Clin Oral Invest (2009) 13:445–451
DOI 10.1007/s00784-009-0249-5

ORIGINAL ARTICLE

Three-year clinical prospective evaluation of zirconia-based posterior fixed dental prostheses (FDPs)

Florian Beuer · Daniel Edelhoff · Wolfgang Gernet · John A. Sorensen

Received: 5 August 2008 / Accepted: 12 January 2009 / Published online: 24 January 2009
© Springer-Verlag 2009

Abstract This clinical study evaluated posterior three-unit fixed dental prostheses (FDPs) made of zirconia substructures veneered with pressable glass–ceramic. Nineteen patients received 21 FDPs replacing either the second premolar, first molar, or second molar. The FDPs were cemented with glass ionomer. Recall examinations were performed every 12 months. The mean service time of the FDP was 40 months. At 30 months, one maxillary FDP exhibited zirconia framework fracture at a thinned occlusal area of the abutment. Loss of retention led to the removal of one FDP after 38 months. The Kaplan–Meier survival probability was 90.5% after 40 months for all types of failures and 95.2% concerning framework fractures. The overpressing technique appears to be reliable in terms of the veneering material. However, one framework fracture was observed in this study.

Keywords Fixed dental prosthesis · Zirconia · Overpressing technique · Conventional cementation · Framework fracture

Introduction

Clinical studies on all-ceramic posterior fixed dental prostheses (FDPs) have recorded high failure rates [16, 21, 22, 33]. Long-term clinical studies evaluating the performance of FDPs made with glass-infiltrated alumina cores showed failure rates of 10% to 12% after 5 years [20, 40]. In contrast, according to the literature, metal–ceramic prostheses have demonstrated failure rates of 1% per year or less [7, 30, 42]. As alternative to glass-infiltrated ceramics, lithia disilicate materials are available. However, fracture rates of 7% after 2 years [8] and 13.3% after 4 years [9] were observed while fractured FDPs were associated with insufficient connector heights. Several studies have shown that zirconia has sufficient strength to function as substructure for posterior FDPs [3, 17, 23, 25, 38, 41]. The load-bearing capacity of three-unit or multiunit FDPs investigated in several in vitro studies exhibited exceptionally high fracture values [4, 13, 15, 36]. Available data on three- to five-unit FDPs with zirconia frameworks reported a 97.8% success rate after 5 years concerning substructure [26]. However, the particular computer-aided manufacturing (CAM) system tested produced restorations with poor marginal fit, resulting in a high rate of marginal caries leading to removal of several FDPs [26]. Studies using fully sintered hot isostatic pressed zirconia ceramic did not report poor marginal fit [17, 38, 41]. Improved marginal accuracy can be achieved by heat-pressing technique [24, 32]. The combination of the veneer overpressing technique and high-strength substructure material could potentially produce a better clinical outcome. Pressing a ceramic margin onto a zirconia framework combines the stability of the zirconia framework and the marginal fit of a heat-pressed material.

Several clinical studies have reported chipping of veneering porcelain [17, 23, 26, 28, 38, 41]. However, in vitro studies have demonstrated a sound bond between zirconia and veneering material [1, 2]. Cohesive superficial failures of the veneering porcelain were the observed failure mode exhibited in clinical studies [17, 23, 28, 38, 41]. A potential reason may be that the powder buildup technique

F. Beuer (✉) · D. Edelhoff · W. Gernet
Department of Prosthodontics, Ludwig Maximilians University,
Goethestr. 70,
80336 Munich, Germany
e-mail: florian.beuer@med.uni-muenchen.de

J. A. Sorensen
Pacific Dental Institute,
12750 SW 68th Avenue,
97223 Portland, OR, USA

frequently results in the incorporation of voids and flaws [39]. Use of more stable veneering materials might reduce the chipping rate compared to traditional veneering porcelains. The porcelains used in the powder technique have a flexural strength in the range of 80 MPa [10] while the ceramics used for the overpressing technique to veneer zirconia show a flexural strength of 120 MPa (product information, DeguDent). However, several in vitro studies reported no difference in load-bearing capacity of crown systems with overpressed veneering ceramics and powder buildup veneering porcelain [6, 39].

The hypothesis is that FDPs fabricated by overpressing zirconia substructures will have fewer complications than conventional powdered porcelain veneering techniques. The aim of this prospective study was to evaluate the long-term clinical performance of posterior three-unit FDPs using a new overpressing material for veneering zirconia substructures.

Materials and methods

Nineteen patients (12 women, seven men) in need of at least one FDP in the posterior region were recruited for the study. The requirements of the Helsinki Declaration were observed and the patients gave informed consent. The ethical board of Munich University has reviewed and approved the study design. In accordance with the requirements for prosthetic restorations, the prospective abutment teeth had to meet the following clinical criteria: periodontally healthy, vital or endodontically treated, sufficient length of the clinical crown (>5 mm), good oral hygiene, and opposing natural teeth or fixed prosthesis. Patients with severe occlusal parafunctions and temporomandibular disorders according to the system of research diagnostic criteria for temporomandibular disorders were not included [11, 12, 29].

Twelve FDPs were placed in the maxilla and nine in the mandible. The FDPs replaced eight premolars, 12 first molars, and one second molar.

Prosthodontic procedures

Control teeth were chosen as a comparison to the future abutment teeth. Control teeth had to be caries free, uncrowned, and contralateral or opposite from the abutment teeth. Pulp vitality, plaque index (PI) according to Silness/Loe [14, 31], bleeding index according (BI) to Muehlemann [18], pocket-probing depth (PPD), and clinical tooth mobility [19] were obtained prior to prosthodontic treatment.

Three experienced clinicians treated all patients. The abutment teeth were prepared as follows:

Margin design, 360° rounded shoulder/chamfer
Axial reduction at margin, 1.2 mm
Occlusal reduction, 1.5 to 2.0 mm
Total occlusal convergence, 6–8°
Particular attention was paid to rounded line angles

Following tooth preparation, direct temporary FDPs were fabricated (Protemp 3 Garant, 3 M ESPE) and cemented (Freegenol, GC Europe) allowing at least 10 days for the gingiva to recover after the preparation trauma. At the next appointment, the temporary FDPs were removed and retraction cords (Ultrapak, Ultradent) were placed according to the V-technique. Therefore, a thin retraction cord (size 00, Ultrapak) was placed in the sulcus first and a second retraction cord was placed above (size 1, Ultrapak). The upper retraction cord was removed after 10 min and a polyether impression (Impregum, 3 M ESPE) was made using a customized impression tray (Orbilock, Orbis Dental). An interocclusal record was made with self-polymerizing polyvinyl siloxane (Futar D, Kettenbach) and the temporary FDP was cemented as described above.

All frameworks were manufactured by a CAM system (Cercon, DeguDent). First, the frameworks were manually fabricated on the master cast out of wax (Nawax compact, Yeti Dental Products) similar to the metal–ceramic technique. All frameworks were cut back in the margin area 1 mm above the margin facilitating a shoulder made of glass–ceramic by the overpressing technique. The shape of the wax frameworks was mechanically captured and digitized, and the data were enlarged by 30%. Next, the frameworks were milled from presintered zirconia blanks. The milled enlarged frameworks were sintered to full density at a temperature of 1,350°C, resulting in shrinkage to the original wax framework dimensions.

Frameworks were checked for fit and adapted according to the literature [5, 43]. After the adaptation process, the thickness of the substructure was measured at defined points (Fig. 1) and documented.

Cercon Ceram Express, a new overpressing veneering ceramic with the correct coefficient of thermal expansion to match zirconia, was developed by DeguDent. An anatomical wax-up was made on the zirconia framework, invested

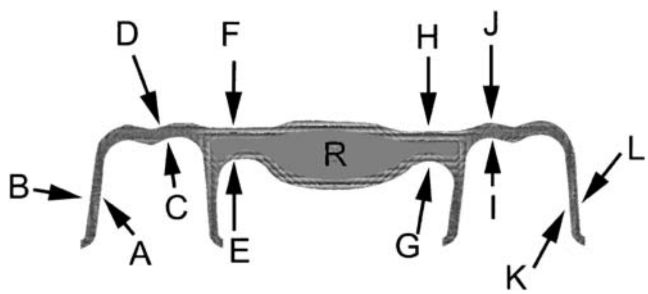

Fig. 1 Diagram of the zirconia substructure exhibiting different measurement locations to control and document the substructure thicknesses. *Letters A* to *F* represent the mesial abutment; *letters G* to *L* exhibit the distal abutment

and overpressed according to the manufacturer's directions. The overpressed anatomically shaped FDP was tried in; the occlusal contacts were marked and adjusted using a red ring Diamante ball instrument (Brasseler, Komet) with water-cooling spray. The temporary restoration was cemented again and the FDP was finished in the dental laboratory by additional veneering if esthetically necessary (Cercon Ceram S, DeguDent) and a final glazing.

After aluminum oxide abrasion (50-µm particle size, 500-HPa pressure) and degreasing (80% ethanol) of the internal retainer walls, the FDPs were cemented (Ketac Cem Aplicap, 3 M ESPE). In situations where the occlusion required adjustment, the ground surfaces were polished using special ceramic polishers (Identoflex, KerrHawe) with three coarseness levels at a speed of 5,000 rotations per minute with water-cooling spray.

Baseline evaluation

At least 14 days after cementation, the baseline examination was performed. Pulp vitality of abutment and control teeth was tested using liquid carbon oxide. PPD of the abutment teeth and the reference teeth at two sites per tooth was assessed. Plaque index, bleeding index, tooth mobility, static, and dynamic occlusal contacts were checked and documented. Clinical photographs were taken of each patient. Alginate impressions of both jaws were made to fabricate study casts. Precision impressions (Aquasil, Dentsply) were made of each FDP. The patient and the dentist rated the overall esthetics and function on a visual analog scale (VAS; 0 = worst, 10 = best).

Follow-up examinations

At each annual recall appointment, the patients were examined for technical and biological complications of their FDP. Clinical examination and intraoral photographs were used to assess the following technical parameters: framework fracture, fracture or chipping of the veneering material, caries, and the relation of the crown margin to the soft tissue. Further, the periodontal parameters and the occlusal analysis were documented. Again, impressions were made as described above. Finally, the patients were asked to score their FDP again in terms of functional and esthetic outcome.

Statistical analysis

The obtained data were evaluated using a statistical program (SPSS 15.0, SPSS Inc.). Descriptive statistics were applied to the data. An analysis of survival according to Kaplan–Meier was performed on all failures and on framework fractures. A comparison of PI, BI, and PPD between test and control teeth and comparison between pretreatment and 3-year posttreatment were carried out using the Wilcoxon test. The VAS score concerning esthetics and function was evaluated for differences in the patients' and the dentists' judgment using the Wilcoxon test. The level of significance was set at 5%.

Results

The subject recall rate was 100% allowing evaluation of all inserted FDPs after 3 years. The mean age of the patients was 50.9 years (range from 27 to 71 years). One endodontic treatment was performed after 14 months on a mandibular second molar demanded by the patient's wish to eliminate cold sensitivity. The endodontic treatment access hole was sealed with composite resin filling material.

No chipping of veneering porcelain was observed.

After a mean observation time of 40 months (range 37 to 44 months), two FDPs required replacement.

One framework fracture occurred after a 30-month service time: the mesial abutment of an FDP replacing a maxillary first molar fractured from buccal to palatal (Fig. 2). The antagonist tooth was covered by a composite crown. Fractographic analysis revealed a zirconia coping thickness of 0.3 mm at the origin of the fracture and occlusal contact on the framework in this area (Figs. 3 and 4). The measured thickness of the substructures is presented in Table 1.

Loss of retention occurred on a distal abutment of a mandibular FDP replacing the first molar. The FDP was removed by the emergency dentist.

The survival rate of all FDPs placed was 90.5% after 40 months in service (Fig. 5). The success rate for the zirconia substructures after 40 months was 95.2% according to Kaplan–Meier.

The evaluation of the periodontal parameters is shown in Table 2. Plaque index, bleeding index, and pocket-probing

Fig. 2 Detailed view of fractured retainer

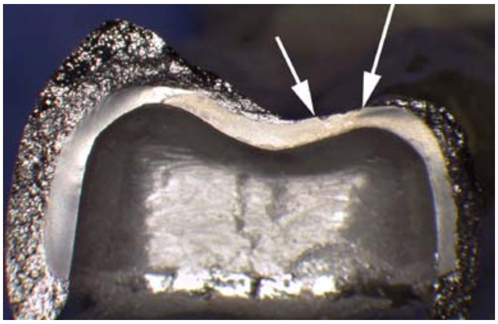

Fig. 3 Sputter-coated fractured retainer after removing; the crack had the origin in the area marked with *white arrows*

depth did not change significantly over the clinical service time of the FDPs.

The overall esthetics of the FDP showed a mean (SD) value of 7.4 (1.9) scored by dentists and 9.5 (0.9) scored by patients on the VAS. The difference was significant ($p<0.001$). Evaluation of overall function of the FDP failed to show significant difference ($p=0.719$) while dentist and patients scored a mean VAS score (SD) of 8.9 (2.1) and 9.1 (2.0), respectively.

Discussion

The success rate of posterior FDPs with overpressed zirconia frameworks was 95.2% after 3 years. One FDP fractured at 30 months at the mesial abutment. Hence, zirconia as a framework material exhibits better clinical stability compared to previously used all-ceramic systems [23, 25, 26, 28, 41]. Flaws induced to the exposed zirconia substructure while adjusting the occlusal surface was the most probable course of failure. Expansion of investing material in the mold during the heating process could have caused tension to the zirconia substructure. As ceramics are brittle materials, their resistance against tension is low [35, 37]. High pressure is developed during the pressing process, which might have been another factor causing the fracture [8, 9, 34]. Also, high pressures could have caused surface damages.

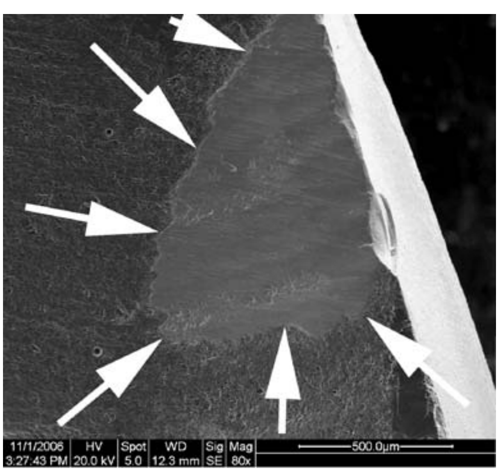

Fig. 4 SEM picture of the fractured retainer; zirconia substructure exposed on the occlusal surface at the area marked with *white arrows*

Table 1 Zirconia substructure thickness at different measurement locations

Measurement Location	Minimum thickness (mm)	Maximum thickness (mm)	Mean thickness (mm)	Standard deviation (mm)
Connection between points A and B	0.4	0.7	0.6	0.1
Connection between points C and D	0.3	1.0	0.7	0.2
Cross section mesial connector (connection between points E and F)	10.0	16.0	12.2	1.4
Cross section distal connector (connection between points G and H)	11.0	17.0	13.3	1.6
Connection between points I and J	0.5	1.2	0.7	0.2
Connection between points K and L	0.4	0.8	0.5	0.1

The most important factor was the 0.3-mm thickness of coping, which was due to underreduction of the occlusal surface (Fig. 3). The occlusal surface of the FDP had to be adjusted resulting in the exposure of the zirconia surface (Fig. 4). Damage on the surface could have been the onset of the fracture. However, achieving a reproducible minimum thickness is almost impossible when a CAM system is used because it duplicates the manually fabricated wax-up. It is possible that framework thicknesses below the recommended 0.4 mm can occur as result of manual fabrication. A computer-aided design/CAM system facilitates a defined reproducible minimum thickness of the framework material. In addition, more research has to be carried out to determine the minimum zirconia substructure thickness for the overpressing technique.

Clinical studies that used the powdered porcelain buildup technique reported chipping rates of 20% after 31 months [23], 8% after 37 months [38], 15.2% [26] and 30% after 5 years [17]. A systematic review reported estimated rates of ceramic chipping per year for metal–

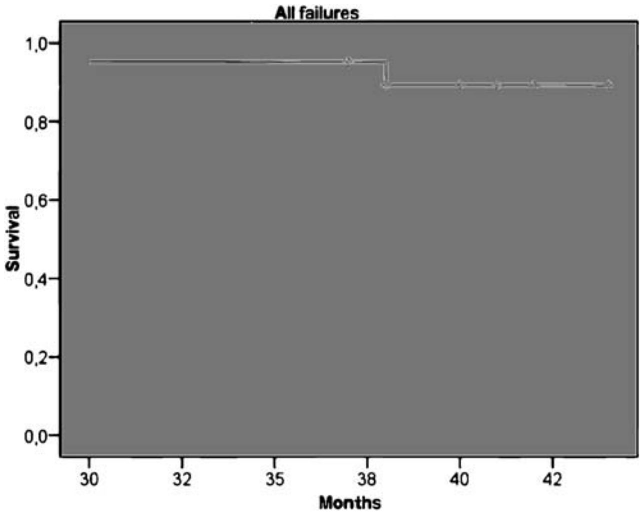

Fig. 5 Survival analysis of restorations in service

ceramic FDP and all-ceramic FDP of 0.59% and 2.92%, respectively [28].

In all-ceramic systems, the flaw population (size, number, and distribution) can be related to the material or be affected by the fabrication process. Thus, it might be expected that overpressing has a higher density and introduces fewer flaws than layering, resulting in better strength properties, as it is a more controlled procedure [24, 39]. In comparison, the powder buildup technique is less controlled and subject to variability due to the individual building and firing procedures. However, no significant differences in the fatigue and fracture properties following overpressing or powder buildup of the veneering material could be found in vitro [6, 39]. Another laboratory study reported similar load-bearing capacities of overpressing and powder buildup veneering materials. Core fractures were observed in specimens veneered with overpressing material explaining the failure of this study [6]. As the fracture of veneering porcelain is of a complex nature, more in vitro studies and clinical trials are required to understand this multifactor subject.

The second FDP, which was removed, lost retention at the distal abutment after 38 months. This could not be explained by the preparation design as the master cast was examined after the failure occurred. The height of the abutment tooth preparation was 4.5 mm and the preparation angle was according to the study guidelines. The conventional cementation protocol could have caused this failure. Another study, which used adhesive luting for zirconia FDPs, also reported loss of retention [26]. The estimated risk of loss of retention was reported 0.47% per year for all-ceramic FDP while metal–ceramic FDP showed 0.66% per year [28]. Good results of this study can be explained by the clinical approach with four appointments. Making impressions at least 10 days after preparation guaranteed stable soft tissue conditions without difficulties caused by gingiva inflammation. This resulted in highly precise impressions, master casts, and restorations and could have influenced periodontal parameters and caries activity at the abutments positively. An additional appointment for try-in of the overpressed FDPs assured that no corrections of the occlusal surface had to be made before cementing the FDPs in the following appointment. The surface quality could have influenced the chipping rate in this study positively. However, the described prosthetic concept has been established as a standard protocol at the authors' institutions.

The periodontal parameters of the retainers and control teeth were not significantly different. This concurs with the results of other clinical studies and indicates the biocompatibility of this type of fixed prosthesis [27, 38, 41]. In addition, no effect of the restoration on the periodontal parameters was detected after 3 years.

After staining and glazing of the FDPs, sufficient esthetics were achieved. However, the dentists were more critical with their judgement in terms of esthetics compared to the patients.

Table 2 Wilcoxon test performed on periodontal parameters, level of significance 5%

Compared parameters	*p* value according to the Wilcoxon test
PI mesial retainer before treatment PI mesial retainer after 3 years	0.712
PI distal retainer before treatment PI distal retainer after 3 years	0.200
PI control tooth before treatment PI control tooth after 3 years	0.248
BI mesial retainer before treatment BI mesial retainer after 3 years	0.217
BI distal retainer before treatment BI distal retainer after 3 years	0.109
BI control tooth before treatment BI control tooth after 3 years	0.055
PBD mesial retainer before treatment PBD mesial retainer after 3 years	0.197
PBD distal retainer before treatment PBD distal retainer after 3 years	0.332
PBD control tooth before treatment PBD control tooth after 3 years	0.564
PI mesial retainer after 3 years PI control tooth after 3 years	0.284
PI distal retainer after 3 years PI control tooth after 3 years	0.180
BI mesial retainer after 3 years BI control tooth after 3 years	0.225
BI distal retainer after 3 years BI control tooth after 3 years	0.957
PBD mesial retainer after 3 years PBD control tooth after 3 years	0.317
PBD distal retainer after 3 years PBD control tooth after 3 years	0.244

Finally, the patient and dentist satisfaction with function of the overpressed zirconia FDPs was comparable to previous studies [25, 26, 38].

Conclusion

According to the results of this clinical study, the following conclusions can be drawn:

- Zirconia frameworks veneered by an overpressed ceramic exhibited sufficient strength for three-unit posterior FDP.
- The overpressing technique for veneering porcelain exhibited no chipping.
- Future research should be aimed at determining the minimum framework thickness for the overpressing technique for veneering.

Acknowledgments This study was funded by DeguDent. The authors wish to sincerely thank Josef Schweiger, Marlis Eichberger, and John Meinen for fabricating the restorations at the laboratory of Munich Dental School.

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Aboushelib MN, de Jager N, Kleverlaan CJ, Feilzer AJ (2005) Microtensile bond strength of different components of core veneered all-ceramic restorations. Dent Mater 21:984–991
2. Aboushelib MN, Kleverlaan CJ, Feilzer AJ (2006) Microtensile bond strength of different components of core veneered all-ceramic restorations. Part II: zirconia veneering ceramics. Dent Mater 22:857–863
3. Barnfather KD, Brunton PA (2007) Restoration of the upper dental arch using Lava all-ceramic crown and bridgework. Br Dent J 202:731–735
4. Beuer F, Steff B, Naumann M, Sorensen J (2008) Load-bearing capacity of all-ceramic three-unit fixed partial dentures with different computer-aided design (CAD)/computer-aided manufacturing (CAM) fabricated materials. Eur J Oral Sci 116:381–386
5. Beuer F, Aggstaller H, Edelhoff D, Gernet W, Sorensen J (2009) Marginal and internal fits of fixed dental prostheses zirconia retainers. Dent Mater 25:94–102
6. Beuer F, Schweiger J, Eichberger M, Kappert HF, Gernet W, Edelhoff D (2009) High-strength CAD/CAM-fabricated veneering material sintered to zirconia copings—a new fabrication mode for all-ceramic restorations. Dent Mater 25:121–128
7. Creugers NH, Kayser AF, van 't Hof MA (1994) A meta-analysis of durability data on conventional fixed bridges. Community Dent Oral Epidemiol 22:448–452
8. Esquivel-Upshaw JF, Anusavice KJ, Young H, Jones J, Gibbs C (2004) Clinical performance of a lithia disilicate-based core ceramic for three-unit posterior FPDs. Int J Prosthodont 17:469–475
9. Esquivel-Upshaw JF, Young H, Jones J, Yang M, Anusavice KJ (2008) Four-year clinical performance of a lithia disilicate-based core ceramic for posterior fixed partial dentures. Int J Prosthodont 21:155–160
10. Herrero AA, Sierraalta M, Razzoog ME (2006) Flexural strength of several porcelain systems for zirconium ceramics. J Dent Res 85:abstract 1355
11. John MT, Zwijnenburg AJ (2001) Interobserver variability in assessment of signs of TMD. Int J Prosthodont 14:265–270
12. John MT, Hirsch C, Reiber T, Dworkin S (2006) Translating the research diagnostic criteria for temporomandibular disorders into German: evaluation of content and process. J Orofac Pain 20:43–52
13. Kohorst P, Herzog TJ, Borchers L, Stiesch-Scholz M (2007) Load-bearing capacity of all-ceramic posterior four-unit fixed partial dentures with different zirconia frameworks. Eur J Oral Sci 115:161–166
14. Loe H, Silness J (1963) Periodontal disease in pregnancy. I. Prevalence and severity. Acta Odontol Scand 21:533–551
15. Luthy H, Filser F, Loeffel O, Schumacher M, Gauckler L, Hammerle CH (2005) Strength and reliability of four unit all-ceramic posterior bridges. Dent Mater 21:930–937
16. Marquardt P, Strub JR (2006) Survival rates of IPS empress 2 all-ceramic crowns and fixed partial dentures: results of a 5-year prospective clinical study. Quintessence Int 37:253–259
17. Molin MK, Karlsson SL (2008) Five-year clinical prospective evaluation of zirconia-based Denzir 3-unit FPDs. Int J Prosthodont 21:223–227
18. Muehlemann HR, Schroeder HE (1964) Dynamics of supragingival calculus formation. Adv Oral Biol 1:175–203
19. O'Leary T (1974) Indices for measurement of tooth mobility in clinical studies. J Periodontal Res Suppl 14:94–105
20. Olsson KG, Furst B, Andersson B, Carlsson GE (2003) A long-term retrospective and clinical follow-up study of In-Ceram Alumina FPDs. Int J Prosthodont 16:150–156
21. Raigrodski AJ, Chiche GJ (2002) All-ceramic fixed partial dentures, Part I: in vitro studies. J Esthet Restor Dent 14:188–191
22. Raigrodski AJ, Chiche GJ, Swift EJ Jr. (2002) All-ceramic fixed partial dentures, Part III: clinical studies. J Esthet Restor Dent 14:313–319
23. Raigrodski AJ, Chiche GJ, Potiket N, Hochstedler JL, Mohamed SE, Billiot S et al (2006) The efficacy of posterior three-unit zirconium-oxide-based ceramic fixed partial dental prostheses: a prospective clinical pilot study. J Prosthet Dent 96:237–244
24. Ries S, Wolz J, Richter EJ (2006) Effect of design of all-ceramic resin-bonded fixed partial dentures on clinical survival rate. Int J Periodontics Restorative Dent 26:143–149
25. Sailer I, Feher A, Filser F, Luthy H, Gauckler LJ, Scharer P et al (2006) Prospective clinical study of zirconia posterior fixed partial dentures: 3-year follow-up. Quintessence Int 37:685–693
26. Sailer I, Feher A, Filser F, Gauckler LJ, Luthy H, Hammerle CH (2007) Five-year clinical results of zirconia frameworks for posterior fixed partial dentures. Int J Prosthodont 20:383–388
27. Sailer I, Holderegger C, Jung RE, Suter A, Thievent B, Pietrobon N et al (2007) Clinical study of the color stability of veneering ceramics for zirconia frameworks. Int J Prosthodont 20:263–269
28. Sailer I, Pjetursson BE, Zwahlen M, Hammerle CH (2007) A systematic review of the survival and complication rates of all-ceramic and metal-ceramic reconstructions after an observation period of at least 3 years. Part II: fixed dental prostheses. Clin Oral Implants Res 18(Suppl 3):86–96
29. Schmitter M, Ohlmann B, John MT, Hirsch C, Rammelsberg P (2005) Research diagnostic criteria for temporomandibular disorders: a calibration and reliability study. Cranio 23:212–218
30. Scurria MS, Bader JD, Shugars DA (1998) Meta-analysis of fixed partial denture survival: prostheses and abutments. J Prosthet Dent 79:459–464
31. Silness J, Loe H (1964) Periodontal disease in pregnancy. Ii. Correlation between oral hygiene and periodontal condition. Acta Odontol Scand 22:121–135

32. Sulaiman F, Chai J, Jameson LM, Wozniak WT (1997) A comparison of the marginal fit of In-Ceram, IPS Empress, and Procera crowns. Int J Prosthodont 10:478–484
33. Taskonak B, Mecholsky JJ Jr, Anusavice KJ (2006) Fracture surface analysis of clinically failed fixed partial dentures. J Dent Res 85:277–281
34. Taskonak B, Sertgoz A (2006) Two-year clinical evaluation of lithia-disilicate-based all-ceramic crowns and fixed partial dentures. Dent Mater 22:1008–1013
35. Tinschert J, Zwez D, Marx R, Anusavice KJ (2000) Structural reliability of alumina-, feldspar-, leucite-, mica- and zirconia-based ceramics. J Dent 28:529–535
36. Tinschert J, Natt G, Mautsch W, Augthun M, Spiekermann H (2001) Fracture resistance of lithium disilicate-, alumina-, and zirconia-based three-unit fixed partial dentures: a laboratory study. Int J Prosthodont 14:231–238
37. Tinschert J, Natt G, Mohrbotter N, Spiekermann H, Schulze KA (2007) Lifetime of alumina- and zirconia ceramics used for crown and bridge restorations. J Biomed Mater Res B Appl Biomater 80:317–321
38. Tinschert J, Schulze KA, Natt G, Latzke P, Heussen N, Spiekermann H (2008) Clinical behavior of zirconia-based fixed partial dentures made of DC-Zirkon: 3-year results. Int J Prosthodont 21:217–222
39. Tsalouchou E, Cattell MJ, Knowles JC, Pittayachawan P, McDonald A (2008) Fatigue and fracture properties of yttria partially stabilized zirconia crown systems. Dent Mater 24:308–318
40. Vult von Steyern P, Jonsson O, Nilner K (2001) Five-year evaluation of posterior all-ceramic three-unit (In-Ceram) FPDs. Int J Prosthodont 14:379–384
41. Vult von Steyern P, Carlson P, Nilner K (2005) All-ceramic fixed partial dentures designed according to the DC-Zirkon technique. A 2-year clinical study. J Oral Rehabil 32:180–187
42. Walter M, Reppel PD, Boning K, Freesmeyer WB (1999) Six-year follow-up of titanium and high-gold porcelain-fused-to-metal fixed partial dentures. J Oral Rehabil 26:91–96
43. Witkowski S, Komine F, Gerds T (2006) Marginal accuracy of titanium copings fabricated by casting and CAD/CAM techniques. J Prosthet Dent 96:47–52

Copyright of Clinical Oral Investigations is the property of Springer Science & Business Media B.V. and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.