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Comparison of fracture-load values of cantilevered FDPs

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Abstract

Objective. Evaluation of the effect of different framework designs and of fatigue on the fracture-load values of cantilevered fixed dental prostheses (FDPs). The load values were compared with those for lithium disilicate ceramic and metal–ceramic FDPs. ***Materials and methods.*** Fifty cantilevered FDPs were manufactured using a zirconia framework veneered with a feldspathic ceramic. Ten FDPs were made from a lithium disilicate ceramic and 10 were designed as metal–ceramic FDPs. All FDPs were anchored by two premolar crowns to replace a missing premolar. Twenty of the 50 zirconia FDPs were regarded as the control groups; these were divided into two groups—with and without fatigue. The other 30 zirconia FDPs were divided into three test groups with different framework designs. The load to fracture was measured and fracture sites were identified. The Kruskal–Wallis test and the Mann–Whitney U-test were used for statistical analysis. ***Results.*** Most of the all-ceramic FDPs fractured within the distal wall of the terminal crown abutment. The mean fracture-load ranged between 346–493 N for the FDPs with the 0.7 mm framework. Mean values for the three zirconia test groups ranged from 529–590 N. Reinforcement of the framework resulted in significantly higher fracture-loads than for the control group. Values for lithium disilicate restorations were significantly lower than those for the test groups and the values for the metal–ceramic group were significantly higher than those for the test groups. ***Conclusion.*** Although reinforcement of the distal crown core might enhance the fracture resistance of all-ceramic cantilever FPDs, they cannot yet be unreservedly recommended for clinical use.

Key Words: *cantilever, fdp, zirconia*

Introduction

Although survival of cantilevered fixed dental prostheses (FDPs) [1] seems to be shorter than that of end abutment-supported FDPs [2,3], in respect of patient comfort and acceptance [4] cantilevered FDPs remain a desirable alternative to removable partial dentures [4,5]. Patient acceptance of dental restorations does, however, also require natural looking FDPs and conventional metal-based FDPs have an esthetic drawback—a change in the natural translucency because of the metal framework. These disadvantages of conventional metal-reinforced cantilevered FDPs and the desire for esthetic and metal-free restorations have led to increased research into tooth-colored materials, especially for all-ceramic FDPs. In recent years, the mechanical properties of new all-ceramic core materials, for example zirconia, have enabled treatment with a wider range of all-ceramic FDPs.

Although promising results have been obtained for zirconia end-abutment FDPs, few data are available for zirconia cantilevered FDPs. Initial, promising, clinical results for posterior FDPs have been reported [5,6], but these studies exclude—as do most studies on zirconia—patients with bruxism. Although diagnosis of bruxism remains questionable [7] or time-consuming procedures, all-ceramic cantilevered FDPs should be able to withstand the mastication forces of all patients. Available *in-vitro* studies have revealed fracture-load values for cantilevered zirconia FDPs are small [8] compared with end-to-end FDPs—and substantially less than the recommended 1000 N for all-ceramic FDPs [9].

A previous *in-vitro* study [10] revealed that reinforcement of the zirconia framework resulted in significantly higher fracture-load values.

Thus, the objective of this *in-vitro* study was to evaluate fracture-load values for cantilevered FDPs manufactured using a reinforced zirconia framework.

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The null hypothesis was that fracture load values of FDPs with the reinforced framework design did not differ significantly from fracture load values of metal-ceramic FDPs or lithium disilicate all-ceramic FDPs. The effect of fatigue was also tested for zirconia FDPs.

Materials and methods

Design of test and control groups

The FDPs were designed as three-unit FDPs using two abutments [11] and the cantilever has the width of a premolar.

Thus, a total of seventy cantilevered FDPs were made for this *in-vitro* study. Fifty FDPs were made with a Y-TZP framework (Lava; 3M Espe, Seefeld, Germany) and different framework designs. Ten cantilevered FDPs were made using lithium disilicate ceramic (IPS Empress 2; Ivoclar Vivadent, Ellwangen, Germany) and 10 cantilevered FDPs were made as metal–ceramic FDPs (Remanium star, Dentaurum, Ispringen, Germany).

The 70 models included in the statistical analysis were divided into seven groups:

- *Group C1*: The FDPs of group C1 were regarded as the control group. The axial wall thickness of the zirconia cores was constant at 0.7 mm and the connector area of the zirconia framework was designed with a cross-sectional plane of 12 mm^2 (4 mm in height and 3 mm in width). Thermal cycling and mechanical loading were conducted.
- *Group C0*: The FDPs in group 0 were designed in the same way as those of group 1. In comparison with group C1, no thermal cycling or mechanical loading was conducted.
- *Group Z1*: In comparison with group C1, the framework of the FDPs in group Z1 was reinforced by increasing the distolingual, distobuccal and occlusal wall thickness to 1 mm.
- *Group Z2*: Compared with group C1, the framework of the FDPs in group Z2 was reinforced by increasing the complete wall thickness of the distal abutment to 1 mm.
- *Group Z3*: Compared with group C1, the framework of the FDPs in group Z3 was reinforced by using an additional notch (1 mm deep and 2 mm wide) in the distal abutment (Figure 1).
- *Group L*: The FDPs were made using lithium disilicate glass ceramic (Empress 2, Ivoclar Vivadent) in accordance with the manufacturer's instructions, with the same dimensions as the FDPs of group C1.
- *Group MC*: Compared with group C1, the FDPs in group MC were made with a Cr–Co alloy metal framework (Remanium star, Dentaurum) and the FDPs were veneered with VM®13 (Vita, Bad Säckingen, Germany).

Fabrication of the models

All abutment teeth were prepared for full crowns and the cantilevered FDPs were designed as three-unit FDPs, replacing one premolar of 7 mm span length.

A chamfer with a depth of 1.2 mm and a six-degree angle of convergence was prepared on the first and second mandibular premolars of the Frasaco study model (Frasaco, Tettnang, Germany). To ensure preparation was standardized, the tooth preparations were made with diamonds with a three-degree angle of incidence (Komet; Lemgo, Germany), using a parallelometer (S-3 Master; Schick, Schemmershofen, Germany).

Ten second premolars of group 3 also received a notch in the occlusal area (1 mm deep and 2 mm wide) (Figure 1).

The prepared teeth were duplicated (Omnidouble, Ispringen, Germany) and in each case identical abutment teeth were cast from Cr–Co alloy Remanium star (Dentaurum). Thus, in total 70 metal models were made (10 metal models for each test or control group). To simulate physiological tooth mobility the metal teeth were covered with heat-shrink tubing (CPX 55; Polyolefin, Kentec, Waldshut, Germany). The abutment teeth were then embedded in PMMA resin (Palapress; Hereaus Kulzer, Hanau, Germany) by using a preoperatively prepared key of autopolymerizing acrylic resin (Palavit G; Heraeus Kulzer) for exact location.

Impressions were made with polyether impression material (Impregum; 3M Espe), in accordance with the manufacturer's instructions. The stone dies were then cast with suprastone material (Fujirock; GC America, IL).

Zirconia FDPs

The zirconia frameworks were made from prefabricated zirconia blanks prepared from 3 mol%

Figure 1. Preparation design of the distal abutments in group Z3 (zirconia FDPs).

yttrium-stabilized zirconium, by use of a Lava scanning and milling machine (Lava Scan, Lava Form; 3M Espe), and then sintered at 1500°C (Lava therm; 3M Espe).

The frames were veneered with the appropriate feldspathic ceramic (Lava Ceram; 3M Espe); a prefabricated silicone key was used for all models to ensure identical veneer thickness of 1 mm. The veneering procedure and the temperature gradient were in accordance with the manufacturer's instructions (3M Espe). The conventional firing procedure was used without extra cooling time.

Lithium disilicate ceramic and metal–ceramic FDPs

The FDPs of group L were prepared using the IPS Empress 2 system (Ivoclar Vivadent), in accordance with the manufacturer's instructions using the conventional firing protocol, with dimensions identical with those of the zirconia FDPs of group C1 (0.7 mm axial wall thickness, connector area 12 mm^2, 1 mm veneer thickness).

The metal–ceramic FDPs of group MC were prepared with a Cr–Co alloy metal framework (Remanium star, Dentaurum) and were veneered with VM®13 (Vita, Bad Säckingen, Germany), in accordance with the manufacturer's instructions using the conventional firing protocol, with the same dimensions as the FDPs of group C1.

Fracture load testing

After completion of the FDPs, their metal abutments and inner surfaces were cleaned with 90% ethanol. All FDPs were seated with dual-curing hybrid cement (Rely X Unicem, 3M Espe), in accordance with the manufacturer's instructions. An overview of the groups is given in Table I.

All FDPs (except Group C2) were subjected to 10 000 thermal cycles between 6.5–60°C (dwell time 45 s., dripping time 2 s), Willytec thermocycler, Version 3.0; Willytec GmbH, Graefelfing, Germany) and to 600 000 simulated chewing cycles (m = 5 kg, V = 30 mm/s, F_{max} = 80 N, F_{static} = 50 N; Willytec Dual-axis chewing simulator, Version 3.1; Willytec GmbH) at the distal fossa of the pontic.

After mechanical loading, the FDPs were evaluated under a stereomicroscope to detect fracture lines in the veneer.

The fracture-load values were then determined by loading the samples to failure in a universal testing machine (Z 005, Zwick Inc, Ulm, Germany). The force was applied to the distal aspect of the pontics (cross-head speed 0.5 mm/min, fracture threshold for shut-off 80% decrease in test force) with 0.3 mm tin foil between the loading element (steel sphere, D = 6 mm) and the pontic to reduce local stress. First damage of the veneer was evident as a peak in the force–displacement diagram, because of spontaneous loss of resistance (drastic decrease of test force).

Statistical analysis was performed using SPSS (Version 18.0; Chicago, IL). To determine the effects of differences between the groups, the Kruskall–Wallis test then the Mann–Whitney U-test were performed, with the level of significance set at ≤ 0.05.

Results

None of the FDPs debonded during thermal cycling or mechanical loading. Chipping of the veneering ceramic was observed for two FDPs in group L after thermal cycling and during mechanical loading.

In group C1, the mean fracture-load value was 346 N and for the FDPs in group C0, the mean fracture-load value was 493 N.

For the FDPs of group Z1 the mean fracture-load value was 529 N, significantly higher ($p \leq 0.001$) than values for group C1, but not significantly higher than values for group C0 ($p = 0.353$).

For the FDPs of group Z2 the mean fracture-load value was 564 N (values were again significantly higher ($p \leq 0.001$) than for group C1 but not for group C0 ($p = 0.089$).

Table I. Overview of test and control groups.

Group	Framework thickness of the mesial abutment	Framework thickness of the distal abutment	Distal connector	Thickness of the veneering material	Occlusal notch in distal abutment	Thermal cycling and mechanical loading
C1	0.7 mm	0.7 mm	12 mm^2	1 mm	No	Yes
C0	0.7 mm	0.7 mm	12 mm^2	1 mm	No	No
Z1	0.7 mm	Localized reinforcement 1 mm	12 mm^2	1 mm	No	Yes
Z2	0.7 mm	Complete reinforcement 1 mm	12 mm^2	1 mm	No	Yes
Z3	0.7 mm	0.7 mm	12 mm^2	1 mm	Yes	Yes
L	0.7 mm	0.7 mm	12 mm^2	1 mm	No	Yes
MC	0.7 mm	0.7 mm	12 mm^2	1 mm	No	Yes

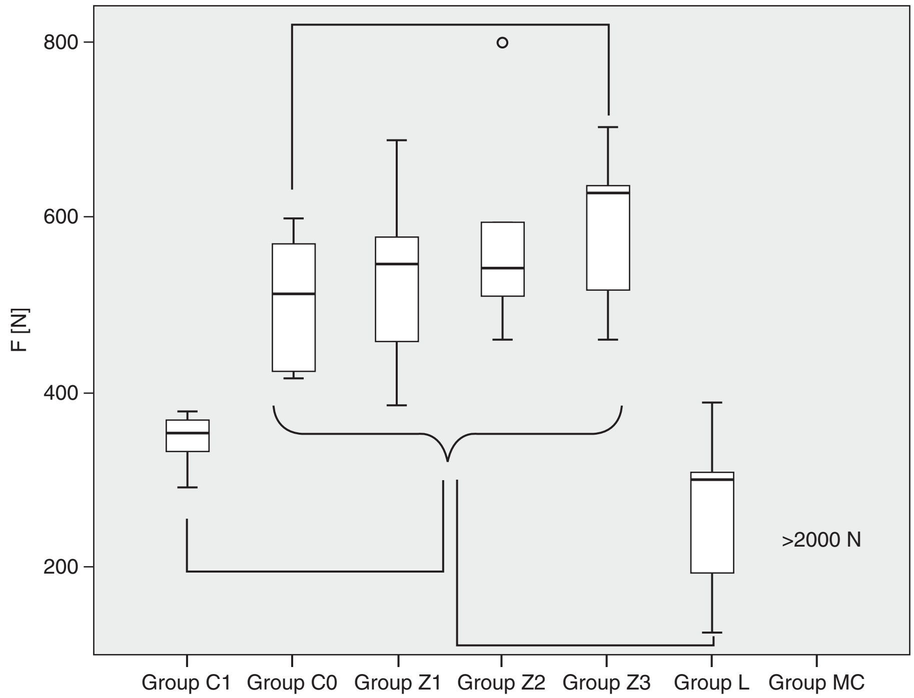

Figure 2. Fracture-load values. Significant differences between the groups are connected by line.

Values for group Z3 were also significantly higher ($p \leq 0.001$) than for group C1 and for group C0 ($p = 0.009$); the mean fracture-load value was 590 N.

For FDPs of group L, the mean fracture-load value was 274 N. The values for group L were significantly lower than for all other test groups ($p \leq 0.001$), except the FDPs in group C1 ($p = 0.053$).

For the FDPs in group MC the fracture-load values all reached 2000 N, when the test was stopped. No fracture of the framework was observed for these FDPs and the values were significantly higher than for all the other groups ($p \leq 0.001$).

Detailed fracture-load values are illustrated in Figure 2 and listed in Table II.

Reinforcement of the zirconia framework with an additional notch in the distal abutment (group Z3) resulted in the highest fracture-load values of zirconia FDPs in this study, but the values were not significantly higher than those for group Z1 ($p = 0.075$) or for group Z2 ($p = 0.218$).

Omission of thermal cycling and mechanical loading resulted in significantly higher fracture-load values of the zirconia FDPs ($p \leq 0.001$) than for zirconia FDPs with thermal cycling and mechanical loading.

All all-ceramic FDPs except the metal–ceramic FDPs were loaded until total failure; no framework fracture was observed. No delaminations or fractures of the veneer were observed for zirconia FDPs without a framework fracture.

Most of the fracture lines of the zirconia FDPs ($n = 48$) were within the distal wall of the terminal abutment crown (Figure 3).

Discussion

The null hypothesis of the present study has to be rejected—the fracture-load values of zirconia cantilever

Table II. Fracture-load values.

		Group						
		C1	C0	Z1	Z2	Z3	L	MC
F [N] (ultimate fracture-load values)	Min	291	415	384	460	458	126	> 2000
	Max	376	598	686	797	701	388	
	Mean	346	493	529	564	590	274	
	SD	27	70	85	92	77	88	
Fv [N] (first damage of the veneering material)	Mean	249	342	341	304	302	240	282
	SD	50	55	82	92	97	94	87

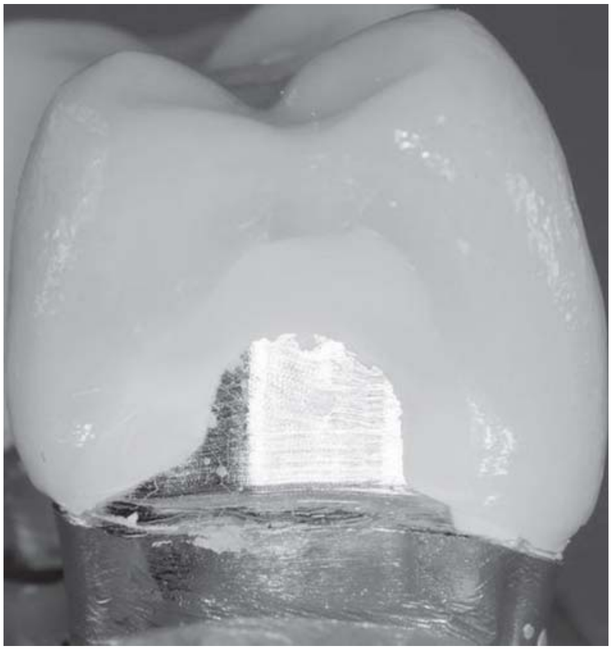

Figure 3. Fracture of the distal crown wall.

FDPs were significantly lower than fracture-load values of metal-ceramic FDPs. However, if all-ceramic cantilevered FDPs are to be used as an alternative to conventional metal–ceramic FDPs they must fulfill one major criterion—the FDPs must withstand posterior mastication forces of ~ 500 N. [12]. On the basis of these results, reinforced zirconia FDPs might be recommended for clinical use.

Available data for expected posterior mastication forces vary widely, however. Values range from 150 N for maximum local forces observed for cantilevered FDPs, if all stresses are actively concentrated on the distal cantilever [13] to 700 N for maximum forces acting on the cantilever [14]. Observations of mean maximum bite forces in the molar region exceed 800 N, moreover [15].

Apart from different results for expected occlusal forces, some authors have advised a safety margin for all-ceramic FDPs, because of reduction of fatigue strength by up to 50% under loading and because of sub-critical crack growth [9,16,17,18]. Fracture resistance of 1000 N has therefore been recommended for all-ceramic FDPs [9]. Although comparable data for end-to-end fixed partial dentures with a high-strength zirconia framework are indicative of values up to 1200–1400 N [19], none of the all-ceramic cantilevered FDPs in this study met this expectation; indeed, none of these FDPs achieved the required fracture resistance of 1000 N. Although it must be considered that this study simulated reduction of fatigue strength as a result of mechanical loading, with a significant effect for zirconia FDPs [20], it was also shown in the study that the fracture-load values obtained were not even half those obtained for end-to-end FDPs.

One reason for the moderate values in this study might be the experimental arrangement, including force applied at the distal aspect of the pontic only, which has been shown to be the arrangement with the greatest stress [21,22].

For a long time the connector area was regarded as the most vulnerable part of all-ceramic FDPs. Finite element analysis for all-ceramic cantilevered FDPs, which shows that the greatest stress for these FDPs is in the connector area, supports this assumption [23]. In our study the connector area was set at 12 mm^2, with the intention of ensuring clinical esthetics and periodontal health. Starting from the assumption of stress peaks in the distal connector area, one would assume that the fracture lines would occur in the connector area between the pontic and the terminal abutment. Contrary to these expectations, most of the connectors withstood the forces and the fracture lines ran in the distal wall of the terminal abutment, indicating the weak point of the cantilevered FDPs is located in the crown wall of the terminal abutment. This assumption may be supported by the significantly higher fracture-load values of occlusally and lingually reinforced frameworks. These observations may be explainable on the basis of a rotary motion vector around the center of the FDPs [24,25]. The axial load on the cantilever pontic may produce reactive forces distal to the terminal abutment—compressive strain in the lower part of the distal crown wall and tensile strain in the upper part. This assumption would be in accordance with the predominant modes of fracture described in this study—chipping of the distal crown wall.

The first clinical results for cantilevered FDPs indicate, nevertheless, that cantilever zirconia FDPs seem to be successful. Over a 4-year observation period, no framework fracture was observed [6]. However, although the incidence of zirconia framework fracture has generally been found to be rare, it remains a risk factor for failure of up to 8% for end-to-end FDPs [26], although most clinical studies exclude patients with bruxism and high mastication forces. Since the diagnosis of bruxism remains questionable or time-consuming, zirconia FDPs has to be stable enough to withstand the mastication forces of all patients—including patients with bruxism. Thus, the results of this present *in-vitro* study may be helpful for the dentists to make a decision for the individual patient—pro or contra cantilever (zirconia) FDPs.

With regard to cantilevered FDPs with their exceptional position, because of the distribution of contact points affecting fatigue effects [27] and the limited long-term stability caused by sub-critical crack growth under stress [17], the authors recommend fracture-load values comparable with the load values of end-to-end FDPs before clinical use.

In summary, within the limitations of an *in-vitro* study, the results indicate that all-ceramic cantilevered FDPs cannot be recommended unreservedly for replacement of a missing tooth in the posterior region.

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