

File ID 107171  
Filename Chapter 5 Alternative veneering and core design of zirconia FPDs

---

SOURCE (OR PART OF THE FOLLOWING SOURCE):

Type Dissertation  
Title A focus on zirconia : an in-vitro lifetime prediction of zirconia dental restorations  
Author M. Rosentritt  
Faculty Faculty of Dentistry  
Year 2008  
Pages 154

FULL BIBLIOGRAPHIC DETAILS:

<http://dare.uva.nl/record/273659>

---

*Copyright*

*It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use.*

---

---

## CHAPTER 5

*Alternative veneering and core design of zirconia FPDs.*

**Keywords:** zirconia, veneering, fracture resistance, artificial aging, CAD/CAM

### 5.1 Abstract

**Objectives.** Zirconia frameworks are used as alternatives for conventional metal-supported restorations, but clinical results indicate that chipping of the veneering may not be fully excluded. The aim of this study was to investigate the capability of pressable veneering ceramics, modified core design and composite veneering as alternatives for zirconia three-unit fixed partial dentures.

**Materials and Methods.** Three-unit zirconia FPDs (n=48; Cercon Base, Degudent) were milled and eight cores per group were veneered with a laboratory composite using selective infiltration etching (C<sub>SIE</sub>) surface treatment or a phosphoric acid acrylate (C<sub>PA</sub>). FPDs with pressable ceramic veneering were investigated in press on, press over and cut-back techniques. One framework was modified by milling an additional circular embossment for an occlusal support of the ceramic layering veneering. FPDs with conventional framework-design and layering ceramic veneering were used as a reference. All restorations were adhesively luted on human molars, thermally cycled with synchronous mechanical loading and, finally, fractured in a universal testing machine.

**Results.** After TCML, median fracture results between 987 N and 1482 N were found. Composite veneering revealed values between 1136 N (C<sub>SIE</sub>) and 1443 N (C<sub>PA</sub>). For the pressable ceramic veneering 987 N, 1089 N and 1149 N were found, respectively. FPDs with modified framework showed fracture values of 1482 N.

**Conclusion.** Layering and pressable ceramic veneered FPDs showed only small differences in fracture resistance. Composite veneering on zirconia may profit from additional bonding when zirconia surface pre-treatment is performed. The core design furthermore improved the fracture resistance of FPDs.

## **5.2 Introduction**

Yttria-stabilized tetragonal zirconia ceramics are gaining importance as alternative core materials for dental applications. These high-strength ceramics (flexural strength: 800-1200 MPa) are indicated as core for all ceramic fixed partial dentures (FPDs) in stress-bearing posterior areas [1, 2]. Veneering of the zirconia core is performed for protection, function and aesthetical aspects with weaker glass ceramics with crystalline phases. For veneering, a broad offering of products is available using layering techniques, pressable alternatives or a combination of both variations. Although clinical data show no fracture of the zirconia framework, up to 15% chipping of the veneering is reported with early introduced layering veneering materials [3-7]. These failures may be a result of an inadequate relation between core and veneering, mismatch between thermal expansion coefficient, firing temperature or modulus, superficial zirconia transformation, or an influence of the integrity of the zirconia veneer interface [8-11]. The veneering ceramic with a tenfold lower reliability ( $m \sim 1 \text{ MPa} \times \text{m}^{1/2}$ ) in comparison to zirconia, may be affected especially with pre-existing bulk or surface defects [12]. During chewing, local occlusal stress may superpose with global compressive residual stress resulting in lateral cracks and chipping [13, 14].

Finite element analysis [15], fracture tests [16] and microtensile investigations [17] show a strong influence of the type of veneering, pressable or layering, as well as for the combination with liner. It has been supposed that the tensile bond strength is extremely influenced by the strength of the veneering material, reducing the strength of the combination zirconia-glass ceramic to the strength dimension of the veneering itself [17]. The question arises as to whether veneering with comparable materials but different application (press or layering technique) or different materials (composite or ceramic) with layering application may influence the overall strength and failure behaviour of FDPs, too. Furthermore, may the surface treatment of the core allow improvement of the strength of the restoration even with the application of a comparable low-strength composite material? In comparison to ceramic veneering, an occlusal composite veneering is easy to handle and may prove beneficial when the removable antagonist denture should be protected against high loading and wear. Beyond this, press techniques on frameworks with alternative marginal and occlusal design (press on, press over or press over and cut back) are supposed to influence the strength of the restoration. In comparison to layering veneering, press ceramic is applied at a 90°C higher firing temperature in combination with pressure and may, therefore, allow a better circumfluence of the core and improved adaptation. Moreover, the slow cooling rate caused by the investment may prevent large temperature differences between the core and veneer resulting in lower stress formation due to differences in thermal expansion coefficients.

Although an interfacial failure is supposedly responsible for chipping, investigations on FPDs reported failures with a thin veneering layer remaining on the zirconia core [9]. Chipping may be a result of the material combination, but it is additionally influenced by the applied load during application. Guzatto et al. [2] showed that a tetragonal–monolithic transformation is accompanied with localized stress, which may cause micro-cracks at the glass phase of the veneer. Localised stress in a bi-layer system is supposed to lead to failures in the veneering layer at a depth of some hundred microns above the core [18, 19]. Identical thickness of the veneering is reported essential for an equal distribution of the loading [15, 20], but a veneering supporting core design may further improve the strength of a restoration. The lateral chewing movement predominantly causes chipping in lingual-buccal direction. Therefore, it is supposed that an experimental modification of the framework with 1 mm circular embossment may support the veneering and increase the loading capability of a FPD. The aim of this study was to investigate the potential of veneering press ceramics, modified core design or composite veneering alternatives for zirconia three-unit FPDs. An artificial mouth was used for a time lapsed aging of the restorations simulating the influence of chewing force and temperature loading on the restoration. FPDs were controlled during aging and fracture resistance was determined after aging.

### **5.3 Materials and Methods**

For simulating the periodontium, the roots of human molars were coated with a polyether layer (1 mm thick, Impregum, Seefeld, 3M Espe). This layer allowed maximum tooth mobility in axial and vertical directions of 0.1 mm when the teeth were loaded with 50 N. Two treated teeth were inserted into PMMA resin (Palapress Vario, Kulzer, Wehrheim, Germany) forming an oral gap of 10 mm. Human molars were used to ensure a clinically relevant modulus of elasticity of the abutments and simulate a relevant bonding between FPD and tooth.

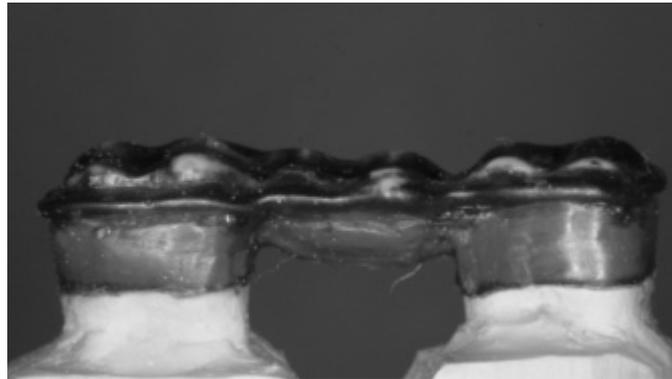
Ninety-six teeth were prepared with a 1 mm deep circular chamfer preparation for ceramic restorations. Forty-eight zirconia ceramic three-unit FPDs cores (Cercon Base, DeguDent GmbH, Germany) were fabricated according to the manufacturer's instruction with a connector cross-section of 12 mm<sup>2</sup> (height 4 mm). The Yttria-stabilized zirconia cores were milled in „white“ ceramic condition (Cercon Brain) and sintered to final dimensions (Cercon Heat) (**Table 5.1**).

**Table 5.1:** Group design, veneering material, thermal expansion and firing or polymerisation temperature.

| <b>Group</b>                                       | <b>Reference</b>                        | <b>Emboss</b>       | <b>C<sub>PA</sub></b>                                | <b>C<sub>SIE</sub></b>     | <b>P<sub>on</sub></b>   | <b>P<sub>over</sub></b>         | <b>P<sub>cut</sub></b>        |
|----------------------------------------------------|-----------------------------------------|---------------------|------------------------------------------------------|----------------------------|-------------------------|---------------------------------|-------------------------------|
| <b>Comments</b>                                    |                                         | circular embossment | Core surface treatment with phosphoric acid acrylate | SIE core surface treatment | Press on                | Press over (with Liner)         | Press over & Cut- back        |
| <b>Veneering</b>                                   | Ceramic layering technique              |                     | Composite veneering /layering technique              |                            | Ceramic press technique |                                 |                               |
|                                                    | Cercon Ceram S (DeguDent GmbH, Germany) |                     | SR Adoro (Ivoclar-Vivadent, FL)                      |                            | Cercon Ceram            | XPress (DeguDent GmbH, Germany) | Cercon Ceram XPress + Ceram S |
| <b>Thermal expansion [µm/mK] 25-500°C</b>          | 9.5                                     |                     | ~65                                                  |                            | 10.0                    |                                 |                               |
| <b>Temperature [°C] (Firing / Polymerisation*)</b> | 830                                     |                     | 104*                                                 |                            | 940                     |                                 |                               |

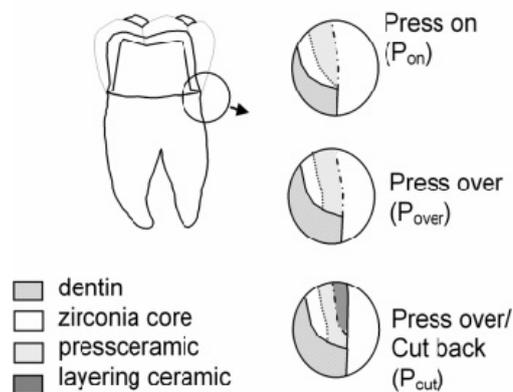
The frameworks showed a conventional design according to standard ceramic or porcelain fused to metal (PFM) techniques. For an improved mechanical support of the ceramic veneering an experimental framework was provided with a circular embossment (**Fig. 5.1**) with a height and depth of 0.8-1 mm.

**Fig. 5.1:** Core design (waxup) with circular embossment.



This framework was veneered with ceramic in the layering technique (Cercon Ceram S). Three framework groups were veneered with a pressable ceramic (Cercon Ceram Express) using different marginal and occlusal design: press on zirconia core (**P<sub>on</sub>**), press over zirconia with reduced core shoulder (**P<sub>over</sub>**) and press over core and cut the back occlusal contour (finally veneered with Cercon Ceram S) (**P<sub>cut</sub>**) (**Fig. 5.2**).

**Fig. 5.2:** Marginal design for restorations with press veneering.



Two frameworks were veneered with a composite veneering material (SR Adoro, Ivoclar-Vivadent, Schaan, FL) as an antagonist protecting veneering alternative. The laboratory veneering composite was polymerized under light and heat (104°C, Targis Power; Ivoclar-Vivadent, Schaan, FL). The treatment for the veneering was a commercially available phosphoric acid acrylate-based metal/zirconia primer (Ivoclar-Vivadent Schaan, FL) ( $C_{PA}$ ). The primer contains < 70 % tert. butyl alcohol, < 25 % methyl isobutyl ketone, < 6 % phosphonic acid acrylate and 2 % benzoylperoxide.

For the frameworks of group  $C_{SIE}$  a special surface treatment of the framework was performed called selective infiltration etching (SIE; Aboushelib MN et al.: Selective infiltration etching technique for a strong and durable bond to zirconia-based materials. *J Prosth Dent*, 2007; submitted). The basic idea of SIE is to use the grain boundary sliding mechanism that occurs during fast heating. This method is used to infiltrate the superficial layer of the PTZ framework with a glassy phase that is subsequently removed by acid etching. After removal of the glassy phase, a nanoporous surface remains, which provides interlocking with resins or other materials.

The thickness of all veneering was in clinically relevant dimensions between 0.5 and 1.5 mm. Liner was used in pressable veneering ( $P_{over}$ ). As a reference, zirconia FPDs with a standard framework and layering ceramic veneering (Cercon Ceram S) were investigated. All FPDs were adhesively luted to the abutment teeth using the dual-curing composite cement Variolink II (high viscosity) and the dentin adhesive system Syntac classic (Ivoclar-Vivadent, Liechtenstein) after total etching. All abutments were fit checked (Silasoft, Detax, Germany), adjusted and sandblasted with 50  $\mu\text{m}$  / 2 HPa before cementation.

Thermal cycling and mechanical loading (TCML) was performed to simulate a 5-year period of oral service (loading parameters: 1,200,000 mechanical loadings with 50 N and a simultaneous thermal cycling with distilled water between 5°C and 55°C; 3,000 times with 2 min each cycle). A human molar was adjusted as antagonist in a three-point contact relation on the pontic of the FPD in an articulator (AmmanGirrbach, Koblach, Austria) and both tooth and FPD were transferred to the simulator. Antagonist-tooth relation was controlled with an occlusal foil. All restorations were optically controlled during aging and failure during aging was recorded.

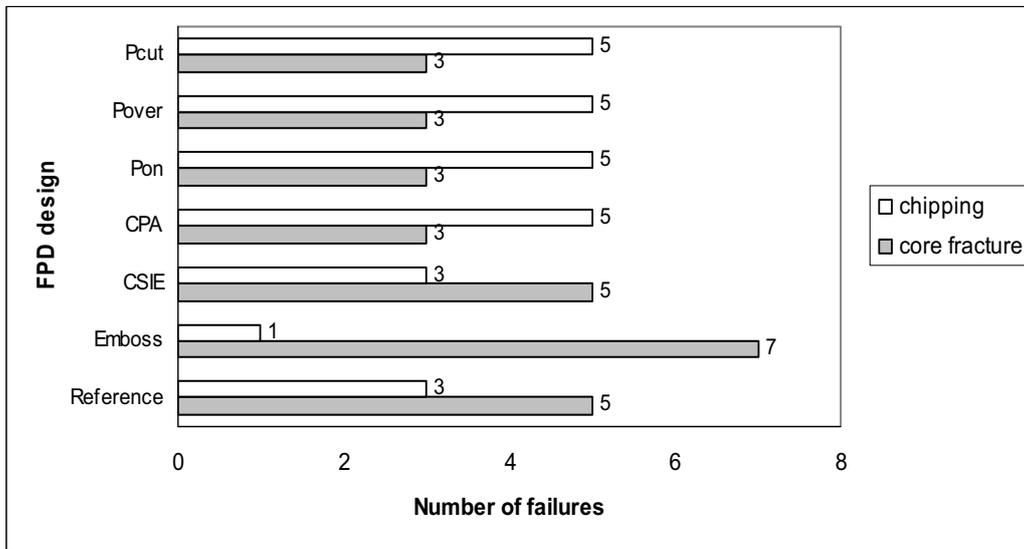
After aging, all FPDs were loaded until failure using a testing machine (Zwick, Ulm, Germany,  $v=1$  mm/min). The force was applied using a steel ball ( $d=12$  mm) while a tin foil (1 mm thickness) between pontic and antagonist was used to prevent force peaks. The FPDs were optically examined before and after fracture testing. Failure mode was divided into fracture of the veneering or the core. Medians and 25%/75% of the fracture resistance [N]

were calculated. Statistical analysis was performed using Mann Whitney-U test and two-variant Pearson correlation ( $\alpha=0.05$ ).

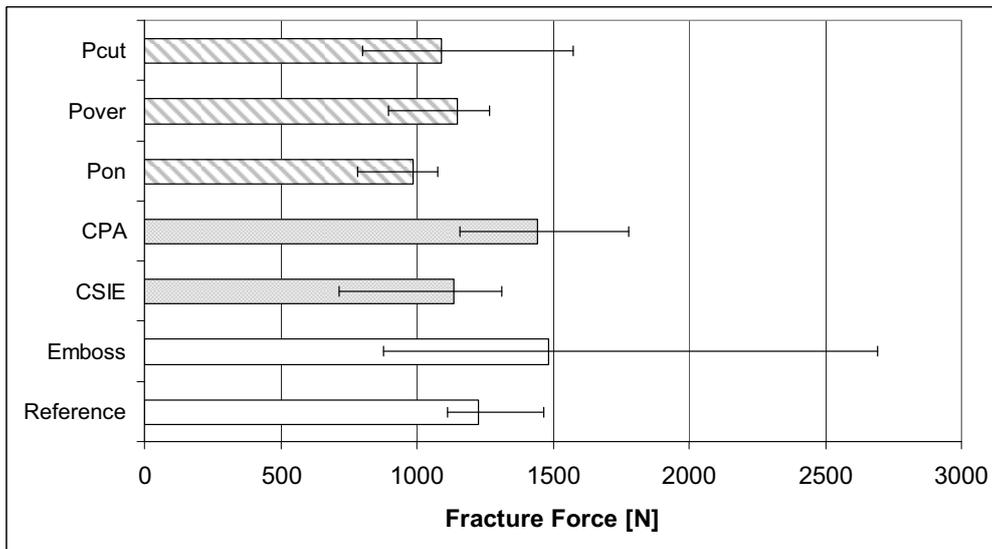
#### **5.4 Results**

The investigated systems showed fracture values after TCML from 987 N up to 1482 N. There were no statistically significant differences between the two types of composite veneering  $C_{PA}$  and  $C_{SIE}$  ( $p=0.083$ ), although the treatment with phosphoric acid acrylate revealed about 300 N higher median values. No significantly different results were found for the three press veneering techniques ( $p>0.279$ ), regardless of whether the ceramic was pressed on without liner (987 N), pressed over with liner (1149 N) or pressed over and cut back for subsequent veneering with layering technique (1089 N). The press systems provided the lowest distribution of the fracture results. Press techniques had lower results compared to the reference layering technique (1227 N), the variation with circular embossment (1482 N) and both types with composite veneering ( $C_{PA}$ : 1443 N and  $C_{SIE}$ : 1136 N). The circular embossment showed the highest median fracture results and highest individual value combined with an extreme distribution of the results. All systems survived TCML without any visible cracks or fracture of the veneering. The composite veneering showed a higher occlusal wear in comparison to the ceramic veneering. After fracture testing, two types of fracture, namely the chipping of the veneering in the connector area as well as fracture of the core was found. For all press systems and  $C_{PA}$  five chippings and three fractures of the core were found. The layering ceramic and FPDs with  $C_{SIE}$  treatment provided three chippings and five fractures. FPDs with embossment showed seven core fractures and only one chipping. Number and type of failure are provided in **Fig. 5.3** and **5.4**.

**Fig. 5.3:** Number of FDPs with different failure pattern (core fracture and chipping).



**Fig. 5.4:** Fracture force of the tested FDPs according to type and material of veneering (median, 25%/75%).



### 5.5 Discussion

All tested veneering variations on zirconia core, whether composite, layering or pressable veneering, showed median fracture resistance between 987 N and 1482 N. These results are in the same range as for other zirconia FDPs [21] and may be clinically applicable since all tested FDPs should withstand posterior chewing forces of about 500 N [22] without damage. In general, varying results between 706 N and 1900 N [23, 24] were found for zirconia FDPs

without veneering according to the testing design and material. The influence of the veneering is stated in FEA [15] and experimental investigations [10]. It was reported, that the application of a veneering ceramic increased [1] or decreased the fracture resistance of all-ceramic FPDs.

Contrary to expectations, the press ceramic veneering provided only comparable or lower fracture resistance in comparison to the conventional layering technique. Although higher bond strength was found between the zirconia and press ceramic [17], the higher application pressure and temperature that are supposed to affect flow behaviour of the ceramic and wetting of the core did not improve the strength of the FPDs. A possible explanation might be that a higher TEC of the press ceramics in comparison to the layering ceramics may have caused different residual stresses on the ceramic interface. Only a marginally different fracture pattern was found between the layering technique (5x) in comparison to press veneering (3x), in what may be a small amount of evidence for variations of the bonding between the core and veneering.

No significant differences, neither in fracture force nor fracture pattern were found between the three different types of press veneering applications. This may suggest that the application technique and marginal design are subordinate for achieving sufficient fracture resistance under the applied testing conditions. Typical FPD fracture pattern [8, 25], which are chipping and fracture from the connector area to the occlusal centre of the FPD, confirmed that the marginal areas are not involved in the damage behaviour of FPDs. Repeated mechanical loading on FPDs with inaccurate marginal adaptation would cause stress on the FPD margin. In the long term fractures from the preparation line would be initiated especially when the margin of the restoration consists of low strength veneering ceramic (press over technique). Although liner is supposed to decrease the bonding strength in combination with the pressable veneering [17], we found no reduction of fracture resistance when the liner was applied.

Astonishing results were found for the composite veneering. Although composite provided a lower modulus of elasticity than ceramic, the fracture resistance of the composite veneered FPD was in the same range as the results for the ceramic veneered FPDs and even somewhat higher than some press ceramic veneered FPDs. Reasons may be explained by a minimal or lacking chemical bonding between the inert zirconia and glass-ceramic veneering. Physically, the bond between two materials is a result from differences in the brittle/elastic/visco-elastic behaviour and shrinkage of the veneering onto the core. An influence of the core surface roughness (due to milling or surface treatment) can be assumed and sandblasting of the core may improve the micromechanical interaction. However, surface roughening may damage the core by crack initiation or reduce the bond to the veneering due to splintering of superficial ceramic layers in the long-term. During mechanical loading, local occlusal stress may

superpose with global compressive residual stress, resulting in lateral cracks and chipping [26]. The veneering ceramic with a small reliability may be affected especially with pre-existing bulk or surface defects [27]. In contrast, the composite showed a good adaptability on the zirconia core, and polymerization should cause shrinkage with mechanical interlocking onto the core. Induced local polymerization stress, which may lead to stress cracking on alloy FPDs during TCML [28], could not be found on the zirconia cores. In contrast to earlier assumptions, thermal conductivity may influence stress cracking instead of thermal expansion (alloy:  $\sim 15 \times 10^{-6} \text{ K}^{-1}$ , zirconia:  $\sim 10 \times 10^{-6} \text{ K}^{-1}$  and composite  $\sim 65 \times 10^{-6} \text{ K}^{-1}$ ). A striking result is found regarding the pre-treatment of the zirconia before the composite was applied. The SIE treatment, which uses a grain boundary sliding mechanism that occurs during fast heating to infiltrate the superficial layer of the PTZ framework with a glassy phase, showed good fracture resistance. Superior values were found with a phosphoric acid acrylate. These results underline the necessity of the core treatment on the bonding and, finally, strength of the FPDs. Phosphoric acid treatment might improve the wettability of the zirconia surface with the composite, but more probable is the fact that a chemical bonding is achieved between phosphoric parts of the bonding agent and the zirconia surface on the one side and the bonding agent and the composite on the other side [29]. Although SEM pictures illustrate the difference between the zirconia surface with SIE or phosphoric acid acrylate treatment, further investigations should be performed.

Beside the influence of veneering material and zirconia treatment on fracture resistance, modified FPD design caused surprising results. Although median values were in the same range of all other tested systems, extreme high forces – up to 2692 N! - were found. These results may, on one hand, be attributed to an increased cross-section of the core, but on the other hand, may confirm the influence of a veneering supporting core design on the overall strength of FPDs. Especially in applications for patients with high chewing forces, such framework design may help to avoid early failure of the veneering. It may be supposed that the high deviation of the results may be attributed to the thickness variations and crack initiation during milling of the embossment. Further investigations on this topic should be performed.

Summarizing, the results indicate that small increases in fracture resistance of FPDs may be achieved with layering ceramic veneering in comparison to press-ceramic alternatives. The strength of the FPDs seemed to depend on the properties of the veneering ceramic itself. Composite veneering on zirconia may profit from additional bonding after the zirconia surface treatment, and the design of the framework may furthermore improve the fracture resistance of FPDs.

## 5.6 References

1. Tinschert J, Natt G, Mautsch W, Augthun M, Spiekermann H. Fracture resistance of lithium disilicate-, alumina-, and zirconia-based three-unit fixed partial dentures: a laboratory study. *Int J Prosthodont* 2001;14:231-238.
2. Guazzato M, Albakry M, Ringer SP, Swain MV. Strength, fracture toughness and microstructure of a selection of all-ceramic materials. Part II. Zirconia-based dental ceramics. *Dent Mater* 2004;20:449-456.
3. Bornemann G, Rinke S, Huels A. Prospective clinical trial with conventionally luted zirconia-based fixed partial dentures-18-month results. *IADR/CED 2003 #842*.
4. Sailer I, Feher A, Filser F, et al. Prospective clinical study of zirconia posterior fixed partial dentures: 3-year follow-up. *Quint Inter* 2006;37:685-693.
5. Pospiech P, Nothdurft FP. Long-term behaviour of zirconia-based bridges: three years results. *IADR 2004 #230*.
6. Vult von Steyern P, Carlson P, Nilner K. All-ceramic fixed partial dentures designed according to the DC-Zirkon technique. A 2-year clinical study. *J Oral Rehabil* 2005;32:180-187.
7. Raigrodski AJ, Chiche GJ, Potiket N, Hochstedler JL, Mohamed SE, Billiot S, Mercante DE. The efficacy of posterior three-unit zirconium-oxide-based ceramic fixed partial dental prostheses: a prospective clinical pilot study. *J Prosthet Dent* 2006;96:237-244.
8. Kelly JR, Tesk JA, Sorenson JA. Failure of All-ceramic Fixed Partial Dentures in vitro and in vivo: Analysis and Modeling. *J Dent Res* 1995;74:1253-1258.
9. Sundh A, Sjogren G. A comparison of fracture strength of yttrium-oxide- partially-stabilized zirconia ceramic crowns with varying core thickness, shapes and veneer ceramics. *J Oral Rehabil* 2004;31:682-688.
10. Taskonak B, Mecholsky JJ, Jr., Anusavice KJ. Residual stresses in bilayer dental ceramics. *Biomater* 2005;26:3235-3241.
11. Isgro G, Pallav P, van der Zel JM, Feilzer AJ. The influence of the veneering porcelain and different surface treatments on the biaxial flexural strength of a heat-pressed ceramic. *J Prosthet Dent* 2003;90:465-473.
12. Curtis AR, Wright AJ, Fleming GJ. The influence of simulated masticatory loading regimes on the bi-axial flexure strength and reliability of a Y-TZP dental ceramic. *J Dent* 2006;34:317-325.
13. Deng Y, Miranda P, Pajares A, Guiberteau F, Lawn BR. Fracture of ceramic/ ceramic/ polymer trilayers for biomechanical applications. *J Biomed Mat Res Part A* 2003;67:828-833.
14. Hutchinson JW, Suo Z. Mixed mode cracking in layered ceramics. *Adv Appl Mech* 1992;29:163-191.

15. De Jager N, Pallav P, Feilzer AJ. The influence of design parameters on the FEA-determined stress distribution in CAD-CAM produced all-ceramic dental crowns. *Dent Mater* 2005;21:242-251.
16. Thompson GA, Rekow DE. Dental Ceramics and the molar crown testing. *J Appl Oral Sci* 2004;12:26-36.
17. Aboushelib MN, Kleverlaan CJ, Feilzer AJ. Microtensile bond strength of different components of core veneered all-ceramic restorations. Part II: Zirconia veneering ceramics. *Dent Mater* 2006; 22: 857-863.
18. Thompson GA. Influence of relative layer height and testing method on the failure mode and origin in a bilayered dental ceramic composite. *Dent Mater* 2000;16:235-243.
19. Jung YG, Wuttiphan, S, Peterson IM, Lawn BR. Damage modes in dental layer structures. *J Dent Res* 1999 78:887-897.
20. Lawn BR, Deng Y, Lloyd IK, Janal MN, Rekow ED, Thompson VP. Materials design of ceramic-based layer structures for crowns. *J Dent Res* 2002;81:433-438.
21. Rosentritt M, Behr M, Lang R, Handel G. Experimental design of FPD made of all-ceramics and fibre-reinforced composite. *Dent Mater* 2000;16:159-165.
22. Jung YG, Peterson IM, Kim DK, Lawn BR. Lifetime-limiting strength degradation from contact fatigue in dental ceramics. *J Dent Res* 2000;79:722-731.
23. Filser F, Lüthy H, Kocher P, Schärer P, Gauckler LJ. High load bearing, high reliable all-ceramic dental bridges ba the direct ceramic machining process. *Eur Cells Mat* 2001;1:7-8.
24. Sundh A, Sjogren G. Fracture resistance of all-ceramic zirconia bridges with differing phase stabilizers and quality of sintering. *Dent Mater* 2006;22:778-784.
25. Taskonak B, Mecholsky JJ Jr, Anusavice KJ. Fracture surface analysis of clinically failed fixed partial dentures. *J Dent Res* 2006;85:277-281.
26. Hutchinson JW SZ. Mixed mode cracking in layered materials. *Adv Appl Mech* 1992;29:163-191.
27. Curtis AR, Wright AJ, Fleming GJ. The influence of surface modification techniques on the performance of a Y-TZP dental ceramic. *J Dent* 2006;34:95-106.
28. Rosentritt M, Behr M, Bruckner H, Handel G. Composite veneering of metal based fixed partial dentures. *J Oral Rehabil* 2005;32:614-619.
29. Yoshida K, Tsuo Y, Atsuta M. Bonding of dual-cured resin cement to zirconia ceramic using phosphate acid ester monomer and zirconate coupler. *J Biomed Mat Res Part B, Appl Biomater* 2006;77:28-33.

