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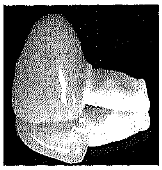
Zirconia Ceramic Single-Retainer Resin-Bonded Fixed Dental Prostheses (RBFDPs) After 4 Years of Clinical Service: A Retrospective Clinical and Volumetric Study



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The aim of this study was a retrospective assessment of the up to 8-year clinical outcomes of zirconia ceramic single-retainer resin-bonded fixed dental prostheses (RBFDPs). Fifteen subjects (9 women, 6 men) with 15 anterior zirconia ceramic RBFDPs were included. The RBFDPs replaced 5 maxillary central incisors, 7 maxillary lateral incisors, and 3 mandibular lateral incisors. The patients willing to participate were recalled and the survival of the RBFDPs was assessed. The technical outcome was evaluated with modified United States Public Health Service criteria. Fracture and/or chipping of the restoration, occlusal wear, marginal adaptation, marginal discoloration, shape, surface texture, and esthetic integration were recorded. Biologic parameters were assessed, including vitality, probing pocket depth, gingival recession, plaque control record, bleeding on probing, and periodontal mobility. Data were descriptively analyzed using a paired t test ($P < .05$). Fifteen subjects with 15 RBFDPs were examined after a mean follow-up period of 53.3 months (SD, 23 months). No catastrophic failures occurred. The 4-year survival rate was 100%. Two early debondings occurred with successful recementation. No chipping of the veneering ceramic occurred. No differences in biologic outcomes between test and control teeth were found. The zirconia ceramic RBFDPs exhibited excellent clinical results in anterior regions and had a positive effect on the esthetic outcomes of the pontic regions.
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During the last 40 years, the resin-bonded fixed dental prosthesis (RBFDPs) has evolved to a predictable treatment alternative for the replacement of missing teeth. In the past, this treatment suffered from high failure rates due to debonding and could only be recommended as a provisional solution.[1] However, due to significant improvement of both materials and clinical techniques, the clinical outcomes of RBFDPs are compelling today. A significant improvement was the reduction of the number of fixation retainers from two or more to just one. This modification considerably reduced the RBFDP debonding rates.[2] Furthermore, the introduction of a minimally invasive preparation design encompassing more retention and an increase in bonding surface area ameliorated the outcomes of RBFDPs. Finally, new resin cements with improved bonding capacity to various types of materials led to better anchorage of the RBFDPs.[2]

The most interesting modification, however, was the use of ceramics instead of metal as the framework material for RBFDPs, which had a surprisingly positive effect on clinical outcomes.[3–5] All ceramic single-retainer RBFDPs in the anterior region seldom exhibited debonding and their survival rates exceeded 94% after 10 years.[3] The RBFDPs in the latter study were made using glass-infiltrated alumina, which is no longer in use because a more stable ceramic zirconia was developed. A study with zirconia-based RBFDPs showed even better results than the one previously mentioned.[4]

Due to these improvements, all ceramic single-retainer RBFDPs may be considered a permanent solution for many different patient situations. The main advantage of resin-bonded prostheses is their low invasiveness. Significantly less tooth substance needs to be removed for a resin-bonded partial denture than for other types of tooth-borne restorations.[6,7] Another important advantage of the resin-bonded prosthesis is the low patient morbidity associated with the clinical treatment, especially compared with implants. Finally, the treatment time and the costs are lower for resin-bonded prostheses compared with conventional fixed dentures or implants.[8] This specific advantage is increasingly important for patients today.

As mentioned above, the main limitation of RBFDPs, the high debonding rate, appears to be valid only for traditional metal-ceramic RBFDPs.[1] Single-retainer RBFDPs made using ceramic, specifically zirconia, performed very well in this respect.[4]

Yet, to be fully accepted as a treatment alternative for the replacement of missing anterior (and possibly also posterior) teeth, the zirconia ceramic RBFDP needs to perform similarly to single-implant crowns or conventional tooth-borne restorations.[9,10] Unfortunately, to date, clinical studies of zirconia ceramic RBFDPs are lacking.

Therefore, the purpose of this retrospective clinical study was to assess the survival rate and technical and biologic complication rates of anterior single-retainer cantilever zirconia ceramic RBFDPs after a mean 4 years of clinical service.

Method and materials

Patients and reconstructions

The study's included subjects were treated with one zirconia ceramic single-retainer (cantilever) RBFDP in the anterior region of the maxilla or mandible. Inclusion criteria were as follows: adolescents with contraindications for implants due to the age, adults with contraindications for implants out of general medical or site specific reasons (eg, gap too narrow), patients desiring a minimally invasive treatment, and patients desiring an all ceramic tooth-borne reconstruction.

The site-specific inclusion criteria were as follows: single tooth gap in the anterior region (central or lateral incisor), healthy neighboring teeth, adequate interocclusal space in horizontal and vertical dimensions for the placement of an RBFDP retainer, and no obvious signs of bruxism.

Fifteen study subjects (9 women, 6 men) were treated with 15 anterior zirconia ceramic RBFDPs at the Clinic for Fixed and Removable Prosthodontics and Dental Material Science, University of Zurich, with regular follow-up within a standard maintenance care recall program. After approval of the study by the local ethical committee, subjects were informed about the purpose of the study and provided consent.

The age of the subjects ranged from 13.1 to 75.1 years (mean, 27.5 years) at insertion of the reconstructions. The zirconia ceramic RBFDPs replaced 5 maxillary central incisors, 7 maxillary lateral incisors, and 3 mandibular lateral incisors.

Restorative procedures

All patients underwent dental hygienic pretreatment prior to the restorative treatment phase according to their individual needs. The respective sites were analyzed clinically and by means of study casts with respect to the bonding area for the RBFDP retainer. The following horizontal and vertical dimensions had to be fulfilled at maximal intercuspidation: overjet ≥ 0.5 mm allowing for sufficient space for a retainer; overbite < 1.0 to 1.5 mm to provide sufficient area for bonding; centric occlusal contacts located in the incisal third, leaving space for the retainer; and adequate vertical and bucco-oral space for the connector (minimal

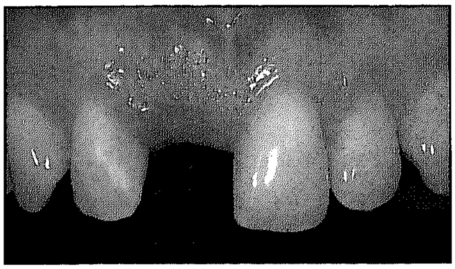


Fig 1a *Clinical situation after augmentation of the pontic area with soft tissue and prior to the restorative treatment phase.*

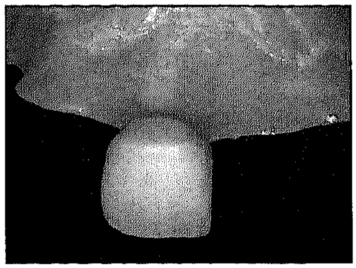


Fig 1b *Removable resin tooth with added flowable composite for conditioning of the pontic area.*

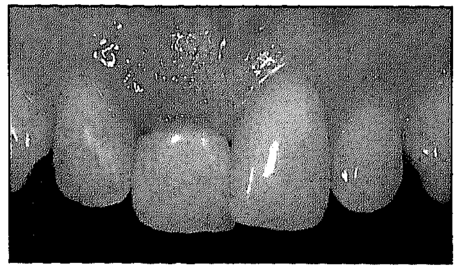


Fig 1c *First conditioning step starting from the palatal region at the pontic site; note the blanching of the soft tissue indicating pressure by the modified pontic.*

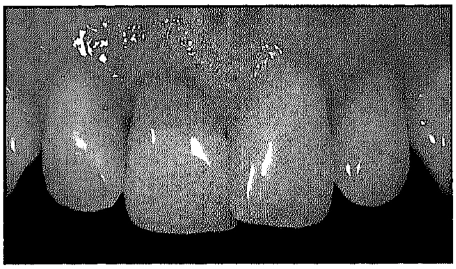


Fig 1d (left) *Final conditioning step; note the amount of added composite for the shaping of the pontic area.*

Fig 1e (right) *Pontic site after the conditioning.*

vertical dimension of 3 mm, minimal bucco-oral dimension of 2 mm, ie, 6 mm²).

Furthermore, the choice of the best suitable abutment tooth was made after evaluating the occlusal and functional relationships with the aid of the study casts. The criteria for the choice of abutment tooth were size of the palatal/lingual surface area that can be used for the bonding and shape of the palatal/lingual surface, ideally oval or round to allow for a "wraparound" design of the retainers. For example, for the replacement of a lateral incisor, a canine was preferred over a first incisor as abutment tooth due to its round palatal/lingual surface.

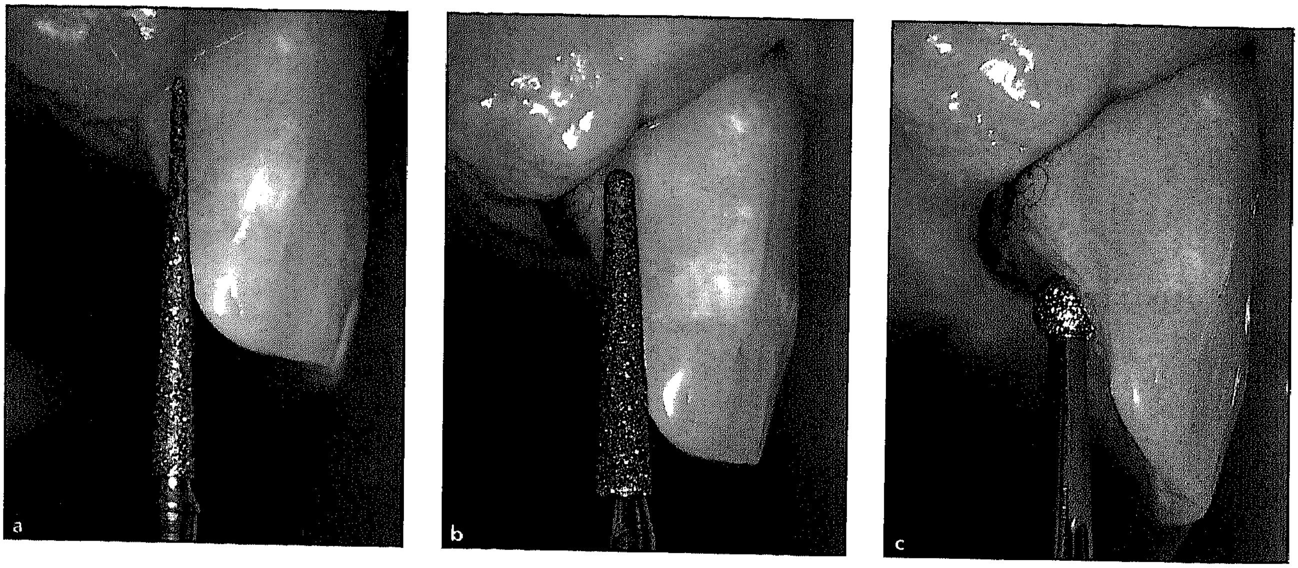
Finally, the edentulous pontic area was clinically analyzed in horizontal and vertical dimensions with respect to soft tissue volume. In 7 of the 15 subjects, a deficiency of the ridge volume in a horizontal and/or vertical direction was found. In these 7 subjects, connective tissue grafts were performed to augment the deficient pontic sites prior to the restorative treatment phase.

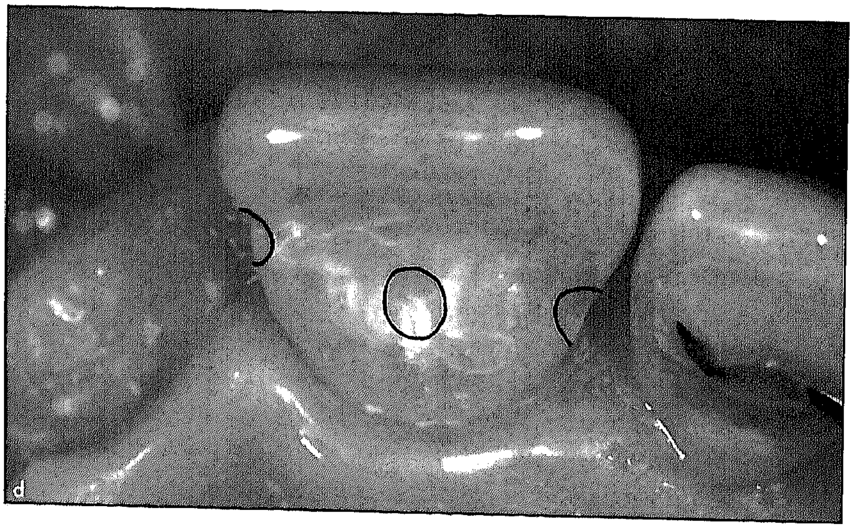
For all patients, removable provisionals were fabricated and used for the conditioning of the edentulous pontic area. The conditioning was performed to shape the soft tissues into an ovate pontic-like shape and, hence, to allow for a natural emergence profile of the pontics. For the conditioning, flowable composite (Tetric Flow, Ivoclar Vivadent) was applied in a stepwise approach to the basal region of the provisional pontic, inducing pressure to the soft tissues in the edentulous area and thereby shaping this region. This procedure was repeated two or three times at intervals of 8 to 10 days until the desired shape of the pontic area was achieved (Figs 1a to 1e).

Finally, the respective abutment teeth were prepared with minimal invasiveness to allow for retention of the RBFDP and to simplify the positioning at cementation.

The minimally invasive preparation design for anterior zirconia-based resin-bonded prostheses encompassed the preparation of a mesial and a distal vertical groove (6-degree taper) and a tiny slot at the palatal/lingual cingulum region (Universal Prep Set, Intensiv) (Figs 2a to 2d).

Impressions of the prepared arches were made with an A-silicone impression material (President). The impressions of the opposing arches were made with alginate. The impressions were poured with class IV stone (Fujirock).





Figs 2a to 2c *Demarcation of mesial and distal vertical grooves with separating bur and veneer burs and of centric stop with round diamond bur.*

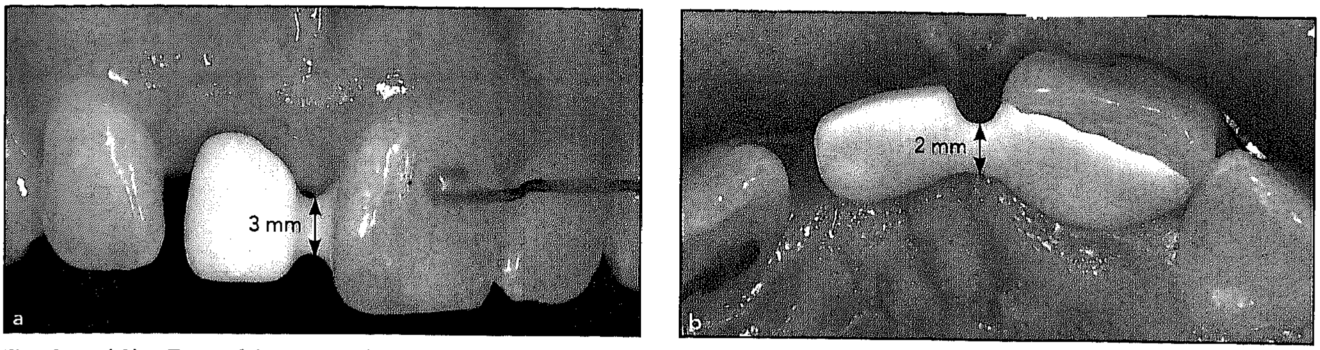
Fig 2d *Detailed view of the abutment tooth preparation design, encompassing a mesial and distal vertical groove and a centric stop.*

Two computer-aided design/computer-assisted manufacture (CAD/CAM) systems (Cerec inLab, Sirona and Etkon/Cares, Straumann) were used for the fabrication of the zirconia RBFDP frameworks. The stone casts were scanned in the laboratory with the respective scanners, and the frameworks were virtually designed.

The dimensions of the zirconia frameworks were: 0.5 mm thickness of retainer and 6 mm^2 cross section of connector (2 mm wide, 3 mm high) (Figs 3a and 3b), with shape and size of pontic according to the emergence profile of the respective site.

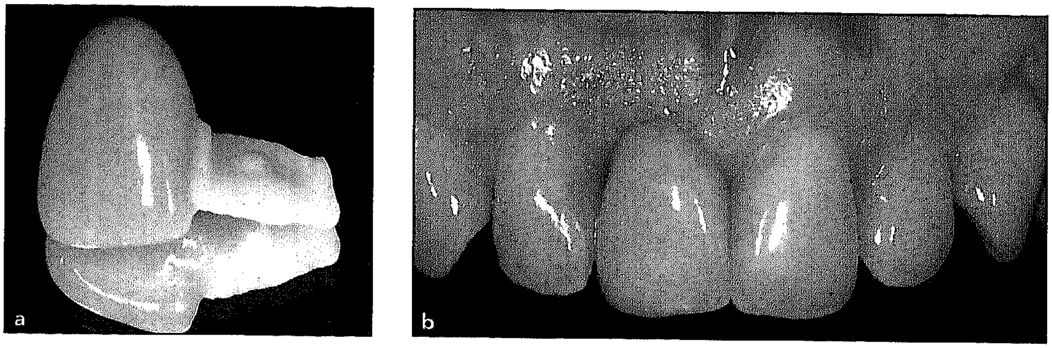
The frameworks were milled from Y-TZP white-stage zirconia blanks (IPS e.max ZirCAD, Ivoclar Vivadent and Cerion, Straumann) and sintered to full density. Depending on the CAD/CAM system employed, this process took place either in the laboratory (Cerec inLab) or in a centralized production facility (Etkon/Cares, Straumann). The frameworks were clinically checked with respect to fit and to the shape and size of the retainer, connector, and pontic. The anatomical support of the veneering ceramic by the framework was analyzed. Finally, the frameworks were manually veneered with zirconia veneering ceramic (Initial, GC).

All RBFDPs were adhesively cemented using resin cement



Figs 3a and 3b *Try-in of the zirconia framework and check of the dimensions and shape.*

Figs 4a and 4b *Zirconia ceramic single-retainer RBFDP before and after insertion.*



(Panavia 21 TC). For cementation, a rubber dam was applied and the abutment teeth were meticulously cleaned with pumice. Next, the palatal/lingual retention area of the abutment teeth was etched with a 37% phosphoric acid (1-minute application). Furthermore, the corresponding primer of the resin cement (ED Primer) was used as a pretreatment per the manufacturer's recommendation.

The zirconia surface was cleaned with alcohol, and silane (Clearfil Porcelain Bond) was applied according to the manufacturer's recommendations. Finally, the cement was applied to the RBFDP retainers and the reconstructions were seated. A glycerine gel (Oxyguard) was used to cover the margins for the setting of the resin cement. Constant finger pressure was applied during the setting time (Figs 4a and 4b).

After cementation and the removal of excess cement, the occlusion and function were meticulously checked. The occlusal/functional requirements of the RBFDPs were evenly distributed centric occlusal contact points at the RBFDPs and the neighboring teeth and evenly distributed loading of the pontic and neighboring teeth at function (laterotrusion, protrusion). Adjustments were performed where necessary. The ground ceramic surfaces were meticulously polished (Optrafine, Ivoclar). No specific occlusal guards were fabricated after delivery of the RBFDPs.

Finally, impressions of the sites with the RBFDPs were made with the A-silicone impression material (President) to fabricate stone replicas (Fujirock) for monitoring of the soft tissue volume in the pontic area (baseline replicas).

Clinical follow-up examination

At the follow-up examination, the survival of the RBFDPs was assessed (ie, RBFDP in situ with/without complication). Furthermore, the technical and biologic outcomes of the reconstructions were evaluated.

The technical outcome was assessed using modified United States Public Health Services

Table 1 USPHS criteria

USPHS	Alpha (A)	Bravo (B)	Charlie (C)	Delta (D)
Framework fracture	No fracture of framework			Fracture of framework
Veneering fracture	No fracture	Chipping, but polishing is possible	Chipping down to the framework	New reconstruction is needed
Occlusal wear	No occlusal wear on reconstruction or on opposite teeth	Occlusal wear on reconstruction or on opposite teeth is < 2 mm	Occlusal wear on reconstruction or on opposite teeth is > 2 mm	New reconstruction is needed
Marginal adaptation	No probe catch	Slight probe catch, but no gap	Gap with some dentine or cement exposure	New reconstruction is needed
Anatomical form	Ideal anatomical shape; good proximal contact	Slightly over or under contoured, weak proximal contact	Highly over or under contoured, open proximal contact	New reconstruction is needed

(USPHS) criteria.[11] A detailed description of the applied criteria has been published before[12] and will, therefore, only be briefly summarized here. The RBFDPs were checked for their marginal adaptation, integrity of framework, integrity of veneering ceramic, anatomical shape, and occlusal surface quality (presence or absence of wear) of the veneering ceramic. An outcome was rated A when no problems were found, B when small but clinically acceptable defects were found, C when the defects reached a level that was no longer clinically acceptable, and D when the RBFDP had to be replaced due to the defect (Table 1).

The biologic outcome was analyzed by determining the probing pocket depth (PPD), gingival marginal level (MG), plaque control record (PCR), bleeding on probing (BOP), and periodontal tooth mobility (according to Flemming et al)[13] at the test (abutment) and control (analogous, contralateral, unrestored) teeth. Pulp vitality of the test and control teeth was tested using carbon dioxide. Radiographs and clinical photographs of the abutment teeth were made. One investigating clinician performed all follow-up examinations using magnification loupes of ×3.6 (Zeiss).[14]

Again, impressions of the arches with the RBFDPs were made with the A-silicone impression material and follow-up stone replicas of the sites were fabricated.

Volumetric evaluation of soft tissue changes

The baseline and follow-up stone replicas were scanned with a CAD/CAM scanner (Imetric 3D), and the imported data of each timepoint per patient were captured as stereolithography (STL) files. These STL files were then imported into another digital imaging software program (Swissmeda/SMOP) for analysis of the volumetric changes in the pontic areas. The images of the baseline and follow-up datasets were superimposed and matched in one common coordinate system using the best-fit algorithm at the tooth surfaces. Subsequently, the volumetric changes in the pontic area over time were measured.[15–17]

A defined area of interest at the pontic sites was measured and the volume difference between the two timepoints was calculated. The region of interest exhibited a trapezoid shape and was located at the buccal aspect of the RBFDP pontic, starting 1 mm below the gingival margin and extending apically to the mucogingival border and laterally to interproximal areas (Fig 5). Due to the individually variable anatomical situations, the measured area varied between patients but was kept constant at one patient/site over time.

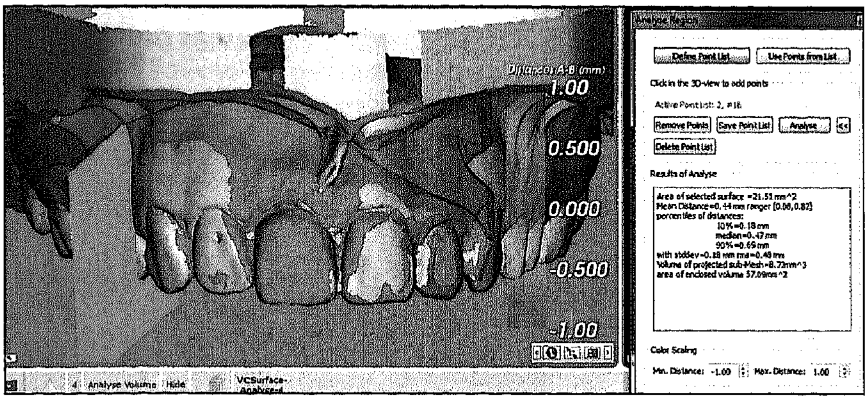


Fig 5 *Superimposition of STL data of the baseline (yellow) and follow-up (green) casts; metric analysis of the volume change in the area of interest (blue).*

Statistical analysis

Descriptive statistics were applied to the data. The median follow-up time was calculated using Graphpad Prism (GraphPad Software). The 5-year survival rate of RBFDPs was computed by dividing the number of RBFDPs without failure by the total number of clinically examined RBFDPs. Complication rates were calculated by dividing the number of observed events (using USPHS criteria) by the total number of analyzed RBFDPs.

Furthermore, the volumetric data were analyzed descriptively. Since the area of interest was different in size for each patient, the mean change of volume from baseline to follow-up was calculated. Thereby, different sites could be compared in terms of volume changes irrespective of their size and the size of the measured area. Then, the total mean value and SD of the volumetric changes were assessed.

Finally, for comparison of PPD, MG, AL, and BOP between test and control teeth, the paired *t* test was used. Biologic data were analyzed by SPSS version 17.0 (IBM). The level of statistical significance was set at $\alpha = .05$.

Results

The 15 subjects with the 15 zirconia ceramic RBFDPs were examined after a median clinical service time of the RBFDPs of 49.4 months (range, 12.7 to 92.2 months), corresponding to a mean time in function of 4 years.

No catastrophic failure due to fracture of an RBFDP occurred. Furthermore, none of the RBFDPs had to be removed due to technical or biologic complications. Hence, the zirconia ceramic RBFDPs had a survival rate of 100%.

Technical outcomes

Debonding occurred at two RBFDPs at 1.3 and 5.4 months after cementation. Both RBFDPs were recemented and were successful for the remaining follow-up period of 39.6 months and 30 months, respectively. For the recementation, the abutment tooth surface was cleaned and reetched using the same procedures as at initial cementation. The retainers of the RBFDPs were carefully sandblasted (30 µm Al_2O_3, two bar, 10-cm distance) and silanized (Clearfil Porcelain Bond Activator), and the reconstructions were recemented using a new batch of the inital resin cement (Panavia 21 TC). No further problems occurred.

In general, the technical outcomes of the RBFDPs were excellent. Most interestingly, no chipping of the veneering ceramic was found. Detailed information on the technical evaluation (USPHS criteria) of the RBFDPs is given in Table 2.

Biologic outcomes

No differences in biologic outcomes were found when test (abutment) and control (analogous

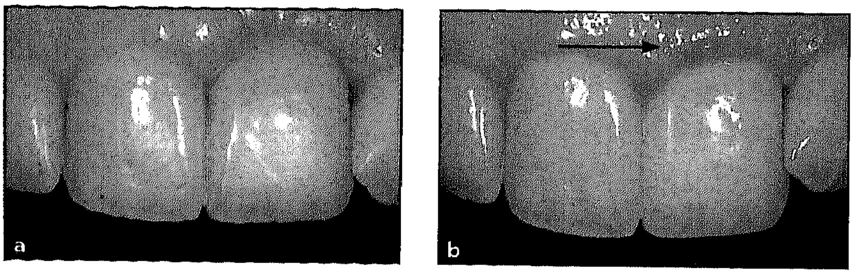
Table 2 USPHS rating of the zirconia ceramic RBFDPs at follow-up

	USPHS			
	Alpha (A)	Bravo (B)	Charlie (C)	Delta (D)
Framework fracture	100% (n = 15)			
Veneering fracture	100% (n = 15)			
Occlusal wear	33.3% (n = 12)	63.9% (n = 23)	2.8% (n = 1)	
Marginal adaptation	100% (n = 15)			
Anatomical form	100% (n = 15)			

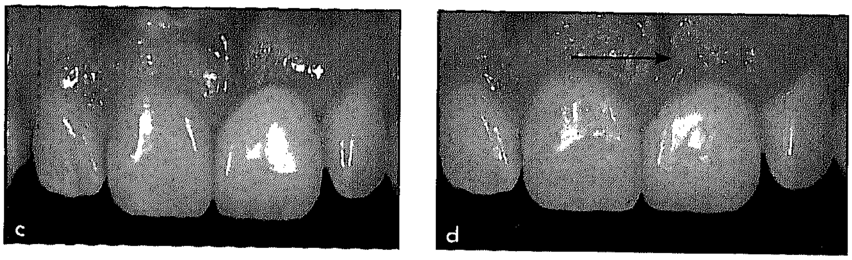
Table 3 Overview of the biologic parameters assessed

	Zirconia ceramic RBFDPs	
	Test teeth	Control teeth
PPD	2.3 ± 0.3	2.2 ± 0.2
MG	−0.1 ± 0.5	−0.1 ± 0.4
PCR	0.3 ± 0.3	0.2 ± 0.2
BOP	0.3 ± 0.3	0.4 ± 0.3

PPD = pocket probing depth; MG = level of gingival margin with respect to cemento-enamel junction; PCR = plaque control record; BOP = bleeding on probing.



Figs 6a and 6b *Zirconia ceramic RBFDP at baseline and follow-up; note the change of soft tissue profile at the pontic site.*



Figs 6c and 6d *Second example with the zirconia ceramic RBFDP at baseline and follow-up showing a change of soft tissue profile at the pontic site.*

untreated) teeth were compared. All biologic parameters indicated healthy conditions. The test teeth showed a distinct positive feedback on tooth vitality. No restriction in postoperative sensitivity was recorded. Five test teeth and one control tooth showed slightly increased tooth mobility (≥ 0.5 mm). Detailed information on the biologic outcomes of the RBFDPs is given in Table 3.

Volumetric analysis of the pontic sites

The study casts of 13 patients were evaluated with respect to the volumetric changes in the pontic areas. For the remaining two patients, it was not possible to superimpose the baseline and follow-up casts with good fit, possibly due to distortion of one of the two impressions and the respective casts.

The pontic areas of the evaluated 13 patients exhibited a mean increase of soft tissue volume of 3.2 mm^3 over time (Figs 6a to 6d). The soft tissue changes ranged from an increase of volume of 0.7 mm^3 to 8.7 mm^3. Detailed information on the volumetric changes and the respective sites is given in Table 4.

Discussion

The zirconia ceramic single-retainer anterior RBFDPs exhibited excellent survival rates and very low complication rates in the present retrospective study. No framework fractures were found and, more interestingly, no chipping of the zirconia veneering ceramic occurred. Debonding of two RBFDPs happened early after cementation, but the technical problem was solved with successful recementation.

Furthermore, the biologic integration of the RBFDPs was excellent. The only differing biologic parameter between test and control teeth was slightly increased tooth mobility found at one third of the abutment teeth but only at one control tooth.

Yet, most interestingly, the volumetric assessment displayed a positive effect of the RBFDPs on the shape and volume of the soft tissues in the pontic areas. All evaluated pontic sites exhibited an increase in soft tissue volume over time in the esthetic area of interest, ie, at the buccal aspect of the pontic.

The positive findings of the zirconia ceramic RBFDPs in this study are in accordance with the literature on all ceramic RBFDPs. As an example, single-retainer RBFDPs made using glass-infiltrated alumina exhibited a 10-year survival rate of 94.4% in a recently published study.[3] Another clinical trial on zirconia ceramic single-retainer RBFDPs showed a survival rate of 100% after 3 years.[4] Accordingly, in the present study the survival rate was 100% even after a follow-up of up to 8 years.

Table 4 **Overview of patients/sites and their respective follow-up periods**

Patient initials	Volumetric assessment: Follow-up period (mo)	Soft tissue augmentation	Change in volume baseline to follow-up (mm³)
BA	87.0	Yes	1.7
SM	49.4	Yes	7.9
SC	81.1	No	2.6
SA	76.4	No	1.3
DS-F S	51.2	Yes	8.7
SB S	92.2	Yes	1.3
DR-M M	30.0	No	2.4
KO	64.6	No	3.0
GT	43.4	Yes	1.1
BV	51.1	Yes	6.3
LT	47.1	No	1.2
ZF	39.6	Yes	3.6
LM	25.6	No	0.7
CS	12.7	No	na
FP	47.6	No	na

These recent results of the all-ceramic RBFDPs are much better than the outcomes reported before for RBFDPs. A systematic literature review on earlier types of RBFDPs reported a low 5-year survival rate of 87.7%.[1] In this review, studies published between the years 1990 and 2006 were analyzed. All except one study[18] reported on metal-ceramic RBFDPs. A number of factors such as change in design or choice of different materials might be responsible for the increase in the survival rates of the RBFDPs.

The first important improvement was the change of the RBFDP design from a two or more retainer to a single-retainer, cantilever design. Metal-ceramic multiple-retainer, RBFDPs had a high risk of de-bonding of one of the retainers and subsequent secondary caries beneath the loose retainer.[19] Multiple-retainer all ceramic RBFDPs suffered from high rates of fracture mostly occurring at one of the retainers.[18] In this latter study, however, the fractured ceramic RBFDPs were successful as single-retainer prostheses for more than 10 years after removal of the fractured retainer.[3]

Besides the design, the change of materials used for the fabrication of the RBFDPs might be another influential factor for the improved outcomes of more recent types of RBFDPs. At present, the adhesive cementation of ceramics is predictable and well established in daily clinical routine, whereas the adhesive cementation of metals remains difficult. The predominant reason for loss of metal-ceramic RBFDPs was debonding.[1] In contrast, this problem seldom occurred with all ceramic RBFDPs.[3] For metals, several technique-sensitive pretreatment steps are needed to establish the chemical bond of resin cements. It has to be considered, though, that the adhesive cementation of the high-strength ceramic zirconia is technique sensitive as well. This ceramic cannot be etched like glass ceramic and, therefore, needs specific phosphate-monomer containing silanes and resin cements for the adhesive cementation.[20] Early de-bonding of two zirconia ceramic RBFDPs was found in this investigation. Both RBFDPs were successfully recemented and remained in situ without further problems for 30 and 39.6 months, respectively. The same was reported in the other study of zirconia ceramic RBFDPs.[4]

In general, fracture of a single-retainer all-ceramic RBFDP was very seldom a complication. Only one fracture of a single-retainer RBFDP made out of glass-infiltrated alumina was reported,[3] and no fractures of zirconia ceramic RBFDPs were found in the present or a previous study.[4] This observation is supported by the very good results reported for conventional zirconia ceramic fixed partial dentures[21–23] and for implant reconstructions[24,25] exhibiting no or very low fracture rates. Zirconia exhibits the highest fracture strength and fracture toughness of all dental ceramics today and can be applied in different indications with very good outcomes.

A recent clinical investigation comparing the outcomes of 39 cantilever RBFDPs and 39 single-implant crowns showed similar 5-year survival rates and, even more interestingly, better success rates than the RBFDPs.[26] Fewer complications occurred at the RBFDPs and, consequently, less need for re-intervention was reported.[26] Hence, today, in the case of single-tooth gaps in the anterior and possibly also in the posterior region,[5] cantilever RBFDPs may be considered a valid treatment alternative to single implants, especially in young patients or patients with medical contraindications for implant surgery (eg, due to immune-suppression, active treatment of malignancy, drug abuse, psychiatric illness,[27] or lack of space for an implant).

A very interesting observation made in the present study was the positive effect of the zirconia ceramic RBFDPs on soft tissue esthetics. Over time, the pontic areas improved in shape and, stunningly, also in soft tissue volume. As a consequence, the esthetic outcome was improved and an even more natural appearance of the pontics was achieved over time. As for the possible reasons for this improvement, the massaging effect of the moving pontics during function may be assumed. The present observation needs to be further elucidated in future studies.

Conclusion

The anterior zirconia ceramic single-retainer RBFDPs in the present study exhibited excellent clinical outcomes at a mean follow-up of 4 years. This treatment technique, therefore, should be considered as an alternative to single-implant crowns in the future.

Acknowledgments

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