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Fiber-reinforced composite partial fixed dental prostheses supported by short or extra-short implants: A 10 year retrospective study

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Abstract

Introduction: This study evaluated the 10-year survival and success of partial fixed dental prostheses (P-FDPs) fabricated with a milled fiber-reinforced composite (FRC) framework, supported by short or extra-short implants.

Methods: Patients restored with FRC P-FDPs supported by short or extra-short implants were included in this retrospective study. Kaplan–Meier analysis was used to calculate the survival and success rates of the prostheses. Univariate and multivariate Cox regression models, clustered to adjust for multiple implants and prostheses being placed in the same patient, were used to correlate changes in peri-implant bone levels with patient, implant, and prosthesis-related covariates.

Results: This study followed 121 FRC P-FDPs supported by 261 implants, placed in 96 patients. At 118 months in function, the P-FDP survival rate was 95.9% (95% CI: 87.5%–98.7%), and the success rate was 89.8% (95%CI: 80.4%–94.8%). Differences in prosthesis span length, abutment/pontic ratio, and the presence of distal extensions (cantilevers) did not affect the prosthetic outcomes. Bone levels around implants were stable, with an average rate of change of −0.01 ± 0.05 mm/month. Cox regression revealed that grafted sites were correlated with peri-implant bone loss, while longer prosthetic spans were correlated with bone gain.

Conclusion: P-FDPs comprised of milled fiber-reinforced composite frameworks, supported by short and extra-short implants, had high survival and success rates for up to 10 years.

KEYWORDS
dental materials, marginal bone level, prosthesis survival, retrospective study

What is known

CAD/CAM milled fiber-reinforced composites (FRC) frameworks have demonstrated high survival rates when supported by regular-length implants, which encouraged their use in more challenging scenarios, such as with short or extra-short implants in atrophy conditions.

What this study adds

An encouraging long-term prognosis can be expected for restoration of atrophic maxillary and mandibular arches when restored with partial fixed FRC frameworks supported on only short and extra-short implants.

1 | INTRODUCTION

Implant-supported partial fixed dental prostheses (P-FDPs) provide a predictable solution to tooth loss that does not require preparation of sound tooth structures. The estimated 5-year survival for this treatment modality is 95.2%, which decreases to 86.7% after 10 years.[1] A variety of materials have been explored for use in implant-supported P-FDPs, from metal frameworks veneered with acrylic or porcelain[2] to a variety of all-ceramic materials for framework or monolithic reconstructions.[3] Recently, the European Association for Osseointegration (EAO) position paper concerning materials selection for implant-supported reconstructions stated that metal-ceramic are preferred over ceramic restorations in situations such as increased crown-to-implant ratio, cantilever reconstructions, and P-FDPs.[4] Also, due to the high risk of framework fracture and catastrophic fracture of the veneering material, it was suggested that porcelain fused to zirconia P-FDPs could not be considered the material of first priority, reaffirming the information published in the previous EAO consensus and in a systematic review.[5,6] While noting monolithic zirconia as a possible alternative, both the EAO consensus and the systematic review highlighted the lack of literature on their long-term performance. This demonstrates a need for a reliable prosthetic framework material that demonstrates long-term success.

Fiber-reinforced composite (FRC) resin is a metal-free restorative material that can be milled into implant-supported frameworks using computer-aided design/computer-aided manufacturing (CAD/CAM) systems. It has been expected to provide an improved biomechanical performance for reconstructions, especially for implant-supported reconstructions, due to its lower elastic modulus relative to metal or zirconia frameworks, which might increase the restoration resilience and, consequently, favor chewing force dampening and stress distribution.[7–9] Previously published in vitro research showed a high probability of survival (reliability) of veneered FRC P-FDP similar to metal ceramics. In those studies, fatigue failures were confined to the veneered resin composite material and did not extend to the framework, allowing for chairside repair for continued function and avoiding replacement of the entire restoration.[10,11] Similarly, clinical studies have demonstrated a cumulative rate of 100% over 8 years for FRC full-arch fixed dental prostheses (FA-FDPs), installed over four implants placed in severely atrophic mandibles (Cawood and Howell class V and VI).[12] These results encouraged further research to evaluate the clinical outcomes of FRC milled frameworks in P-FDP frameworks.

While most data concerning the survival of P-FDP are derived from regular sized implants (especially length), further investigation is warranted when short (6–10 mm in length) and extra-short (≤6 mm)[13] implants are used for support.[14] Findings from a recent systematic review and meta-analysis suggest that restorations supported by short implants might be a viable treatment option with minimal implant failure (2% after 12–120 months of follow-up) and stable marginal bone level.[15] Particularly, FRC P-FDPs installed over short and extra-short implants placed in severely atrophic mandibles have presented an overall implant and prosthetic survival rate of 98.5% and 94.1% after 5 years, respectively, with a minimal marginal bone level change over time.[12] Together, these favorable data encourage the long-term investigation of FRC P-FDP performance, when installed in biomechanically unfavorable clinical scenarios.

Therefore, this study aimed to evaluate the survival and complication outcomes of P-FDPs with FRC frameworks, supported by short or extra-short implants, over a period of up to 10 years. The specific aims were to evaluate: (i) the survival and success rates of the prostheses; (ii) the influence of prosthetic design on survival and success rates, and (iii) the effect of P-FDPs on peri-implant bone levels.

2 | MATERIALS AND METHODS

2.1 | Study population

After approval of an Institutional Review Board (NEIRB# 14-338, 2014), the retrospective study was designed according to the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) criteria.[16] Data from patients were collected according to the Declaration of Helsinki and the Good Clinical Practice guidelines.

All patients treated at the Implant Dentistry Centre in Boston, USA, who received FRC P-FDPs with three or more units, supported by short and extra-short implants (Bicon LLC, Boston, USA) between 2012 and 2022 were included in this study. The prostheses' frameworks were milled from FRC discs or blocks (TRINIA, Bicon LLC) and veneered with either HC Disks (Shofu, Kyoto, Japan), Ceramage (Shofu) or denture teeth (Physiostar NFC+, Candulor, Switzerland; SR Phonares II, Ivoclar Vivadent, Lichtenstein). Indirect composite resins were used to establish gingival aesthetics (Ceramage, Shofu).

2.2 | Data collection

The following data were recorded for each patient: gender; the presence of systemic conditions (status of diabetes mellitus, smoking, and osteoporosis/osteopenia); and the date of last follow-up. For each implant placed, the following data were recorded: the date of implant

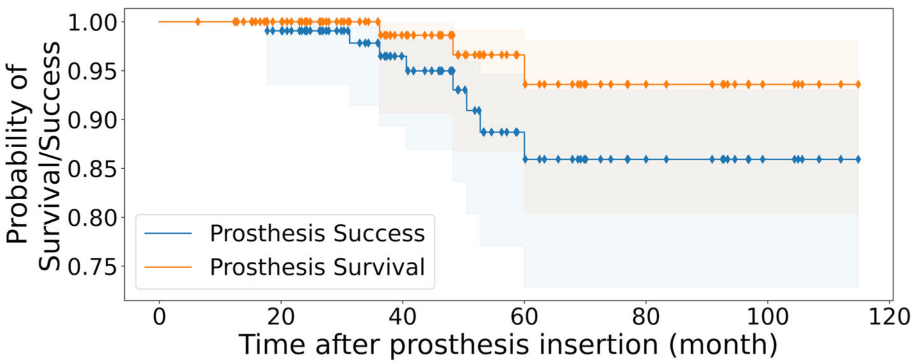

FIGURE 1 Kaplan–Meier curves for FRC P-FDP prosthesis survival and success probabilities. Shaded regions represent 95% confidence intervals. FRC, fiber-reinforced composite; P-FDP, partial fixed dental prosthesis

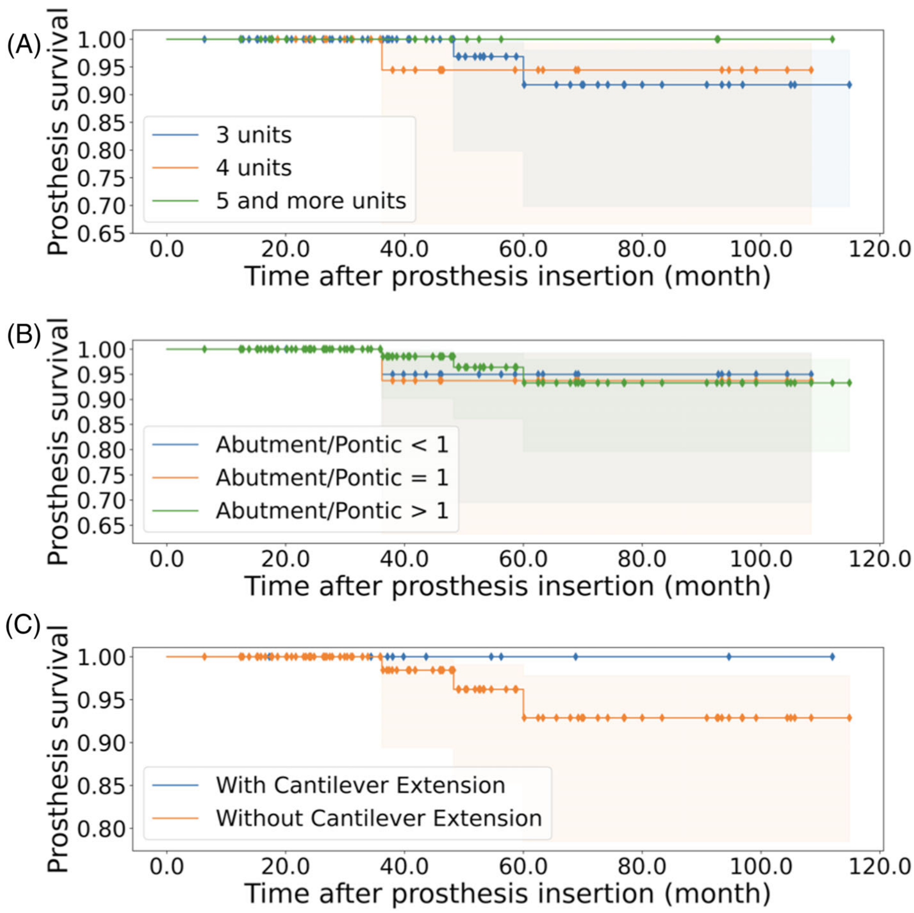

FIGURE 2 The effect of P-FDP design variables, including (A) prosthesis span, (B) abutment/pontic ratio, and (C) cantilever extensions on prosthesis survival probabilities. Shaded regions represent 95% confidence intervals. There were no significant differences between groups. P-FDP, partial fixed dental prosthesis

surgery; the patient's age at the time of implant surgery; the implant's location, length, diameter, and well size; whether the implant was coated with hydroxyapatite (HA); whether a bone graft material was used; and the marginal bone levels (MBLs) at different time intervals. For each prosthesis, the following data were collected: the date of prosthesis insertion; the patient's age at the time of prosthesis insertion; the locations of abutments and pontics on the bridge; and the material on the opposing arch.

MBLs surrounding implants were measured both mesially and distally and were defined by the distance from the top of the implant to the marginal bone.[12] Measurements were performed by magnifying the panoramic radiographs and calibrating the scale using implant lengths and diameters, via the DEXIS Imaging Suite Software (KaVo Dental, Germany.)

2.3 | Data analysis

Statistical analyses were performed using lifelines version 0.26.0, a software library in Python (Python Software Foundation, Wilmington, USA). The survival of implants and prostheses were analyzed using Kaplan–Meier survival analysis. The success rate of P-FDPs, which was defined by the restoration remaining in situ free of all complications over the entire observation period, was also measured as a primary outcome of the study.

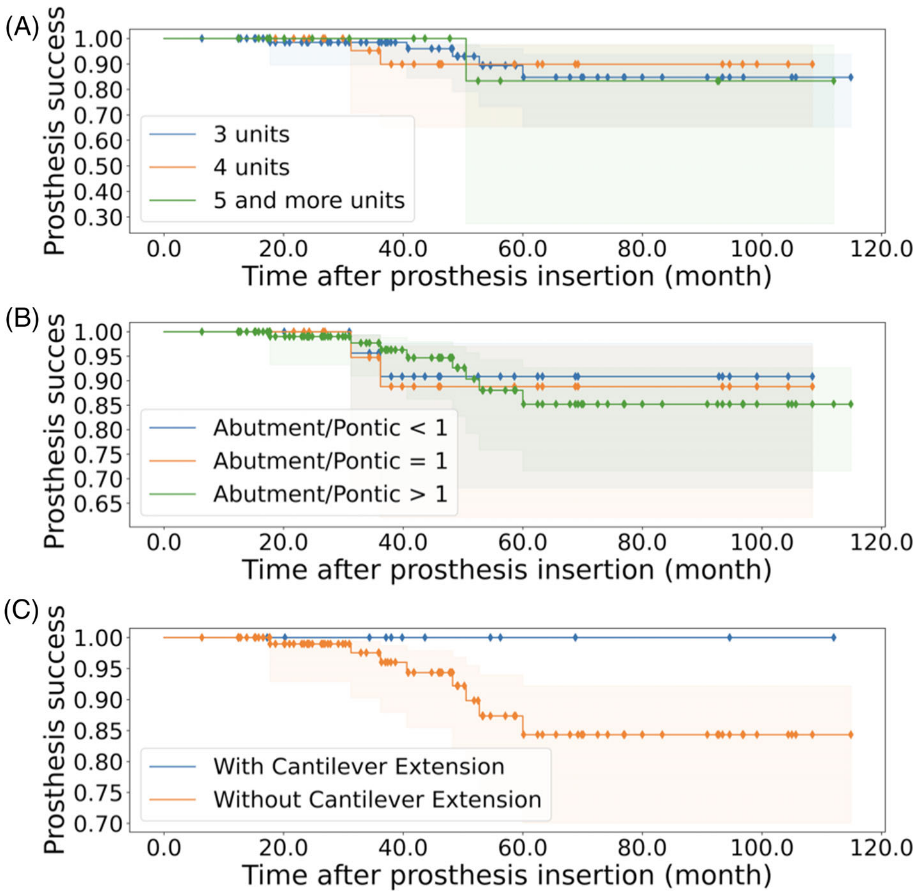

FIGURE 3 The effect of P-FDP design variables, including (A) prosthesis span, (B) abutment/pontic ratio, and (C) cantilever extensions on prosthesis success probabilities. Shaded regions represent 95% confidence intervals. There were no significant differences between groups. P-FDP, partial fixed dental prosthesis

Univariate and multivariate Cox regressions, clustered by patient using the robust variance estimator to adjust for multiple implants/prostheses being placed in the same patient, were performed to assess the effect of study variables on peri-implant MBLs.

The following covariates were analyzed in this study: patient covariates including age, gender, diabetes mellitus, osteoporosis, and smoking; implant covariates including length, diameter, locking taper bore diameter, hydroxyapatite coating, location, and bone grafting; as well as prosthesis covariates including P-FDP span, cantilever extensions, abutment/pontic ratio, and the restoration on the opposing arch. The outcome was measured by the difference in peri-implant MBL. When a continuous outcome variable such as changes in MBL is used for Cox regression, the resulting hazard ratios can be interpreted as representing a unit change in the outcome variable.

3 | RESULTS

3.1 | Cohort description and up to 10 years FRC P-FDP success/survival

This study included 96 patients with 261 implants supporting 121 P-FDPs. Patient ages at time of prosthesis insertion (Figure S1) ranged from 40 to 93 years old (mean: 68.46; standard deviation: 12.03 years old.) Patient age distributions were equivalent between the two genders (within ±4 years, $p = 0.02$), as validated by a two-sided *t*-test. Implant length was 7.28 ± 1.43 mm on average, with 149 implants being short (6–10 mm) and 112 implants being extra-short (≤6 mm). The distributions of study covariates are reported in Tables S1–S3.

Kaplan–Meier survival analysis revealed a survival probability of 95.9% (95% CI: 87.5%–98.7%) for FRC P-FDPs supported by short and extra-short implants, up to 118 months after prosthesis insertion (Figure 1). Out of 121 P-FDPs, three prostheses failed and were replaced. The probability of prosthetic success was 89.8% (95% CI: 80.4%–94.8%) over 118 months (Figure 1). Overall, P-FDPs made with FRC material survived at high rates (95.9% over 118 months) and had very few complications (10.2% over 118 months), which included three prostheses that became loose and were re-cemented, and two prostheses were modified to accommodate new pontics.

3.2 | Prosthetic outcomes between different P-FDP designs

Having established the long-term survival and success of FRC P-FDPs, the prosthetic outcomes were analyzed in more detail to explore the potential effect of a prosthesis' design on P-FDP survival and success rates. Kaplan–Meier survival analysis revealed that all three design variables analyzed: prosthesis span, abutment/pontic ratio, and

TABLE 1 Results of univariate Cox regression on peri-implant bone level

Covariate	Coefficient	Lower 95% CI	Upper 95% CI	z	p
Implant length	−1.04453	−2.18434	0.09529	−1.79611	0.072477
Hydroxyapatite coating	−0.37899	−0.88258	0.124597	−1.47503	0.140204
P-FDP span	−0.59121	−1.40127	0.218838	−1.43047	0.152581
Patient age	−0.70085	−1.68567	0.283963	−1.39483	0.163068
Implant in anterior mandible	−0.42048	−1.01702	0.176054	−1.38153	0.167117
Patient gender (male)	−0.14521	−0.57376	0.283331	−0.66414	0.5066
Implant in posterior maxilla	−0.11807	−0.52762	0.291485	−0.56502	0.572058
Implant supported P-FDP on opposing arch	−0.10944	−0.74256	0.523674	−0.33881	0.734755
Natural teeth on opposing arch	−0.06928	−0.51052	0.37196	−0.30774	0.758282
Removable prosthesis on opposing arch	−0.07524	−1.21001	1.059521	−0.12996	0.896599
Cantilever extension on P-FDP	−0.02762	−1.24476	1.189517	−0.04448	0.964522
Implant supported crown on opposing arch	0.042181	−0.48709	0.571448	0.156202	0.875874
Implant in anterior maxilla	0.059928	−0.34268	0.46254	0.291736	0.770488
Implant diameter	0.459312	−0.6313	1.549928	0.825436	0.409124
Implant well size	0.354374	−0.22437	0.933115	1.200123	0.230091
Diabetes mellitus	0.323885	−0.18227	0.830041	1.254168	0.209781
Osteoporosis	0.323885	−0.18227	0.830041	1.254168	0.209781
Implant supported FA-FDP on opposing arch	0.382604	−0.17473	0.939941	1.34549	0.178467
Abutment/pontic ratio	0.576235	−0.2498	1.402268	1.367256	0.171545
Smoking	0.805712	−0.32351	1.934933	1.398456	0.161976
Implant in posterior mandible	0.367817	−0.09763	0.833261	1.548859	0.121416
Bone grafting required	**0.547106**	**0.031612**	**1.0626**	**2.080155**	**0.037511**

Note: Bold values represent significant ($p \le 0.05$) covariates.

extensions (cantilevers), had no significant effect on the survival and success of FRC P-FDPs (Figures 2 and 3). For all length conditions explored (3, 4, or 5+ units); abutment/pontic ratio greater than, equal to, or smaller than 1; extensions (cantilever) whether present or absent, the survival probability for each type of prosthesis was at least 95%, and the probability of complication-free success was at least 88%. These results demonstrate that outcomes were consistent for all types of P-FDP designs examined in the study.

3.3 | Correlations between peri-implant bone level changes and P-FDP covariates

For all 261 implants, MBL measurements were made from radiographs taken at the date of prosthesis insertion and at a subsequent follow-up. The average time between the two radiographic measurements was 38.34 ± 24.08 months. On average, the rate of MBL change over time was −0.01 ± 0.05 mm/month. The distribution of MBL change rates is plotted in the Figure S2.

Univariate and multivariate Cox regressions, clustered by patient to account for multiple implants being placed in the same patient, were used to correlate changes in MBL with patient, implant, and prosthesis-related covariates. Univariate Cox regression (Table 1) revealed that reductions in MBL were correlated with implants requiring bone grafting ($z = 2.08$, $p = 0.04$). Multivariate Cox regression (Table 2) confirmed the correlation between MBL decrease and bone grafting ($z = 2.59$, $p = 0.01$). Additionally, multivariate Cox regression identified a correlation between longer P-FDP spans and MBL gain ($z = -2.09$, $p = 0.04$). Overall, the short and extra-short implants supporting FRC P-FDPs maintained stable bone levels; MBL changes were correlated with bone grafting (decrease) and longer P-FDP spans (increase).

4 | DISCUSSION

This study retrospectively assessed the clinical performance of FRC P-FDPs supported by short and extra-short implants for a period of up to 10 years. The main outcomes studied were P-FDP survival and success. Kaplan–Meier analysis revealed high survival probabilities and success rates of 95.9% and 89.8% respectively, at 118 months after prosthesis insertion. There were five complication events out of the 121 P-FDPs studied, over a period of 10 years. Two were loosened prostheses, which were re-cemented without the need for any additional modification to the prosthesis. The other three prostheses were modified to accommodate new pontics. While their modification excludes them from the definition of prosthetic success, they were not failures of the prosthesis, but rather an example of the FRC

TABLE 2 Results of multivariate Cox regression on peri-implant bone level

Covariate	Coefficient	Lower 95% CI	Upper 95% CI	z	p
P-FDP span	**−0.69141**	**−1.34125**	**−0.04158**	**−2.08538**	**0.037035**
Implant in posterior maxilla	−0.26122	−0.56266	0.040229	−1.6984	0.089432
Patient age	−0.86753	−1.91108	0.176018	−1.62937	0.103234
Hydroxyapatite coating	−0.43394	−0.96348	0.095599	−1.60613	0.108246
Implant length	−0.84531	−2.25018	0.559561	−1.17931	0.238275
Natural teeth on opposing arch	−0.14337	−0.42486	0.138124	−0.99825	0.318159
Implant in anterior mandible	−0.21993	−0.68704	0.247177	−0.92282	0.356102
Patient gender (male)	−0.16964	−0.56652	0.227249	−0.83772	0.402186
Removable prosthesis on opposing arch	−0.36833	−1.38181	0.645151	−0.71231	0.476275
Cantilever extension on P-FDP	0.075648	−1.33949	1.490785	0.104773	0.916556
Implant diameter	0.108856	−0.88773	1.105443	0.214084	0.830482
Implant supported crown on opposing arch	0.068652	−0.34044	0.477744	0.328915	0.74222
Abutment/pontic ratio	0.242881	−0.46808	0.953842	0.669569	0.503133
Implant in posterior mandible	0.153003	−0.26997	0.575973	0.70899	0.478331
Implant supported P-FDP on Opposing arch	0.197937	−0.29962	0.695492	0.779711	0.435561
Osteoporosis	0.122738	−0.18345	0.428922	0.785676	0.432057
Diabetes mellitus	0.122738	−0.18345	0.428922	0.785676	0.432057
Implant in anterior maxilla	0.207605	−0.12559	0.540803	1.22119	0.222014
Smoking	0.65737	−0.35163	1.666374	1.276923	0.201629
Implant well size	0.293892	−0.1554	0.743185	1.282057	0.199823
Implant supported FA-FDP on opposing arch	0.505083	−0.09724	1.107402	1.643556	0.100268
Bone grafting required	**0.627453**	**0.152194**	**1.102712**	**2.587613**	**0.009664**

Note: Bold values represent significant ($p \leq 0.05$) covariates.
Abbreviations: FA-FDP, full-arch fixed dental prosthesis; P-FDP, partial fixed dental prosthesis.

prosthesis' ability to provide for the addition of new pontics without the need for remaking the entire restoration.

Comparing the probability of survival outcomes to previously published outcomes for the gold standard survival rate of 98.7% for metal ceramic prostheses, the 5-year survival probability of 95.9% (95% CI: 87.5%–98.7%) for FRC is similar. When metal-free materials are included in the literature comparison, the 5-year success rate of porcelain fused to zirconia of 77.2% is significantly lower, than the 84.9% for metal-ceramic, as well as of 89.8% (95% CI: 80.4%–94.8%) for FRC P-FDPs.[6] The significantly lower success rates of porcelain fused to zirconia P-FDPs is due to its 22.8% chipping rates, reported as clinically unacceptable.[5] The EAO 2022 position paper confirmed previous findings regarding materials selection for implant-supported P-FDP where both zirconia-ceramic cannot be considered as a first priority due to pronounced risk of framework and veneering material fractures and veneered or monolithic reinforced glass–ceramic cannot be recommended due to high rates of framework fracture. It was also mentioned that although monolithic zirconia is a promising alternative to zirconia-ceramic P-FDP, its literature is still scarce.[4] The promising success rates for the FRC resin P-FDPs investigated in this study may be attributed to the low elastic modulus and low mismatch in the mechanical properties between the FRC and the veneering resin composite compared to metal-ceramic or zirconia-ceramic constructions, which may eventually improve chewing force dampening and stress distribution, decreasing technical and biological complications.[7–9]

It is also noteworthy that the aforementioned meta-analyses on metal-ceramic and zirconia ceramic implant-supported P-FDPs are limited to a 5-year follow-up period. For the P-FDPs in this study, both the survival and success rates were unchanged between the 5- and 10-year follow-up periods, as no prostheses failed or developed complications between the 5-year and 10-year intervals. Consequentially, the 10-year survival probability of 95.9% for FRC P-FDPs is higher than the 86.7% survival from previously reported data on mostly metal-ceramic implant supported FDPs, which did not include 10-year success rates.[17] The stability of FRC P-FDPs during the time period between 5 and 10 years post-insertion is in accordance with previously reported high 8-year survival rates of FRC full-arch FDPs.[12]

To investigate whether the high overall survival and success rates of FRC P-FDPs apply to different prosthetic designs, the outcomes for different P-FDP designs were measured separately. Previous analyses have suggested that parameters in prosthesis design, namely the prosthesis' span, abutment/pontic ratio, and the presence of extensions (cantilevers), can influence the survival of P-FDPs.[11,18] Our findings showed that for all three parameters investigated, there is no significant difference between the Kaplan–Meier outcomes of prostheses with different spans (3, 4, or 5+ units); prostheses with different abutment/pontic ratios (less than, equal to, or greater than 1); and prostheses with and without extensions cantilevers. The results were confirmed with Cox regression, which revealed that neither extensions (cantilevers) nor the abutment/pontic ratio affected peri-implant bone levels significantly. However, multivariate Cox regression showed a correlation between greater prosthesis spans and peri-implant bone gain, which did not affect prosthetic outcomes. These findings suggest that high rates of survival and success and stable marginal bone level may be consistently achieved with FRC P-FDP frameworks under a variety of clinically relevant designs. Biomechanical factors might be associated with the results obtained, including the splinting of implants and the low elastic modulus of the restorative material that more uniformly distribute forces to implants and peri-implant region under loading, especially for extra-short implants.[8,19] Also, the mean marginal bone level change over time (−0.01 ± 0.05 mm) is in agreement with previous literature findings reported for short implants (−0.49 to 2 mm bone loss after 12–120 months follow-up).[15,20,21]

Lastly, this study investigated the influence of patient, implant, and prosthesis-related covariates on peri-implant marginal bone levels. Both univariate and multivariate Cox regressions revealed a correlation between conditions that require bone grafting with a decrease in MBL. These results are in accordance with previous findings, that identified grafted implants as being especially susceptible to bone loss.[22] Multivariate Cox regression also found that longer prostheses were correlated with bone gain surrounding implants—an effect which, as previously mentioned, did not result in significant differences in prosthetic outcomes. These results show that without bone grafting, the short and extra-short implants used to support FRC P-FDPs maintained stable bone levels. Additional prospective long-term clinical studies with a meticulous investigation of survival and success rates as well as technical and biological complications are required to confirm the current favorable performance of FRC P-FDPs.

The limitations of this study include its retrospective nature, which leads to the possibility that there are confounding factors that were not considered. The difficulty of following patients regularly, not only limits the sample size but also may result in bias. Therefore, future prospective studies are needed to provide a more comprehensive evaluation of FRC P-FDPs.

5 | CONCLUSION

The combination of FRC frameworks and short and extra-short implants, which offers the unique advantages of low elastic modulus and high restorative versatility, is a favorable alternative approach for fabricating P-FDPs. For up to 10 years, FRC frameworks have shown high survival and success rates, as well as stable peri-implant bone levels in the current retrospective study.

AUTHOR CONTRIBUTIONS

Yu-Chi Cheng: acquisition of data, analysis of data, interpretation of data, drafting of the article; **Edmara T.P. Bergamo**: acquisition of data, interpretation of data, drafting of the article; **Laura Murcko**: acquisition of data, interpretation of data, drafting of the article; **Muneki Hirayama**: acquisition of data, interpretation of data, drafting of the article; **Paolo Perpetuini**: acquisition of data, interpretation of data, drafting of the article; **Drauseo Speratti**: acquisition of data, interpretation of data, drafting of the article; **Estevam A. Bonfante**: acquisition of data, interpretation of data, critical revision and final approval of the article.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data sets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Abbreviations: FA-FDP, full-arch fixed dental prosthesis; P-FDP, partial fixed dental prosthesis.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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