essential for improving its success [2, 16]. The introduction of high-strength zirconia expands the treatment modalities of metal-free restorations. However, clinical observations for porcelain-fused-to-metal and alumina RBFPDs may not apply to this high-strength zirconia. Our in vitro results of the investigated zirconia cantilever RBFPDs in tendency are comparable to the in vivo reports of RBFPDs: The minimally invasive prepared cantilever group showed a 10% lower fracture resistance before TCML which decreased further to 15% after TCML in comparison to the retentive prepared group. The results varied between about 210 and 227 N for the cantilever restorations and 426 N for the two-retainer RBFPDs and are in the same range as results found for comparable aluminium oxide ceramics [11, 17] (two-retainer, 313 N; single-retainer, 233–291 N). Thus, zirconia showed small, if any, advantages, which may be attributed to the design of the bridges and their bonding. Assuming maximum anterior loadings of 108–382 N [18, 19], the fracture results after TCML were in a range where the clinical application of RBFPDs may show promising results, but failures may occur especially for the cantilever design. Different findings between in vitro and in vivo [9, 11] might be explained by nanoreceptors [20, 21], protecting the restoration by monitoring the bite force in relation to the resistance of a restoration and type of food. An assorted patient selection and patients' carefulness might have contributed to improved in vivo results. In contrast, in vitro conditions demonstrate constantly applied chewing force without regulation (TCML) or static loading to fracture.

Only small differences of the failure pattern were found between the two cantilever groups before TCML. After TCML, a strong increase (20–60%) in the number of debonding could be determined for the minimally prepared RBFPDs, indicating a strong influence of the preparation on the survival of the restoration. This assumption is supported regarding the failure pattern during TCML. The group with retentive preparation showed two fractures of the abutment, whereas for the minimally prepared RBFPDs, two debondings during TCML were found. The results pointed out that the failure of RBFPDs is dependent on the success of the preparation and that RBFPDs' survival may be supported by an improved bonding between cement and tooth and cement and inert zirconia. In spite of the bonding to tooth substance being well understood, bonding to zirconia is discussed controversially. Laboratory tests showed a higher bonding strength of zinc phosphate or glass ionomer compared to adhesive bonding [22], but pull-off tests of zirconia crowns demonstrated no different retentive strength using different types of cements [23]. In this study, the resin-based cement was used with a tribochemical treatment (Rocatec) because this combination was reported to show good bonding results [24, 25]. Another study demonstrated that artificial aging did not significantly influence the bond of Panavia21 Ex to zirconia [26]. It has been described that not all resins polymerise adequately after storage [27] or under different polymerisation conditions [28], especially that light or dual-curing cements may provide inhibited reaction due to the light blocking through the opaque zirconia framework. The degradation of the filler/resin interface is supposed for contributing to cohesive failures of RBFPDs in vivo [29]. An insufficient fitting [30] of the RBFPDs as a result of the framework configuration in addition with polymerisation stress, which is caused by thickness variations of the cement layer [31], may cause resilience. Hydrophilic conventional cements may show a better wetting capability of the zirconia surface, and furthermore, phosphoric acids/monomer derivates were discussed for improving the wettability and bonding quality of the zirconia surface further [24, 32–35].

Significantly higher fracture resistance before and after TCML was found for the two-retainer RBFPDs in comparison to both cantilever groups. No debonding of these bridges was found before or during TCML. The influence of TCML resulted in reduction of the median fracture resistance of about 15% and a shift of the fracture pattern towards debonding and fracture of the RBFPDs. This is in contrast to the assumption that cantilever resin-bonded bridges are superior to the two-retainer design, especially when the mobility of the abutment is relatively high [36]. This assumption led to good clinical prognosis for porcelain-fused-to-metal resin-bonded bridges with cantilever design [37, 38]. An initial clinical report had shown that cantilever bridges may not perform worse than two-retainer restorations [39]. Koutayas et al. [11] found no significant difference between one- and two-retainer resin-bonded bridges constructed of glass-infiltrated alumina ceramic, but these tests were performed without chewing simulation. A similar result was found by Kern [12] who demonstrated that all-ceramic cantilever alumina RBFPDs performed equivalently to conventionally designed two-retainer bridges of the same material. With comparable preparation and bridge design, no significant difference in survival rates was found under in vitro conditions [11].

The survival rate during the 25-N TCML was about 100% for the two-retainer group and 70% for the cantilever groups, with the chance of rebonding relieving RBFPDs. Assuming mean mastication forces in the anterior region between 10 and 35 N [40], our results indicate that zirconia two-retainer RBFPDs may withstand clinical loading. Failure rates and fracture resistance of RBFPDs made of zirconia were not advantageous compared to alumina or lithium disilicate ceramics.

Conclusions

Under the experimental conditions described, the present study showed that significantly higher force was necessary to fracture two-retainer RBFPDs than cantilever resin-bonded bridges. An influence of TCML was observed on the overall failure rate and fracture resistance. The frequency of failure through adhesive debonding increased in non-retentive prepared cantilever RBFPDs.

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