Purpose: To analyze the clinical performance of two-wing–retained resin-bonded fixed dental prostheses (RBFDPs) after 5 years of clinical use with respect to technical and biologic complications, as well as survival and success rates. Materials and Methods: RBFDPs were fabricated from 3Y-TZP zirconia layered by hand (Lava Frame veneered with Lava Ceram; 3M ESPE) or metal (Remanium Star, Dentaurum; layered with Reflex, Wieland). The primary endpoints were debonding and fracture. The secondary endpoints (marginal integrity, marginal discoloration, abrasion of antagonist dentition, patient satisfaction, Gingival Index, and side effects) were evaluated at baseline and after 5 years. Survival and success rates were calculated using the Kaplan-Meier method. Log-rank test was used to compare the survival and success rates of the different materials. Results: The mean observation time was 6 years and 10 months. The estimated cumulative success rate after 5 years was 88.9% ± 10% for metal-supported and 33% ± 16% for all-ceramic two-wing RBFDPs. After conversion into one-wing RBFDPs, the survival rate was 100% in both groups. Debonding of one of the two wings was the major complication. One zirconia framework fracture occurred. Metal-based two-wing RBFDPs showed a significantly higher success rate, but lower esthetic evaluation. Conclusion: Due to a reduction in technical complication rate and less invasiveness, one-wing RBFDPs should be preferred over two-wing RBFDPs whenever possible.

Maxillary lateral incisors show the highest incidence of agenesis in the anterior region. Bilateral agenesis of the maxillary lateral incisors is more common than unilateral agenesis, and the prevalence in women is 1.37 times higher than in men.¹

Three fundamental treatments are available for the management of missing anterior maxillary teeth: autotransplantation, orthodontic space closure, and prosthetic replacements.²–⁴ Fixed prosthetic solutions include implant-supported single crowns (ISCs), traditional fixed dental prostheses (FDPs), and resin-bonded fixed dental prostheses (RBFDPs). The survival rates reported by systematic reviews after 5 years are 96.3% for ISCs, 94.4% for metal-ceramic FDPs, and 91.4% for RBFDPs.⁵–⁷ Traditional FDPs require considerable invasiveness, which is especially critical in young patients who have healthy abutment teeth⁸ and is associated with a high rate of serious endodontic complications.⁹
In contrast, implants can help preserve healthy teeth from tooth structure removal. However, continuous eruption of the adjacent anterior teeth associated with the facial/dentoalveolar growth in young patients can compromise a long-term functionally and/or esthetically satisfying outcome. Especially in patients with a short or long face type, further growth can create a serious risk, even after the age of 20 years.

RBFDPs are often used as an alternative to implant-supported single-crowns, traditional FDPs, or orthodontic procedures in the following clinical situations: (1) implant treatment is contraindicated; (2) extensive surgical interventions should be avoided; (3) the space available is inappropriate for an implant treatment; (4) the patient is too young for an implant-supported prosthetic restoration; (5) an implant-supported prosthetic restoration is rejected by the patient; or (6) an orthodontic gap closure with canine substitution is not possible or is rejected by the patient. Important requirements for the use of RBFDPs are healthy abutment teeth that are free of caries or fillings, sufficient interocclusal space (approximately 0.8 mm), and sufficient amounts of enamel.

Prosthetic restorations with RBFDPs have been described in the scientific literature since the 1970s. Invasiveness was lowered with the introduction of metal-based RBFDPs in the 1980s, and there was no need for unphysiologic splinting of the abutment teeth. In the 1990s, glass-infiltrated aluminum oxide ceramic was first used in a clinical study to manufacture an all-ceramic RBFDP with two retentive wings. RBFDPs made of zirconia appeared to be advantageous, with 10-year survival rates varying from 94.4% to 100%. Various all-ceramic materials besides zirconia have been used for RBFDPs following advances in technology, such as lithium disilicate, glass-reinforced, and alumina-based ceramics. Metal alloys or zirconium oxide ceramics are primarily used for framework fabrication, with a tooth structure removal of 0.5 mm and 0.7 mm recommended for preparation of the retentive wings. The preparation design—especially a retentive preparation geometry—has been shown to play an essential role in the success of RBFDPs and must be matched with the material properties and the adhesive protocol being used.

RBFDPs made of zirconia frameworks presented significantly higher survival rates than other framework materials. Debonding and framework fracture represent the most frequent technical complications for RBFDPs. Cantilever RBFDPs demonstrated lower clinical fracture rates, lower debonding rates, and higher success rates than two-retainer RBFDPs.

Although numerous clinical studies can be found in the scientific literature, there is little evidence on prospective clinical split-mouth studies using zirconia vs metal-based frameworks for anterior RBFDPs. The present prospective randomized split-mouth study analyzed the clinical performance of two-wing–retained RBFDPs after 5 years of clinical use. The null hypothesis states that there is no difference between both RBFDP materials after 5 years of clinical use with respect to technical and biologic complications, as well as survival and success rates.

MATERIALS AND METHODS

Within this split-mouth, prospective clinical study, patients with bilateral agenesis of the maxillary lateral incisors were treated with two different types of two-wing–retained RBFDPs, one made with a metallic framework and the other with a zirconia ceramic framework. The RBFDP type was randomized in every patient. This clinical study was approved by the ethical committee of the university hospital (Project # 150-08).

Study Population

A total of 9 patients with two congenitally missing maxillary lateral incisors in need of an RBFDP were included based on the following inclusion and exclusion criteria:

- Indication for a veneered two-wing RBFDP with a framework made either of Lava (3M ESPE) zirconia (minimum wall thickness of 0.5 mm) or of nonprecious metal (cobalt-chromium [CoCr])
- Minimum age: 16 years
- No planned change in location, patient commitment to attend annual recall appointments
- At least average oral hygiene
- Bilateral agenesis of the maxillary lateral incisors
- Caries-free and periodontally stable adjacent teeth (FDI teeth 13, 11, 23)
- Exclusion of pregnant and lactating women
- Exclusion of patients with parafunctions and bruxism

All patients were informed verbally and in writing about the treatment modalities and gave their written informed consent.

Treatment Protocol and Restoration Fabrication

The restoration types (zirconia vs metal framework) were randomly assigned to treatment site (first or second quadrant).

After determination of the restoration sites, the preparations were carried out regarding the individual needs and prerequisites of the patient—similar to the guidelines and recommendations published by Kern by one skilled prosthodontist (D.E.). The thin lingual veneer-like preparations of the abutment teeth were limited to the tooth enamel and were not extended further than the proximal contacts in the sagittal direction. Further, a fine incisal finishing shoulder and...
a fine cervical chamfer preparation were conducted. A small box in the proximal area on the pontic side and a small pinhole in the middle of the palatal surface were prepared. All preparations were carefully smoothed. Figure 1a shows the preparation before impression-taking. Impressions were taken using a polyether material (Impregum/Permadyne, 3M ESPE), and plaster casts were poured.

The frameworks of the all-ceramic two-wing RBFDPs were designed using a CAD software (Lava software, 3M ESPE) considering an anatomy-driven reduction of the pontic, then milled from 3Y-TZP zirconia (Lava Frame, 3M ESPE) and densely sintered. Subsequently, the frameworks were hand-layered using a silicate sintered ceramic (Lava Ceram, 3M ESPE). The cross-section of the connector of the all-ceramic framework was determined to be at least 6 mm² and the minimum material thickness of the wing to be 0.5 mm. A glazing layer of 0.1 mm was designated.

The metal frameworks were digitally designed and milled from non-precious metal alloy (Remanium Star, Dentaurum; composition according to the manufacturer: Co 60.5%, Cr 28%, W 9%, Si 1.5%, < 1% Mn, N, Nb) and subsequently hand-layered using a silicate sintered ceramic (Reflex, Wieland). Zirconia surfaces were high gloss-polished and glazed afterwards. The mean connector sizes are given in Table 1.

During the clinical try-in appointment, the marginal fit (Fit Test C & B, VOCO), approximal contacts, static and dynamic occlusion, and esthetic appearance were evaluated before the restorations were adhesively bonded.

Adhesive attachment was carried out using composite resin cement (Panavia F 2.0, Kuraray Noritake) in accordance with the manufacturer’s recommendations. Prior to adhesive bonding, the metal and ceramic frameworks were air-abraded with aluminum oxide particles (50-µm grain size, 2-bar pressure, 10-mm distance) and cleaned in an ultrasonic bath with 90% ethanol for 3 minutes. The MDP-containing composite resin cement (Panavia F 2.0) was directly applied to the air-abraded part of the wings of the 3Y-TZP zirconia (Lava Frame). An additional metal primer was applied to the air-abraded part of the wings of the metal frameworks (Alloy Primer, Kuraray Noritake). In all-ceramic RBFDPs, “lite” shaded resin cement was used, while the metal RDFDPs were attached applying shade “OP.” Isolation was ensured by a rubber dam, and the enamel was etched for 30 seconds using 37% phosphoric acid. Figure 1b displays the bonded restorations in situ. Dynamic occlusion and static occlusion were checked.

Recalls and Evaluation
Patients underwent at least one annual recall, and the restorations were analyzed for functionality and esthetics. The primary endpoints were debonding and fracture. Survival and success rates were calculated using the Kaplan-Meier method. If a restoration had to be removed and needed replacement due to debonding, fracture, chipping, or secondary caries, the restoration was rated as a total failure. If a debonding or fracture occurred, but the restoration could be rebonded or modified and further used, it was rated as a technical complication, and the success rate could be calculated as recommended by Kern.²⁰ Log-rank comparison was used to compare the survival and success rates of the different restoration alternatives (metal vs all-ceramic). In these cases, photographs were taken and the clinical procedures documented.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Mean ± SD of Connector Diameters (mm) According to Material and Abutment Tooth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material/tooth</td>
<td>Maxillary central incisor</td>
</tr>
<tr>
<td>Metal framework</td>
<td>7.7 ± 2.4</td>
</tr>
<tr>
<td>Zirconia framework</td>
<td>8.2 ± 3.1</td>
</tr>
</tbody>
</table>

Fig 1 (a) Preparations for two two-wing–retained RBFDPs. (b) Metal and all-ceramic two-wing–retained RBFDPs after adhesive luting.
Secondary Endpoints
The secondary endpoints were evaluated at baseline and after 5 years.

**Marginal integrity.**
The marginal integrity was rated as (1) excellent (no margin could be probed); (2) good (minimal probing possible in some areas); (3) critical (probing possible, observation necessary, but no need for renewal); or (4) unacceptable (restoration needs to be replaced).

**Marginal discoloration.**
The marginal discoloration was rated as (1) excellent (no marginal discoloration could be observed); (2) good (light marginal discoloration, but removable by polishing); (3) critical (marginal discoloration that cannot be removed by polishing, observation necessary, but no need for renewal); or (4) unacceptable (heavy discoloration leading to necessary renewal).

**Abrasion of antagonist.**
Abrasion of the antagonist was rated at baseline and after 5 years as (1) excellent (no abrasion could be observed); (2) good (uniform abrasion perceptible on antagonists and other teeth not referable to the restoration only); (3) critical (considerable abrasion perceptible on antagonists referable to the restoration); or (4) unacceptable (massive abrasion perceptible on antagonists referable to the restoration, exposure of dentin).

**Patient satisfaction.**
Patient satisfaction was assessed at baseline and after 5 years of observation time as: (1) very satisfied, no complaints; (2) satisfied, minor complaints; (3) fairly satisfied; or (4) unsatisfied, with the patient demanding immediate renewal.

**Gingival Index**
The gingival condition according to Loe and Silness was evaluated at baseline and after 5 years as: (0) normal gingiva: natural coral pink gingiva with no inflammation; (1) mild inflammation: slight changes in color, slight edema, no bleeding on probing; (2) moderate inflammation: redness, edema, glazing, and bleeding on probing, and (3) severe inflammation: marked redness and edema, ulceration and tendency to spontaneous bleeding.

**Side effects.**
Possible side effects, such as secondary caries, endodontic complications, or chipping of the veneering ceramic, were evaluated.

The secondary endpoints were evaluated at baseline and after 5 years in accordance with the modified criteria of Ryge and Snyder and Hickel et al using Alpha (indication for excellent), Beta (clinically acceptable), Charlie (indication for renewal due to preventive reasons), and Delta (indication for immediate renewal) ratings.

Data were recorded and analyzed using Microsoft Excel and SPSS version 25.0 (IBM). The survival and success rates were calculated using the Kaplan-Meier method. Log-rank comparison was used to compare the survival and success rates of the different materials used.

**RESULTS**

The mean observation time was 2,515 ± 769 days, which represents 82 months, with a minimum of 1,615 days (53 months) and a maximum of 3,725 days (124 months). The average age of the six female and three male patients was 27 ± 14 years at the time of restoration insertion. During the observation time, several technical complications could be observed. The cumulative success rate is displayed in the lifetime survival curve in Fig 2. The pairwise log-rank comparison (Mantel-Cox) showed significant differences between the metal and ceramic RBFDPs (P = .011) regarding the technical complication and success rates, respectively.

The estimated cumulative success rate after 5 years was 88.9% ± 10% for metal-supported and 33% ± 16% for all-ceramic two-wing RBFPDs. Despite the high number of technical failures, an individual solution could be found in all cases and all restorations could stay in situ, representing a survival rate of 100% over the observation period of 5 years.

**Description of Cases and Technical Failures**
In two patients, no technical complications were found over a period of 2,491 (83 months) and 3,701 days (123 months).

In four patients, unilateral debonding of one retainer wing of the all-ceramic RBFPDs was observed after 940 days (31 months), 1,494 days (50 months), 1,863 days (62 months), and 3,380 days (112 months); twice on the canine, twice on the central incisor. Figure 3a shows a situation of unilateral debonding.

One patient experienced a fracture and loss of one retainer wing of the all-ceramic RBFPD on tooth 21 (624 days, 20 months), and one patient showed a total debonding of both retainer wings of the all-ceramic RBFPD (744 days, 24 months).
One patient exhibited technical failures in both the all-ceramic and the metal RBFDP. In the all-ceramic two-wing RBFDP, the connector of the retainer wing on tooth 13 fractured (247 days, 8 months), and in the metal RBFDP, a debonding of the retainer wing on tooth 23 occurred (821 days, 27 months) (Fig 3b).

The debonding occurred predominantly as an adhesive failure on the zirconia side (between the zirconia and the resin). Depending on the fracture and debonding pattern, the debonded wing was cut off and could either be rebonded or replaced by a composite filling. The restoration was reshaped and polished and could therefore stay in situ, then becoming a one-wing RBFDP. No further side effects or adverse events occurred.

**Marginal Integrity**

The secondary outcome marginal integrity showed better results for the metal than for the all-ceramic RBFDP at baseline. This trend increased after 5 years of observation time (Fig 4a).

**Marginal Discoloration**

The marginal discoloration after 5 years was classified as either excellent or good, apart from one case rated critical in the metal RBFDP group (Fig 4b).

**Abrasion of Antagonist**

Both restoration alternatives caused abrasion of the antagonists after 5 years. Uniform abrasion on all teeth was observed and increased over time in both groups (Fig 4c).

**Patient Satisfaction**

The satisfaction of patients with the all-ceramic RBFDP was assessed to be lower after 5 years. In contrast, patient satisfaction with the metal RBFDP improved over the 5-year observation period (Fig 4d).

**Gingival Index**

The gingival index did not alter significantly over time in either group (Fig 4e).

**Side Effects**

No severe side effects were reported during the overall observation time. One tooth in the all-ceramic RBFDP group showed a light hypersensitivity at baseline that could not be identified at the 1-year recall. No teeth showed endodontic complications or secondary caries. No chipping of the veneering ceramic was observed over the observation period.

**DISCUSSION**

The present study evaluated two-wing RBFDPs with veneered metal frameworks vs frameworks made of veneered 3Y-TZP zirconia over a mean observation time of 6 years and 10 months. Six of the 10 patients in this study were women. This can be explained in part by the findings in the literature reporting a prevalence of bilateral agenesis of maxillary lateral incisors in women.1 The results showed a high technical complication rate in the all-ceramic two-wing RBFDPs. However, after clinical interventions (eg, removal of one retainer), all restorations could stay in situ and could be further used. After removing one of the two retainers, both groups showed excellent survival. Therefore, the null hypothesis was rejected.

The estimated cumulative success rate after 5 years of clinical service showed that only technical complications occurred in 33% of zirconia two-wing RBFDPs, and individual adaptation, modification, or reshaping was required. Despite the high number of technical complications, a satisfying solution for the patient could be found in all cases. The restorations could stay in situ as one-wing RBFDPs, presenting a survival rate of 100% over the observation period of 5 years. The better clinical
Fig 4 Overview of secondary outcomes. 
(a) Marginal integrity.  
(b) Marginal discoloration.  
(c) Antagonist abrasion.  
(d) Patient satisfaction.  
(e) Gingival Index.
performance of one-wing RBFDPs is confirmed by the literature, where cantilever RBFDPs demonstrated a lower clinical complication rate than two-wing RBFDPs in the anterior region.\textsuperscript{31,37} In addition, the patients in the present clinical study were of a young age, where a potential of maxillary and mandibular bone growth might occur, leading to a possibly higher failure rate in two-wing restorations.

A systematic review on different types of RBFDPs in the anterior and posterior region reported an estimated survival of 91.4\% after 5 years and 82.9\% after 10 years.\textsuperscript{7} Debonding (loss of retention) of one of the RBFDPs (15\%) and chipping of the veneering material (4.1\%) were identified to be the most frequent complications over an observation period of 5 years. RBFDPs made of zirconia frameworks combined with a one-wing design showed a significantly higher survival rate and significantly lower debonding rate than two-wing RBFDPs.\textsuperscript{38} Generally, the one-retainer design should be the design of choice when it comes to RBFDPs, as several studies confirm.\textsuperscript{38–41}

Adhesive placement is considered to be a parameter that influences the debonding rate. In the present study design, the same luting material (Panavia F 2.0) was applied for both metal and zirconia frameworks in accordance with the manufacturer’s recommendations. Comparable MDP-containing universal resin cements were successfully used in numerous in vitro studies and clinical trials with a high success rate and can therefore not be an explanation of the low debonding rate observed in the present study.\textsuperscript{7,42}

Due to the limited number of restorations in the present split-mouth study, the secondary outcome parameters, like marginal integrity, marginal discoloration, abrasion of antagonists, patient satisfaction, gingival index, and side effects, did not differ from each other. However, some trends could be observed over the observation time of 5 years: The marginal integrity slightly decreased for the zirconia RBFDPs, whereas the marginal discoloration increased in the metal framework group. In both groups, abrasion of the antagonist canines caused by direct contact with the wing made of metal or zirconia could be observed. This might be attributed to differences in abutment tooth mobility, which can scarcely be compensated by a rigid framework like nonprecious metal or even zirconia, which has an elastic modulus of above 200 GPa.\textsuperscript{43–45} This leads to stress concentration in the connector areas between the wing retainers and the pontic, as well as shear forces in the retainer and on the bonding surface. Debonding can be considered as a kind of stress release in this specific situation, especially in completely rigid ceramic materials.\textsuperscript{14,46}

This goes in line with the observations in the present study, where one fracture of a connector was detected and frequent debonding of one wing of the two-wing zirconia-based RBFDPs was observed. In only one patient did debonding of the retainer wing of the metal RBFDP occur, on tooth 23 after 3 years and 3 months (821 days). This is in accordance with a 5-year clinical study that evaluated 20 anterior Co-Cr ceramic and 20 glass-infiltrated alumina (In-Ceram, VITA Zahnfabrik) cantilever RBFDPs. No incidences of debonding were observed in the metal-ceramic group, but were detected in the all-ceramic group (n = 3).\textsuperscript{47} This is also confirmed by the fact that all-ceramic frameworks seem to be more prone to failure; for example, different types of RBFDPs provided an effective short- to medium-term treatment option, with all-ceramic RBFDPs performing the least well and exhibiting the least favorable mode of failure (ie, catastrophic fracture).\textsuperscript{48}

In the present study, patient satisfaction rose over time in the metal-ceramic group. However, patients were more unsatisfied with the primary esthetics compared to the antagonistic side (ceramic restoration) at all time points. Further, patient satisfaction dropped in the all-ceramic group, which might be associated with the high number of technical complications, such as debonding and fractures. However, despite the number of complications, all patients in the present study were very satisfied with their decision for the RBFDPs as a restorative solution because of the low complexity of the treatment. This is in accordance with another study, where one-wing RBFDPs were compared to ISCs. The level of quality of life (OHRQoL) was similar irrespective of treatment modality.\textsuperscript{49}

In the present study, special attention was drawn to provide adequate connector size, especially in the vertical dimension. A very important parameter for connector dimension is given by the proximal contact areas (PCAs). PCAs decrease from the midline to the posterior teeth because of increasing incisal embrasures. Therefore, vertical PCA height is around 3 mm between maxillary central and lateral incisors, in contrast to 2 mm between maxillary lateral incisors and canines.\textsuperscript{50} As a result, about 30\% more space is available for vertical connector height in the PCA between the central and lateral incisors against the lateral incisor and the canine. Regarding available space for the connector, the first choice for abutment tooth for cantilever RBFDPs is therefore the intact central incisor. In other words, related to two-wing RBFDPs, a higher probability of fracture of zirconia frameworks can be expected in the canine/lateral incisor connector area. However, a higher fracture rate in this connector area could not be identified by the results of the present study. Another aspect in this context might be the preparation design, which was conducted similarly in both groups; first, due to the applied CAD/CAM of both restorations, second due to the wish for a high level of standardization and comparability.
However, failure types of metal-ceramic RBFDPs are independent of the framework design, with a high dominance of debonding. Nevertheless, one-wing RBFDPs represent an excellent, low-complexity treatment alternative to implants for replacing lateral incisors. A limitation of the present study is the relatively small number of patients. Moreover, all clinical studies inherently present influence of bias. However, it can be assumed that the split-mouth design applied compensated for multiple influences from individual patient-related factors, enabling a pairwise comparison. Therefore, the results can be considered to be representative. Nonetheless, there is further need for well-designed randomized controlled clinical trials with larger sample sizes to achieve more accurate results about the clinical success rates of different RBFDP designs in the anterior region.

CONCLUSIONS

1. One-wing retained RBFDPs should be the preferred treatment option over two-wing–retained RBFDPs due to a reduction in technical complication rates and less invasiveness.
2. Metal-based two-wing RBFDPs showed a significantly better success rate.
3. The dominant complication was debonding. Only one framework fracture occurred in the zirconia group.

ACKNOWLEDGMENTS

This study was sponsored by a research grant of 3M ESPE (St Paul, MN). The sponsor was not involved in the collection/interpretation of data, writing the report, or the decision to submit. The authors report no conflicts of interest. Author contributions: D.E.: conceptualization, clinical treatment, writing, supervision; A.L.: writing, editing, data processing; O.S.: writing, review, and editing; J.G.: clinical evaluation, data analysis, writing (original draft), editing.

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THE INTERNATIONAL JOURNAL OF PROSTHODONTICS

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To retrospectively assess clinical and radiographic outcomes of immediately loaded full-arch fixed prostheses supported by axial and tilted implants up to 15 years of function. Patients with one completely edentulous arch received an immediate full-arch fixed prosthesis supported by two anterior axial and two posterior tilted implants. Definitive prosthesis consisting of a CAD/CAM titanium framework and acrylic teeth was delivered 6 months later. Patients were regularly followed to assess clinical parameters and marginal bone level (MBL) changes. Multilevel regression analysis was performed to investigate factors affecting implant failure and MBL. Six hundred ninety-two implants were placed in 72 maxillae and 101 mandibles. Seven maxillary implants (5 axial and 2 tilted) in 6 patients and 12 mandibular implants (6 axial and 6 tilted) in 5 patients failed. 15-year cumulative implant survival was 97.51% and 96.91% in maxilla and mandible, respectively (p = .64). After 10 years, the difference in MBL between axial and tilted implants was not significant in the maxilla (p = .47, 65 patients), while it was in the mandible (p < .001, 80 patients). Significant higher bone loss was reported in the mandible at both 5- and 10-year follow-up (p < .001 and p = .004, respectively). Mixed-effect multilevel linear regression evidenced a correlation between arch and bone loss at 5- and 10-year follow-up, while no correlation was found with age, gender, smoking, diabetes, and history of periodontal disease. This long-term study suggests that the present technique can be considered a viable treatment modality for the immediate rehabilitation of both maxilla and mandible.