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Posterior two-unit cantilevered zirconia resin-bonded fixed partial dentures: A 3-year prospective single-arm clinical trial

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ABSTRACT

Objectives: To evaluate the longevity of cantilevered zirconia-based resin-bonded fixed partial dentures (RBFPDs) in replacing missing posterior teeth, as well as the quality of life and patient satisfaction experienced by those receiving zirconia RBFPDs.

Methods: A prospective single-arm uncontrolled clinical trial was conducted to replace one or more missing premolars or molars with a span of 5 to 8 mm using cantilevered zirconia RBFPDs. Thirty-six participants with 40 prostheses were recruited and underwent a 3-year clinical evaluation. The retainer designs included a minimum thickness of 0.8 mm, a minimum of 200° circumferential wraparound with an occlusal bar, and a connector dimension of 3 × 3 mm. Patient-reported outcomes, including patient satisfaction and Oral Health Impact Profile (OHIP), were assessed.

Results: The average age of participants was 45.8 years, and 72.5 % were women. The success rate of the posterior zirconia RBFPDs was 76.2 %, with an estimated mean success duration of 46.1 months. The survival rate was 88.1 %, with an estimated mean survival duration of 49.4 months. Participants were highly satisfied with the treatment, achieving an average satisfaction score of 80.8 ± 11.9. Participants' total OHIP scores decreased from 52.3 to 39.6 after 3 years, indicating a significant improvement in oral health-related quality of life ($P = 0.009$).

Conclusions: After 3 years, a moderately high survival rate and favourable patient-reported outcomes of posterior cantilevered zirconia RBFPDs were achieved. Therefore, it can be recommended as a conservative treatment option to replace missing posterior teeth, provided that retainer design considerations are taken into account.

Clinical significance: Cantilevered zirconia RBFPDs for posterior teeth can serve as a conservative treatment option that is both aesthetically pleasing and biocompatible. It offers a more cost-effective alternative compared to dental implants, which are often prohibitively expensive for the majority of patients. This approach has the potential to greatly improve patient-reported outcomes.

1. Introduction

The impact of tooth loss has been shown to affect the oral health-related quality of life (OHRQoL) [1] and the need for treatment that impacts patient satisfaction and OHRQoL [2-6]. Dental implants are considered a gold standard by many but they are not suitable for children or teenagers where craniofacial growth is still expected and in some patients, they are medically contraindicated. However, most significantly, they are cost-prohibitive to the majority of the population [7]. Given the reduction of dental caries in many populations conventional fixed partial dentures are too invasive therefore, an alternative cost-efficient, conservative, and effective replacement option is the use of resin-bonded fixed partial dentures (RBFPDs). Traditionally, RBFPDs are adhesively bonded to the etched enamel of a minimally prepared abutment [8-13]. However, metal-ceramic RBFPDs are not acceptable to patients looking for aesthetic or metal-free options. In addition, RBFPDs are usually fabricated from nickel chrome, which is a non-precious, base-metal alloy that may have potential allergic and toxic responses in some patients [14-16]. In contrast, zirconia, a yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) is an all-ceramic, aesthetic, biocompatible, low plaque deposition, high-strength restorative material, and minimal opposing tooth wear when properly finished and

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polished [17-19]. In the past, these restorations encountered complications due to the fracturing of the veneering porcelain's outer layer during function. Thus, prostheses made from monolithic zirconia have gained popularity, as they exhibit reduced complication rates and effectively overcome this issue [20].

The success of zirconia RBFPDs for single missing anterior incisors is evidenced by 10-year results with 98.2 % survival and 92 % success rates [21] which is comparable to the metal-ceramic RBFPDs. However, only incisors were replaced, and intricate tooth preparation was performed that may be technique-sensitive. While there is some successful data on zirconia RBFPDs for anterior teeth [22], there is a paucity of literature on using all zirconia RBFPDs to restore missing posterior teeth. The evidence base for two-unit metal ceramic RBFPDs has grown and demonstrated good success and survival rates with limited adverse effects and should be considered as a standard of care compared to three-unit fixed-fixed RBFPDs [23]. The literature on the use of all zirconia RBFPDs for the replacement of posterior single missing teeth is relatively limited. One recent study reported a 100 % survival rate for 27 zirconia cantilevered RBFPDs replacing missing canines and posterior teeth. Tooth preparation was limited to the enamel and partially extended to the proximal marginal ridge and cusps without static occlusal contacts, allowing for retainer coverage [24]. In a study from the same research centre as previous, a comparison of two phosphate monomer-containing resin cements, Panavia 21 and Panavia V5 (both by Kuraray Noritake Dental, Tokyo, Japan), observed 100 % survival rates for 24 cantilever RBFDPs used to replace posterior teeth over an average observation period of 22.5 months [25].

A high-quality clinical study is needed to inform the use of posterior RBFPDs with minimal tooth preparation to demonstrate its efficacy. Therefore, this prospective clinical study aimed to examine the success and survival of cantilevered zirconia-based RBFPD in replacing missing posterior teeth and the OHRQoL and satisfaction of patients receiving zirconia RBFPDs. The research hypotheses were that 2-unit cantilevered zirconia RBFPDs would exhibit high clinical success and survival rates and that a significant improvement in patient satisfaction and OHRQoL would be observed following posterior tooth replacement using zirconia RBFPDs.

2. Materials and methods

2.1. Participant recruitment and screening

This prospective single-arm uncontrolled clinical trial recruited patients attending a university dental teaching hospital who requested and needed the replacement of one or more missing lone standing posterior teeth (premolar or molar) with a span of 5 to 8 mm. The protocol was registered with clinicaltrials.gov (NCT02793037) and ethics approval was obtained (UW15-205).

Participants were clinically assessed for eligibility and invited to participate after signing written informed consent. They were recruited from January 2015 to November 2018. The inclusion and exclusion criteria are given in Table 1. All participants agreed to receive cantilevered zirconia RBFPD and undergo annual review up to 3 years after cementation. They were then asked to complete the Oral Health Impact Profile (OHIP) questionnaire. Baseline sociodemographic and clinical data were collected at the same appointment, including the presence of caries, presence of hypersensitivity, periodontal probing depth, presence of proximal contacts, presence of hypermobility, and radiographic crestal bone level. Patients were then allocated to be treated as a normal part of care by undergraduate students and hospital dental officers who performed tooth preparations and delivery of prostheses.

Table 1
Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
Treatment planning for 2-unit posterior RBFPD.	Uncontrolled or active dental diseases.
Edentulous span of 5 to 8 mm.	Non-vital or root canal-treated abutment tooth.
Natural teeth or fixed prosthesis opposing the RBFPD.	Periodontal probing depth greater than 5 mm.
Minimum of 12 occluding pairs of teeth.	Mobility of grade 2 or higher (Miller's classification).
Completed other active treatments and in stable. dental health.	Less than 30 % alveolar bone support on the abutment.
	Medical history with debilitating illnesses or compromising medical conditions.

2.2. Design features and tooth preparation

The design features of the prostheses (Fig. 2) followed similar principles to the existing metal-ceramic RBFPD designs [23,26] but with slight modifications specific to an all-ceramic material [27]. On the day of the appointment, minimal tooth preparation was performed on the abutment that would accommodate the retainer design by the operator. When occlusal reduction was indicated for the occlusal bar and rest, tooth preparation of 0.8–1.0 mm was performed if needed. The width of the occlusal bar ranged from 2 to 3 mm representing one-quarter to one-third of the occlusal table width. A silicone working impression was made and poured. Monolithic zirconia (Vita YZ HT zirconia, VITA Zahnfabrik, H. Rauter GmbH & Co. KG) was milled by the Arum 5 × 400 machines (Arum Europe GmbH) based on design principles as outlined in Fig. 1. The intaglio surface of the retainer was airborne-particle abraded with 50 μm alumina particles at 2-bar pressure followed by steam cleaning [28,29]. The zirconia framework was cemented using a resin cement containing phosphate monomers (Panavia F2.0, Kuraray, Osaka, Japan) following the manufacturer's instructions, along with a ceramic primer. This cementation protocol, applied under rubber dam isolation, has been reported to be successful for anterior zirconia resin-bonded fixed partial dentures (RBFPDs) with a durability of up to 10 years [21]. A standardized protocol for polishing in the laboratory and chairside of the zirconia surfaces was followed [30–32]. Occlusion was assessed after cementation to avoid occlusal interferences on the pontic during lateral excursive movements.

2.3. Data collection

A review of the outcome of prostheses at 1, 6, 12, 24, and 36-month intervals were performed. Clinical examinations were performed independently of the treatment provider to minimize possible bias. A proforma was used to provide a structured clinical examination of the participant and prosthesis and to assess for various adverse signs or symptoms including technical complications (decementation, fracture of framework, and fracture of the pontic porcelain) and biological complications (caries, periodontal disease of the abutment teeth, loss of tooth vitality, loss of abutment, tooth movement, increased tooth mobility, and discomfort on chewing). As routine, periapical radiographs were taken at baseline and at 3 years to observe any adverse changes or pathology associated with abutment teeth supporting the RBFPDs. Success and survival of all zirconia RBFPDs were calculated based on the following definitions: success is the absence of complications requiring any type of intervention and survival is the retention of the original prosthesis not requiring remake (time-to-retreatment). Thus survival included any RBFPDs that could be repaired and decemented RBFPDs that could be recemented. All other RBFPD complications were classified as failures. The dates of each event were logged and time intervals of success and survival were calculated.

Patient satisfaction and OHRQoL were investigated using a 14-item questionnaire and an Oral Health Impact Profile (OHIP), respectively. The satisfaction questionnaire contained fourteen questions on participant satisfaction regarding the prosthesis' appearance, comfort, chewing ability, treatment procedure, and arrangement, and whether the patient would choose the same type of prosthesis in the future and

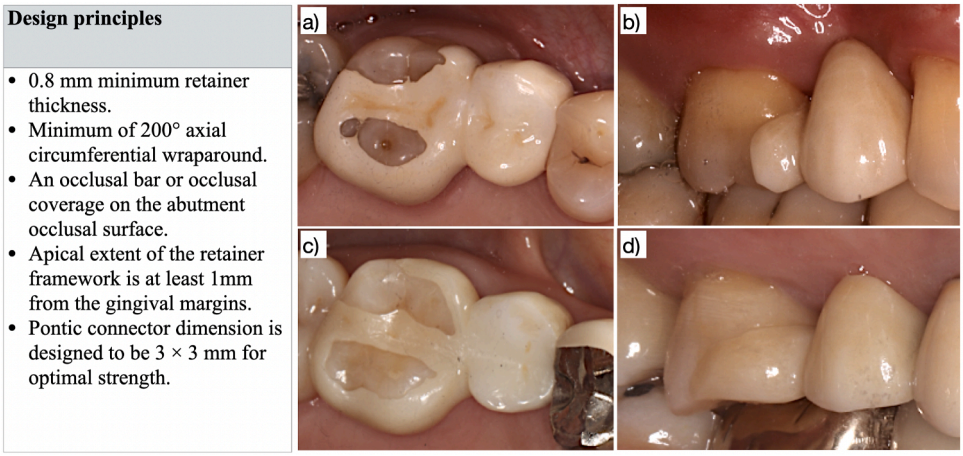

Fig. 1. Design principles for posterior zirconia resin-bonded fixed partial dentures.

recommend others. The OHIP consists of 49 questions from 7 domains, namely functional limitation, physical pain, psychological disruption, social disability and handicap, and participants indicated the frequency of encountering or suffering negative impacts on a Likert scale of 0 (never) to 4 (often). OHIP summary score was calculated by the summation of individual scores, with a higher summary score indicating poorer OHRQoL.

2.4. Statistical analysis

Clinical data and questionnaire responses were entered onto a spreadsheet (Microsoft® Excel für Mac, Version 16.44, Microsoft Corporation, Redmond, WA, USA). Success (time-to-repair), survival (time-to-replacement), and longevity of the zirconia prostheses were presented in Kaplan-Meier success and survival curves. Changes in OHIP scores were compared between baseline and follow-up and analysed using Wilcoxon signed-rank test. Patient satisfaction at the final review was presented using descriptive statistics. All statistical analyses were performed using SPSS 27.0 (IBM, USA). A P-value less than 0.05 was considered statistically significant.

3. Results

This was a single-arm clinical trial investigating posterior zirconia

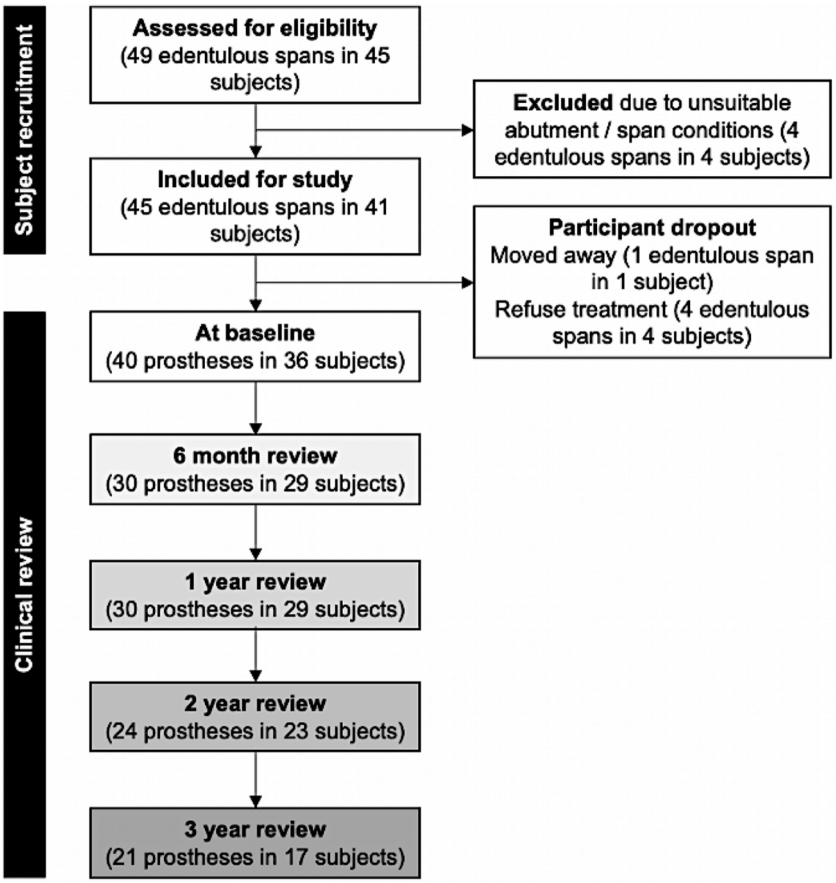

Fig. 2. Flow chart of clinical trial.

RBFPDs performance. Forty-five subjects with 49 premolar-sized edentulous spans were assessed for eligibility and 36 subjects were recruited with 40 premolar-sized edentulous spans (Fig. 2). Thirty-two participants had one single premolar-sized span, two participants had two single premolar-sized edentulous spans, and another two patients had consecutive edentulous spans with the width of two premolars. The sociodemographic and patient characteristics of the 36 participants are presented in Table 2. The majority of participants in this study were female (72.5 %) with a mean age at cementation of 45.8 years. The missing teeth in this study were predominantly premolar (77.5 %), and the remainder were "molars" that had a mesiodistal span of 5–8 mm. The missing teeth are also distributed amongst all four quadrants. Most of the zirconia RBFPDs in this study (72.5 %) were provided by undergraduate students as part of the undergraduate training and the remaining by recently qualified junior hospital dental officers.

Twenty-nine participants with 30 prostheses attended our review visits at six months and one year after cementation. Twenty-three participants with 24 prostheses participated in the two-year review, while 17 participants with 21 prostheses attended the three-year review. Out of the 40 zirconia RBFPDs in this study, two prostheses fractured and were deemed technical failures, two prostheses were decemented but successfully recemented (survived), and one abutment, with an intact prosthesis, was deemed a biological complication due to a periodontal disease involving the progression of a periodontal pocket from 4 mm to 9 mm. The patient declined an extraction, and the prosthesis continued to survive until the most recent evaluation. The achieved success rate was 76.2 %, with an estimated mean success duration of 46.1 months (Fig. 3). The survival rate stood at 88.1 %, with an estimated mean survival duration of 49.4 months (Fig. 4). Due to two instances of decemented prostheses, the survival rates at 36.0 and 37.2 months were 95.5 % and 88.1 %, respectively. During the clinical examination of two decemented prostheses using dental magnification loupes at 2.5x magnification, mixed failures were observed due to the presence of resin cement partially remaining on both the retainer and the tooth surface.

Patient-reported outcomes as measured by the patient satisfaction and OHIP questionnaires were presented in Tables 3 and 4, respectively. In general, participants were highly satisfied with the zirconia RBFPDs, achieving an average satisfaction score of 80.8 ± 11.9. The top three items contributing to patient satisfaction, in descending order, were the operator (91.4 %), speech (89.0 %), and treatment completion time (82.2 %). A majority of participants (97.4 %) opted to recommend this treatment option to others. Following the provision of zirconia RBFPDs, participants' total OHIP scores decreased from 52.3 to 39.6, signifying a significant improvement in oral health-related quality of life ($P = 0.009$). Out of seven domains, scores in four domains showed significant improvements, including psychological discomfort ($P = 0.041$), psychological disability ($P = 0.007$), social disability ($P = 0.007$), and handicap ($P = 0.008$).

Table 2
Baseline sociodemographic and patient characteristics of participants.

	Zirconia RBFPD ($n = 40$) Number (%)
Gender	
Male	11 (27.5 %)
Female	29 (72.5 %)
Mean age at cementation (mean ± SD)	45.8 ± 14.6
Type of missing tooth	
Premolar	31 (77.5 %)
Molar (premolar width)	9 (22.5 %)
Location of missing tooth	
Upper right	16 (40.0 %)
Upper left	10 (25.0 %)
Lower left	4 (10.0 %)
Lower right	10 (25.0 %)
Operator	
Undergraduate dental student	29 (72.5 %)
Hospital dental officer	11 (27.5 %)

4. Discussion

The growing popularity of aesthetic dental prostheses made of non-metallic materials has led to the widespread use of dental zirconia. This trend is supported by research groups in Germany who have systematically evaluated the clinical outcomes of resin-bonded fixed zirconia prostheses [21,24,33,34]. However, scientific evidence of posterior RBFPDs remains limited, and there is limited evidence supporting zirconia as the material of choice. Therefore, it was deemed crucial to further assess and measure the success and longevity of zirconia RBFPDs to establish their clinical applications and evaluate their performance in the posterior region. In this study, two-unit cantilevered zirconia RBFPDs demonstrated moderately high clinical success and survival rates, with high overall OHRQoL, and high patient satisfaction after three years.

Longevity data exists for conventional posterior inlay-retained RBFPDs in three-unit fixed-fixed RBFPD designs, demonstrating variable success rates. These rates range from 83 % "free of any kind of complications" at 5 years [35] and 70.4 % at 10 years [36], to a notably lower 12 % survival rate at 10 years [37]. This variability has been attributed to different retainer designs, with either fixed-fixed design, only inlay retainers, or inlay retainers with "short retainer wings" [38], suggesting that design considerations for posterior RBFPDs are important for success. In this study, the success and survival rates of zirconia RBFPDs after three years were 76.2 % and 88.1 %, respectively, which is consistent with the findings by Shahdad et al. [39]. However, their study included both anterior and posterior zirconia RBFPDs, with the number of posterior prostheses being relatively small, consisting of only 16 prostheses, and using a different resin cement (Multilink Automix, Ivoclar-Vivadent). In contrast, other studies reported excellent longevity for posterior 3Y-TZP zirconia RBFPDs, with 100 % survival rates observed after an average follow-up period ranging from 22.5 to 53 months [24,25]. This discrepancy could potentially be attributed to a smaller sample size, the retainer design, and the fact that treatments were performed by experienced dentists and specialists, which differs from the present study. This indicates that zirconia RBFPD may serve as a viable alternative to metal-ceramic prostheses for posterior tooth replacement, providing that retainer design considerations and clinician factors are taken into account.

One study reported chipping or delamination as high as 25 % for porcelain veneered zirconia implant-supported crowns and FPDs [40]. In addition, tooth-supported porcelain veneered zirconia FPDs demonstrated significantly lower survival and higher minor and major chipping rates than monolithic zirconia FPDs [20]. In light of this, there is now a growing trend to use monolithic zirconia, as performed in the present study. Amongst the two failed prostheses, it was observed that fractures occurred at the thinnest portion of the retainer. As a result, reducing the extension and modifying the margin with an obtuse emergence profile angle could potentially help minimize the likelihood of edge defects and microcracks associated with acute margins, which can ultimately lead to fractures. New designs of frameworks considering this design element need to be implemented and evaluated. This current failure finding contrasts with Yagizi and Kern, who found that caries was the only complication in their study, possibly due to the high strength of 3Y-TZP zirconia and their prosthesis design, which contributed to no technical complications. Furthermore, mixed failures were observed for both decemented prostheses, which is consistent with the findings of a systematic review [41]. This indicates that the adhesion between zirconia and the adhesive resin cement was not the weakest point. The current Kaplan-Meier analysis demonstrated a sharp decline at 36 months, indicating that complications occurred during this period. This finding is consistent with a clinical study conducted in the United Kingdom, which reported that 20 % of metal-ceramic RBFPDs failed within the first four years [42].

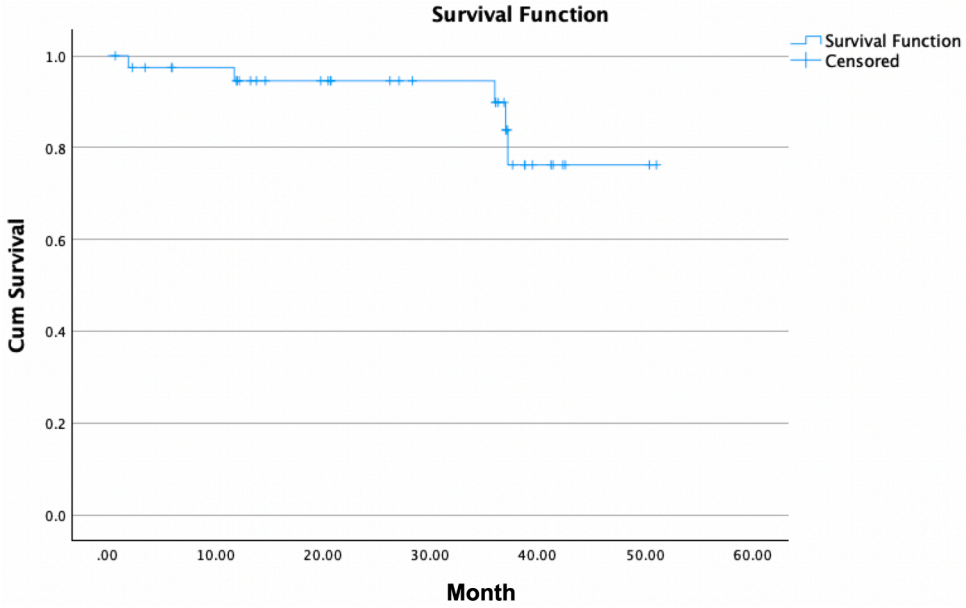

Fig. 3. Success rates of posterior zirconia resin-bonded fixed partial dentures.

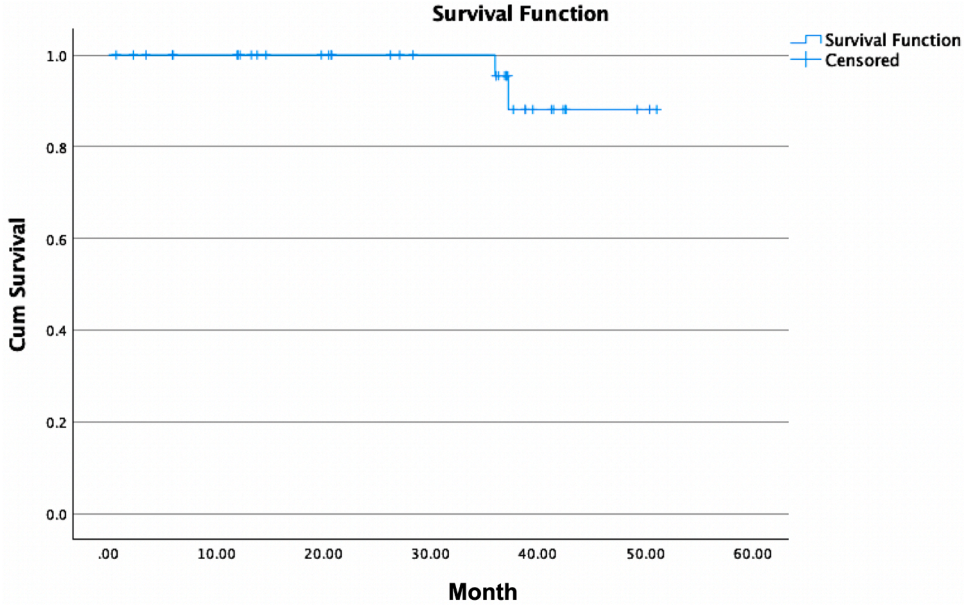

Fig. 4. Survival rates of posterior zirconia resin-bonded fixed partial dentures.

Participants were highly satisfied with the zirconia RBFPDs, as 92.1 % of them would choose this prosthesis design again and nearly 100 % would recommend this treatment to others. This satisfaction could be attributed to the natural-looking tooth colour of zirconia compared to metal, cost-efficiency, and conservative tooth preparation. Two studies reported that 89 % and 93 % of participants would recommend this treatment option to others, which is lower than the present study [4,6]. This difference could be due to both studies using conventional metal retainers, and one of them adopting the Dahl approach [43] during cementation, which may cause abrupt occlusal changes and affect function and speech [10,11]. Additionally, this study's result indicates a higher OHRQoL compared to the study by Lam et al. conducted at the same centre [3] for two-unit metal-ceramic RBFPDs, which may explain the lower quality of life scores. The psychological aspect and social disability domains showed significant improvement from the baseline data, whereas functional and physical disability did not. This suggests that single posterior tooth replacement primarily serves to satisfy patients' psychological desire for completeness rather than significantly improving their function, a notion supported by the shortened dental arch concept.

There were some limitations of this study were identified. First, it was a prospective clinical study with a single arm of participants receiving zirconia RBFPDs. Therefore, studies with longer review periods, larger sample sizes, and conducting a randomized control trial to allow comparison between metal-ceramic and zirconia RBFPDs may be considered. However, given the longevity of such two-unit prostheses, this means outcomes take a long time to find a difference and hence a proof of concept approach was adopted for a single arm. Second, the prostheses were reviewed by a few different operators throughout the study, although all operators were trained and calibrated prior to data collection and the type of data was not subjective in nature. Third, there was some variability in RBFPD design according to patient-specific local

Table 3
The mean satisfaction score (standard deviation) and the number of participants (percentage) that would select/recommend the allocated RBFPDs design at the latest review.

	Zirconia RBFPDs ($n = 38$) Number (SD)
General satisfaction (0–100)	80.8 (11.9)
Appearance (0–100)	81.2 (12.9)
In comparison with natural tooth (0–100)	73.9 (14.5)
Comfort (0–100)	80.8 (9.7)
Chewing ability (0–100)	77.9 (13.8)
Speech (0–100)	89.0 (10.2)
Ease of cleaning (0–100)	73.0 (18.5)
Firmness of prosthesis (0–100)	82.1 (13.2)
Confidence in this prosthesis (0–100)	80.2 (14.1)
Treatment time for completion (0–100)	82.2 (14.2)
Treatment comfort (0–100)	80.8 (12.4)
Operator (0–100)	91.4 (8.6)
Select this prosthesis design again (Yes)	35 (92.1 %)
Recommend to others (Yes)	37 (97.4 %)

0 = least satisfied, 100 = most satisfied.

Table 4
Results of mean OHIP score at baseline and latest review for zirconia RBFPDs.

	Zirconia RBFPDs		
	Baseline ($n = 22$) (SD)	Latest review ($n = 22$) (SD)	p value ($n = 22$) (ES)
Summary OHIP score (0–196)	52.3 (35.6)	39.6 (28.6)	0.009* (0.36)
Functional limitation (0–36)	10.5 (6.9)	9.3 (6.1)	0.389 (0.17)
Physical pain (0–36)	10.4 (6.6)	9.1 (7.4)	0.407 (0.18)
Psychological discomfort (0–20)	5.8 (4.6)	4.2 (3.4)	0.041* (0.35)
Physical disability (0–36)	9.1 (6.1)	7.4 (5.7)	0.303 (0.28)
Psychological disability (0–24)	6.2 (5.3)	3.7 (3.1)	0.007* (0.47)
Social disability (0–20)	4.1 (4.3)	2.0 (2.3)	0.007* (0.49)
Handicap (0–24)	6.2 (4.4)	3.9 (3.1)	0.008* (0.52)

SD: Standard deviation; ES: Effect size; *Significant at $P < 0.05$.
Effect size = mean difference in OHIP score ÷ standard deviation of OHIP score.

tooth-related factors including some prostheses exhibited an occlusal bar while some presented a nearly 360° wraparound. However, this variability was limited because of the design principles set out as described in the materials and methods. All prostheses were fabricated in the same laboratory which was familiar with the design principles and practices in the teaching hospital. In addition, a small number of participants missed their scheduled review appointments due to availability issues and clinic closure during the global coronavirus pandemic in 2020.

Participants of this study are still under regular clinical review and follow-up to investigate the long-term performance of zirconia RBFPDs. Based on the outcomes of the present study, future investigations may focus on the design and mechanics of zirconia RBFPDs and develop and improve the design principles which will minimise technical or biological complications and increase the longevity of the prostheses.

5. Conclusion

Considering the survival and favourable patient-reported outcomes of cantilevered zirconia RBFPDs in the posterior region, this prosthesis can be viewed as a viable alternative to metal-ceramic RBFPDs for replacing missing premolar-sized edentulous posterior spans in the short to medium term. This provides clinicians with more options in prosthesis design, particularly in cases where metal alloy is not the preferred material.

Availability of data

The data extracted from the included studies and the data used for the analyses are available upon request from the corresponding author.

Funding

Nil.

CRediT authorship contribution statement

Walter Yu Hang Lam: Validation, Project administration, Methodology, Investigation, Data curation. **Tong Wah Lim:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Madeline Jun Yu Yon:** Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jimmy Man Ho Chau:** Validation, Methodology, Investigation, Data curation. **Gentle Chin Hung Lai:** Validation, Methodology, Investigation, Data curation. **Denny Chon Pei Wang:** Validation, Methodology, Investigation, Data curation. **Michael G. Botelho:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] A.E. Gerritsen, P.F. Allen, D.J. Witter, E.M. Bronkhorst, N.H. Creugers, Tooth loss and oral health-related quality of life: a systematic review and meta-analysis, Health Qual. Life Outcomes 8 (2010) 1–11, https://doi.org/10.1186/1477-7525-8-126.

[2] P. Hoyle, K. Patel, P. Benson, Does replacement of missing dental units with resin-retained bridges improve oral health-related quality of life?: a systematic review, J. Dent. 91 (2019) 103209, https://doi.org/10.1016/j.jdent.2019.103209.

[3] W.Y. Lam, C.P. McGrath, M.G. Botelho, Impact of complications of single tooth restorations on oral health-related quality of life, Clin. Oral Implants Res. 25 (2014) 67–73, https://doi.org/10.1111/clr.12166.

[4] T.W. Lim, R.I. Idris, M. Mahmud, Patient satisfaction following resin-bonded fixed dental prostheses cemented by using the Dahl concept, Clin. Exp. Dent. Res. 9 (2023) 1089–1095, https://doi.org/10.1002/cre2.774.

[5] T.W. Lim, T.F.T.M. Ariff, Single tooth implant versus resin-bonded bridge: a study of patient's satisfaction, Eur. J. Gen. Dent. 9 (2020) 90–95, https://doi.org/10.4103/ejgd.ejgd_63_20.

[6] N. Creugers, R. De Kanter, Patients' satisfaction in two long-term clinical studies on resin-bonded bridges, J. Oral Rehabil. 27 (2000) 602–607, https://doi.org/10.1046/j.1365-2842.2000.00553.x.

[7] W.Y. Lam, M.G. Botelho, C.P. McGrath, Longevity of implant crowns and 2-unit cantilevered resin-bonded bridges, Clin. Oral Implants Res. 24 (2013) 1369–1374, https://doi.org/10.1111/clr.12034.

[8] M.G. Botelho, A.W. Chan, N.C. Leung, W.Y. Lam, Long-term evaluation of cantilevered versus fixed–fixed resin-bonded fixed partial dentures for missing maxillary incisors, J. Dent. 45 (2016) 59–66, https://doi.org/10.1016/j.jdent.2015.12.006.

[9] M.G. Botelho, X. Ma, G.J.K. Cheung, R.K.S. Law, M.T.C. Tai, W.Y.H. Lam, Long-term clinical evaluation of 211 two-unit cantilevered resin-bonded fixed partial dentures, J. Dent. 42 (2014) 778–784, https://doi.org/10.1016/j.jdent.2014.02.004.

[10] R.I. Idris, Y. Shoji, T.W. Lim, Occlusal force and occlusal contact reestablishment with resin-bonded fixed partial dental prostheses using the Dahl concept: a clinical study, J. Prosthet. Dent. 127 (2022) 737–743, https://doi.org/10.1016/j.prosdent.2020.11.035.

[11] T.W. Lim, S.M. Ab Ghani, M. Mahmud, Occlusal re-establishment and clinical complications of resin-bonded fixed partial dental prostheses cemented at an

increased occlusal vertical dimension: a retrospective study, J. Prosthet. Dent. 127 (2022) 258–265, https://doi.org/10.1016/j.prosdent.2020.06.034.
[12] W.Y. Lam, R.S. Chan, K. Li, K. Tang, T.T. Lui, M.G. Botelho, Ten-year clinical evaluation of posterior fixed-movable resin-bonded fixed partial dentures, J. Dent. 86 (2019) 118–125, https://doi.org/10.1016/j.jdent.2019.06.003.
[13] M.G. Botelho, J.E. Dyson, T.H. Mui, W.Y. Lam, Clinical audit of posterior three-unit fixed-movable resin-bonded fixed partial dentures–A retrospective, preliminary clinical investigation, J. Dent. 57 (2017) 26–31, https://doi.org/10.1016/j.jdent.2016.12.003.
[14] M. Syed, R. Chopra, V. Sachdev, Allergic reactions to dental materials-a systematic review, J. Clin. Diagn. Res. 9 (2015) ZE04–ZE09, https://doi.org/10.7860/JCDR/2015/15640.6589.
[15] V. Garau, M.G. Masala, M.C. Cortis, R. Pittau, Contact stomatitis due to palladium in dental alloys: a clinical report, J. Prosthet. Dent. 93 (2005) 318–320, https://doi.org/10.1016/j.prosdent.2005.01.002.
[16] J.C. Setcos, A. Babaei-Mahani, L. Di Silvio, I.A. Mjör, N.H. Wilson, The safety of nickel containing dental alloys, Dent. Mater. 22 (2006) 1163–1168, https://doi.org/10.1016/j.dental.2005.11.033.
[17] S. Jin, J.-W. Choi, C.-M. Jeong, J.-B. Huh, S.-H. Lee, H. Lee, M.-J. Yun, Evaluating the wear of resin teeth by different opposing restorative materials, Materials (Basel) 12 (2019) 3684, https://doi.org/10.3390/ma12223684.
[18] M. Hisbergues, S. Vendeville, P. Vendeville, Zirconia: established facts and perspectives for a biomaterial in dental implantology, J. Biomed. Mater. Res. B Appl. Biomater. 88 (2009) 519–529, https://doi.org/10.1002/jbm.b.31147.
[19] S. Roehling, K.A. Schlegel, H. Woelfler, M. Gahlert, Performance and outcome of zirconia dental implants in clinical studies: a meta-analysis, Clin. Oral Implants Res. 29 (2018) 135–153, https://doi.org/10.1111/clr.13352.
[20] S. Shihabi, B.R. Chrcanovic, Clinical outcomes of tooth-supported monolithic zirconia vs. porcelain-veneered zirconia fixed dental prosthesis, with an additional focus on the cement type: a systematic review and meta-analysis, Clin. Oral Investig. 27 (2023) 5755–5769, https://doi.org/10.1007/s00784-023-05219-4.
[21] M. Kern, N. Passia, M. Sasse, C. Yazigi, Ten-year outcome of zirconia ceramic cantilever resin-bonded fixed dental prostheses and the influence of the reasons for missing incisors, J. Dent. 65 (2017) 51–55, https://doi.org/10.1016/j.jdent.2017.07.003.
[22] D.S. Thoma, I. Sailer, A. Ioannidis, M. Zwahlen, N. Makarov, B.E. Pjetursson, A systematic review of the survival and complication rates of resin-bonded fixed dental prostheses after a mean observation period of at least 5 years, Clin. Oral Implants Res. 28 (2017) 1421–1432, https://doi.org/10.1111/clr.13007.
[23] M.G. Botelho, M.J. Yon, K.C. Mak, W.Y. Lam, A randomised controlled trial of two-unit cantilevered or three-unit fixed-movable resin-bonded fixed partial dentures replacing missing molars, J. Dent. 103 (2020) 103519, https://doi.org/10.1016/j.jdent.2020.103519.
[24] C. Yazigi, M. Kern, Clinical evaluation of zirconia cantilevered single-retainer resin-bonded fixed dental prostheses replacing missing canines and posterior teeth, J. Dent. 116 (2022) 103907, https://doi.org/10.1016/j.jdent.2021.103907.
[25] N. Passia, M.S. Chaar, M. Kern, Clinical outcome of posterior cantilever resin-bonded fixed dental prostheses using two different luting agents, J. Prosthodont. Res. 67 (2023) 161–163, https://doi.org/10.2186/jpr.JPR_D_22_00033.
[26] J. Lin, Z. Zheng, A. Shinya, J.P. Matinlinna, M.G. Botelho, A. Shinya, Structural stability of posterior retainer design for resin-bonded prostheses: a 3D finite element study, Odontology 103 (2015) 333–338, https://doi.org/10.1007/s10266-014-0173-2.
[27] M. Kern, Quintessenz Verlag. Resin-Bonded Fixed Dental Prostheses: Minimally Invasive–Esthetic–Reliable, 2019.
[28] S. Shimoe, T.-Y. Peng, M. Otaku, N. Tsumura, S. Iwaguro, T. Satoda, Influence of various airborne-particle abrasion conditions on bonding between zirconia ceramics and an indirect composite resin material, J. Prosthet. Dent. 122 (2019) 491.e1–491.e9, https://doi.org/10.1016/j.prosdent.2019.08.016.
[29] J.S. Emerson, G.H. Johnson, M.H. Kronström, Comparison of retention of monolithic zirconia crowns with alumina airborne-particle abraded and nonabraded intaglio using three different cements: a clinical simulation, J. Prosthet. Dent. 131 (2024) 100.e1–100.e5, https://doi.org/10.1016/j.prosdent.2023.09.018.
[30] Y.-H. Huh, C.-J. Park, L.-R. Cho, Evaluation of various polishing systems and the phase transformation of monolithic zirconia, J. Prosthet Dent. 116 (2016) 440–449, https://doi.org/10.1016/j.prosdent.2016.01.021.
[31] Y. Wang, W.Y. Lam, H.W. Luk, M. Øilo, K. Shih, M.G. Botelho, The adverse effects of tungsten carbide grinding on the strength of dental zirconia, Dent. Mater. 36 (2020) 560–569, https://doi.org/10.1016/j.dental.2020.02.002.
[32] M.G. Botelho, S. Dangay, K. Shih, W.Y. Lam, The effect of surface treatments on dental zirconia: an analysis of biaxial flexural strength, surface roughness and phase transformation, J. Dent. 75 (2018) 65–73, https://doi.org/10.1016/j.jdent.2018.05.016.
[33] M. Kern, Fifteen-year survival of anterior all-ceramic cantilever resin-bonded fixed dental prostheses, J. Dent. 56 (2017) 133–135, https://doi.org/10.1016/j.jdent.2016.11.003.
[34] M. Sasse, M. Kern, Survival of anterior cantilevered all-ceramic resin-bonded fixed dental prostheses made from zirconia ceramic, J. Dent. 42 (2014) 660–663, https://doi.org/10.1016/j.jdent.2014.02.021.
[35] M.S. Chaar, M. Kern, Five-year clinical outcome of posterior zirconia ceramic inlay-retained FDPs with a modified design, J. Dent. 43 (2015) 1411–1415, https://doi.org/10.1016/j.jdent.2015.11.001.
[36] M.S. Chaar, N. Passia, M. Becker, M. Kern, Long-term clinical outcome of three-unit fixed-fixed posterior zirconia ceramic inlay-retained FDPs with a modified design, J. Dent. 140 (2024) 104781, https://doi.org/10.1016/j.jdent.2023.104781.
[37] F. Rathmann, W. Bömicke, P. Rammelsberg, B. Ohlmann, Veneered zirconia inlay-retained fixed dental prostheses: 10-year results from a prospective clinical study, J. Dent. 64 (2017) 68–72, https://doi.org/10.1016/j.jdent.2017.06.008.
[38] M.S. Chaar, N. Passia, M. Kern, All-ceramic inlay-retained fixed dental prostheses: an update, Quintessence Int. 46 (2015) 781–788, https://doi.org/10.3290/j.qi.a34552.
[39] S. Shahdad, M. Cattell, J. Cano-Ruiz, E. Gamble, A. Gambôa, Clinical evaluation of all ceramic zirconia framework resin bonded bridges, Eur. J. Prosthodont. Restor. Dent. 26 (2018) 203–211, https://doi.org/10.1922/EJPRD_01810Shahdad09.
[40] S. Schwarz, C. Schröder, N. Corcodel, A.J. Hassel, P. Rammelsberg, Retrospective comparison of semipermanent and permanent cementation of implant-supported single crowns and FDPs with regard to the incidence of survival and complications, Clin. Implant Dent. Relat. Res. 14 (2012) e151–e158, https://doi.org/10.1111/j.1708-8208.2011.00396.x.
[41] N.P. Quigley, D.S. Loo, C. Choy, W.N. Ha, Clinical efficacy of methods for bonding to zirconia: a systematic review, J. Prosthet. Dent. 125 (2021) 231–240, https://doi.org/10.1016/j.prosdent.2019.12.017.
[42] P. King, L. Foster, R. Yates, R. Newcombe, M. Garrett, Survival characteristics of 771 resin-retained bridges provided at a UK dental teaching hospital, Br. Dent. J. 218 (2015) 423–428, https://doi.org/10.1038/sj.bdj.2015.250.
[43] T.W. Lim, Creating space for a resin-bonded fixed partial denture retainer by using the Dahl concept, J. Prosthet. Dent. 131 (2024) 1004–1007, https://doi.org/10.1016/j.prosdent.2022.03.036.