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Longevity of Fiber-Reinforced Composite Fixed Partial Dentures (FRC FPD) - Systematic Review and Meta-Analysis

Short title: Longevity of fiber-reinforced composite fixed partial dentures

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Abstract

Objectives: to assess FRC FPDs longevity through systematically reviewing contemporary clinical evidence. Population investigated comprised patients requiring replacement of a single missing anterior/posterior tooth. Intervention was FRC FPDs. No control/ comparison selected. Outcome was longevity of FRC FPDs. The focus question was: 'What is the longevity of FRC FPDs used to replace one anterior or posterior tooth in patients?'

Data: Randomised, non-randomised, controlled, prospective and retrospective clinical studies were included. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses were applied. The Overall Strength of Clinical Recommendation (OSCR) was assessed using the Strength of Recommendation Taxonomy system. Survival of FPDs was assessed using the Kaplan-Meier method. Analysis of FPD-survival according to location and occurrence of different failures was performed using Logrank and Chi-square testing.

Sources: PubMed, MEDLINE, and Web of Science databases were searched between January 2007 and December 2015.

Study selection: Nine studies were included, involving placement of 592 FRC FPDs in 463 patients. Follow-up periods ranged between 2 months and 8 years. Kaplan-Meier overall survival probability was 94.5% (95% C.I: 92.5%- 96.5%) at 4.8 years. There was no significant difference in survival probability of anterior versus posterior FRC FPDs (P = 0.278). Veneering material fracture/delamination occurred significantly more than other types of failures (Ps < 0.05). A meta-analysis could not be performed. OSCR was moderate.

Conclusions: FRC FPDs demonstrated high overall survival with predictable performance outcomes. However, long-term performance remains unclear.

Funding: no funding sources to report.

Clinical significance: FRC FPDs are viable medium-term management alternatives for replacing single anterior or posterior teeth in patients.

Introduction

Fiber-reinforced composites (FRC), consisting of a plastic matrix reinforced by fine thin fibers [1], have been used for an array of dental applications. These include, but are not limited to, endodontic posts [2], splints for periodontally compromised teeth [3, 4], provisional restorations for implants [5], space maintainers in children [6, 7], posterior metal-free crowns [8] and restorative management of localised tooth wear at increased occlusal vertical dimensions (OVD) [9].

One of the most promising applications of FRCs is their use in the fabrication of fixed partial dentures (FPD). Such restorations are composed of 2 types of composite materials, a fiber reinforced composite substructure and an overlay of resin veneering composite [10]. FRC FPDs can be surface retained [11, 12] and/or inlay retained [13] as they require a minimally invasive preparation. Furthermore, they have improved aesthetics, and can be fabricated either directly or indirectly, and at a lower cost. Therefore, FRC FPDs present a viable treatment alternative to conventional cast metal resin bonded bridges (CM RBB) [14]. However, relatively short-term clinical evidence exists to support the use of FRC FPDs, in contrast to the existing long-term performance data of CM RBBs.

In 2005, the first systematic review on FRC FPDs was published [15]. The review reported a lack of clinical evidence supporting their use, concluding that FRC FPDs should be regarded as experimental. A later systematic review assessing the longevity of FRC FPDs included studies published between 1950 and 2007 [16]. The included studies reported varying follow-up periods, the longest being 5.7 years [17]. The review estimated a survival of 73.4% at 4.5 years for FRC FPDs and identifying that delamination of the veneering composite was the most common reason for failure. Subsequently, there has been a growing number of published studies investigating the survival of FRC FPD with larger sample-sizes, longer follow-up periods, and employing different FRC systems [18-26].

The purpose of this systematic review was to assess the longevity of FRC FPDs, used to replace single anterior or posterior teeth in patients, through systematically reviewing and evaluating existing contemporary clinical evidence.

Materials and methods

The review aimed to systematically identify and assess all clinical studies investigating the survival rate of anterior and posterior FRC FPDs replacing a single tooth. The PICO principle was used to formulate the research focus question [27]. Henceforth, the patient population being investigated comprised patients requiring replacement of a single missing anterior or posterior tooth. The intervention was FRC FPDs; no control/ comparison was selected. The outcome assessed was the longevity of FRC FPD restorations. As such, the formulated research focus question was: 'What is the longevity of FRC FPDs used to replace one anterior or posterior tooth in patients?' The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines where employed in development of the review and applied whenever applicable [28]. Formulation and prospective registration of a research protocol was not performed.

Search strategy

A search was performed using PubMed, MEDLINE, and Web of Science databases to identify suitable studies for inclusion. The last search was performed on 14 January 2016. Two investigators (K.A and C.M) independently searched and screened the results using the agreed search strategy using MeSH terms and text words (Table 1). Blinding of journal names or paper-author/s was not performed. The Peer Review of Electronic Search (PRESS) process was employed with no major revisions advised [29].

Study selection

Only clinical studies were included, with all *in-vitro* studies excluded. Randomised, and non-randomised, controlled, prospective and retrospective studies were included. However, case reports were excluded. Selection was limited to studies involving humans and published in English language between January 2007 and December 2015. Study inclusion was achieved through discussion and agreement between investigators. Selected citations were then independently full-text screened. Citation mining was also performed via cross-referencing and hand searching all reference lists of included articles.

Data extraction and assessment

Once an agreement upon included studies was achieved, data were extracted and assessed from included studies according to the following criteria:

- Study design (prospective/ retrospective)
- Participants' details (number and age of participants)
- Follow-up period
- FRC FPD features (location, type of fiber-reinforcement, type of resin composite used, fabrication technique, retainer type, number of abutments, luting cement/ bonding agent and operator details)
- Assessment protocol (criteria, assessor details, definition of failure)
- Longevity/ survival rate
- Performance (technical and biological performance)
- Funding sources

As far as reported, the survival period for each FPD was extracted and the above characteristics of bridge design were extracted on an individual basis. Data were retrieved from tables, figures, and the main text of the articles. The authors of included studies were not contacted. If reported in the included studies, Kaplan–Meier statistics, number and types of technical complications and the number of failures were also extracted. The overall strength of the systematic review's clinical recommendation was also assessed using the Strength of Recommendation Taxonomy (SORT) grading system [30]

Statistical Analysis

To construct a pooled overall survival curve for the total number of FPDs from the selected studies, a database was made in which individual FPDs from each study were regarded as individual cases. If no individual information but Kaplan–Meier statistics were reported, number of the events were calculated by the Kaplan–Meier survival estimate. If neither individual information nor Kaplan-Meier statistics were reported, then final numbers of failure and survival reported after the follow-up period were extracted. Survival of FPDs was assessed using the Kaplan-Meier method. Sensitivity analysis was also performed. Furthermore, for comparison between FPD survivals in different tooth locations, log-rank testing was also performed. The probabilities of having different types of reported unfavourable events/ failures were estimated and compared by Chi-square test with significance level as 0.05. All analyses were performed using SPSS version 23 (SPSS, Chicago, IL, USA). A meta-analysis was planned, if feasible.

Results

A total of 9 studies, published between 2009 and 2015, were identified and included for assessment and analysis in this systematic review [18-26]. Six studies had a retrospective study design [18-20, 22-24] while three were prospective [21, 25, 26]. Included studies involved the placement of 592 FRC FPDs in 463 patients (age 12 - 80) with follow-up periods ranging between 2 months and 8 years (Table 2). The number of FPDs exceeded the number of patients in all studies, bar one [24], indicating that a number of patients received more than one FPD. However, patient-FPD allocation details were not clearly reported. Two studies reported a drop-out rate of 22% [18, 26], one study reported 13% [20], while remaining studies did not report any drop outs.

Three studies explicitly stated that patients were excluded if they presented with active [25] or extensive periodontal disease [20] or demonstrated a mobility score of 2 or 3 [26]. Patients with parafunctional habits were also excluded in 2 studies [19, 21].

Location

The majority of FRC FPDs replaced anterior teeth (64%, *n*= 378/ 592), with 4 studies investigating anterior FRC FPDs [18, 23-25], 2 studies investigating anterior and posterior FRC FPDs [22, 26] and 3 studies investigating posterior FRC FPDs [19-21]. Moreover, most FRC FPDs were located in the maxilla at 68% (*n*= 387/ 570) of all delivered FPDs, with one study not reporting the exact location of prostheses [19].

The reported survival rates of anterior FRC FPDs varied between 85.6% at 4.5 years [24], 97.7% at 4.8 years [25] and 64% [18] and 94% [23] at 5 years (Table 3). On the other hand, the survival rates of posterior FRC FPDs was 71.4% at 3 years [21], 78% at 5 years [20], dropping to 34% at 8 years [19].

Retainer type

Seven studies reported the use of 2 adjacent abutments for retention of the prosthesis. Wolff et al., however, reported the use of 2 abutments in 25/ 32 of the FPDs and a single abutment in 7 FPDs. Likewise, Frese et al. used two abutments in 20/24 FPDs and a single abutment in 4/24 FPDs.

Three main types of retainers were observed in the included studies: surface, inlay, or hybrid (surface + inlay) retainers. The majority of FRC FPDs were surface retained, constituting 63% (*n*= 373) of all delivered FRC FPDs. Inlay retained, minimal cavity preparation, onlays and full crowns retainers comprised 24% (*n*=142) of FRC FPDs, with hybrid retainers used in 13% (*n*= 77) of cases. Five studies used both surface retainers and inlay/ hybrid retainers [18, 20, 22, 24, 26], while 4 studies used either surface retainers [23, 25] or inlay retainers [19, 21]. (Table 3)

Reporting of design and dimensions of tooth preparations performed on FPD retainer abutment teeth varied between studies. For anterior abutments, Kumbuloglu et al. did not prepare the abutment surface [25]. van Heumen et al. prepared abutment teeth that had opposing occlusal contacts, to accommodate the retainer, and also used proximal grooves to aid retention [18]. Wolff et al. minimally prepared abutment surfaces by ≤1.5mm in depth, when necessary [22]. Similarly, Spinas et al. relied on a palatal preparation ≤ 1.2mm in depth with mesiodistal extensions of 3.5 – 4mm on incisors and canines. Frese et al. mentioned the use of inlay-design preparations, when necessary, without providing any further detail [24]. Posteriorly, van Heumen et al. and Izgi et al. detailed their inlay preparation designs, with varying box dimensions of ≥ 2mm in depth, length and width [20, 21]. Cenci et al simply stated that they followed a conventional inlay preparation design with diverging walls [19], while Malmstrom et al. performed preparations if restorations and or active caries were present in abutment teeth, without detailing the preparation design [26].

van Heumen et al. noted higher survival for surface retained anterior FPDs versus hybrid retained ones with 68% and 52%, survival rates respectively at 5 years [18]. Surface retainers aided by retentive tooth preparations also performed better than retainers without a preparation at 71% and 66%, respectively. However, differences were not statistically significant. In-contrast, van Heumen et al. demonstrated a higher 5-year survival probability for inlay retained posterior FPDs when compared to surface or hybrid retained designs, at 82% versus 78% and 66%, respectively [20]. However, differences were again not statistically significant. Moreover, Malmstrom et al. found no differences in survival between surface, inlay, or hybrid retained FPDs at 2 years [26].

Fabrication technique

Indirect fabrication of FRC FPDs was the preferred fabrication technique in the majority of studies (*n*= 5) [18-20, 23, 25]. Indirect fabrication involved impression making of abutment teeth (with/out tooth preparation), cast pouring, and laboratory fabrication of FPD using the resultant stone cast, prior to intraoral delivery. Conversely, 2 studies relied on direct/ chair-side fabrication with incremental building-up of FRC FPDs veneering composite [21, 26], while another 2 studies used both fabrication techniques separately, indirect and direct, in patients [22, 24]. (Table 3)

Framework material

Unidirectional pre-impregnated E-glass fiber bundles imbedded in a PMMA/ bis-GMA matrix (Stick™/ everStick C&B, StickTech, Turku, Finland) were the material of choice for FPD framework in the majority of studies (*n*= 5) [18, 20, 22, 24, 25]. Izgi et al. and Malmstrom et al. used everStick C&B and a bondable, non-impregnated reinforcement-woven polyethelene fiber ribbon (Ribbond; Seattle, WA, USA) [21, 26]. Cenci et al. solely used Ribbond™ [19], while Spinas et al. used unidirectional pre-impregnated E-glass fibers in a mesh/ weave formation (Vectris™; Ivoclar Vivadent, NY, USA) [23] (Table 3).

Malmstrom et al. reported no statistically significant differences in survival between glass and polyethelene fiber frameworks at 2 years [26]. Izgi et al. demonstrated a slightly improved survival probability of 71% for polyethelene fiber at 3.3 years versus glass fiber at 2.9 years [21]. The authors, however, acknowledged that in their trial framework comparison was difficult to achieve given the varying follow-up time periods and insufficient sample sizes.

Veneering resin composite material

Microhybrid composites were the most commonly used veneering composite material, with 6 studies choosing it for fabrication of the FPD pontic [18, 20, 21, 24-26]. Two studies reported using microfilled composite [19, 23] and Wolff et al. did not report the type of veneering composite used [22]. (Table 3)

Cenci et al. did not find any statistically significant differences in survival of FPDs between the different microfilled composites used in their up to 8 years follow-up study, with an overall survival of 34% [19].

Bonding protocol

Bonding protocols varied between studies, with five studies using dual-cured resin cements [18-20, 23, 25] while the remaining four studies reported using light-cured bonding agents [21, 22, 24, 26]. Seven studies used flowable composite as a liner in retainer area to improve adaptation and bonding of the fiber-reinforced framework to the FPD abutments [18, 20-22, 24-26]. In contrast, Cenci et al. reported the use of a

1mm increment of microhybrid resin composite placed on the pulpal-axial wall to aid retention of framework [19], while Spinas et al. did not report on the use of any added means of retention [23]. (Table 3)

Kumbuloglu et al. reported no statistically significant differences in survival when comparing FPDs cemented using different types of resin cements, or FPDs placed with or without dental dam isolation, at 7.5 years [25].

Operator details

Operators involved in delivery of FRC FPDs varied in their number and experience. Wolff et al. involved 8 specialist operators [22], two studies involved 6 experienced operators [18, 20], Malmstrom et al. involved 6 postgraduate residents [26], Cenci et al. and Frese et al. reported having one experienced operator each [19, 25], Spinas et al. reported one operator with no further details on experience or seniority [23], while 2 studies did not report operator details [21, 24].

Malmstrom et al. demonstrated that the level of operator experience did not affect the survival of FRC FPDs placed in their study, with no statistically significant differences in survival, at two years, between beginner operators and more experienced ones [26].

Assessment details

Six studies used a modification of the United States Public Health Service (USPHS) evaluation criteria to assess FRC FPDs [19, 21-24, 26] (Table 3). Two studies relied on clinical examination of periodontal status, and presence of caries, wear, discolouration, fractures and dislodgements [18, 20]. Kumbuloglu et al. assessed FRC FPDs for any technical (chipping, debonding or fracture of tooth/restoration) and biological failures (caries) [25]. The number of assessors and their calibration details varied between studies. Only 4 studies reported the use of 1 or 2 calibrated assessors [19, 22, 24, 26]. Spinas et al. reported one assessor with no calibration details [23], while 4 studies did not report any assessor details [18, 20, 21, 25].

Definition of major failure

Six studies considered the FRC FPD to have failed if problems, such as fracture of framework, or fracture or delamination of veneering composite, or a combination of problems occurred that could not be repaired with the FPD in-situ [18, 20, 22-24, 26].

Izgi et al. also considered partial or total debonding of FPD, in-addition to fracture and delamination as failures [21]. However, 2 studies did not clearly define FRC FPD failure [19, 25]

Longevity/ survival rate

Reporting of FRC FPD longevity varied between the included studies. Six studies used the Kaplan-Meier (KM) method to calculate the overall survival probability of the prostheses [18-20, 22, 24, 25]. Izgi et al. reported the estimated KM probability for E-glass based FPDs and polyethelene based FPDs separately [21]. Malmstrom et al. only reported the overall survival of placed FPDs at 2 years with no probability calculation [26]. The study did however calculate the KM curves based on location (anterior/ posterior and maxilla/ mandible), retainer type (surface/ inlay/ hybrid), fiber material (E-glass/ polyethelene), and operator experience (beginner/ proficient) [26]. On the other hand, Spinas et al. simply reported the overall survival of FPDs, with no calculation of KM estimates [23].

Observation periods varied between 2 months and 8 years, and reported survival rates varied between 34.2% and 97.7%. An overall survival curve for the included studies was constructed (Figure 2). Calculated Kaplan-Meier overall survival probability based on the data from all sets of patients (n=592) at 4.8 years was 94.5% (95% confidence interval (CI), 92.5%- 96.5%) (Table 4). Also, at 2 years, the calculated survival rate was 96.2% (95% CI, 94.6%-97.7%). Sensitivity analysis was performed and found that the calculated Kaplan-Meier overall survival probabilities based on the data excluded either one of the included studies were similar to the above results. Calculated survival probabilities at 2 and 4 years ranged from 94.5% to 97.5% and ranged from 93.2% to 95.8%, respectively, if excluding either one of the included studies.

Total sample size of 423 (anterior: n =291, posterior: n = 132) were analysed for comparison of survivals between anterior and posterior locations (Table 5) since 2 studies (Wolff, 2011; Malmstrom, 2015) were excluded as they had both anterior and posterior cases but did not report separated survival information. Log-rank analysis of survival probability of anterior versus posterior FRC FPDs demonstrated that the survivals were not significantly different between these 2 tooth locations (P = 0.278) (Figure 4). At 5 years, the survival rate of anterior FDPs was 72.1% (95% CI, 63.2%-80.9%) while the survival rate of posterior was 79.7% (95% CI, 72.6%-86.8%).

Of the 592 FPDs, 56 (9.5%) cases reported fracture/delamination of veneering, 33 (5.6%) cases reported debonding, 22 (3.7%) cases reported framework fracture and 26 (4.4%) cases reported other problems (Table 6). Chi-squares of the proportions with Bonferroni adjusted p-value indicated that the probabilities of these four types of failures were significantly different ($P < 0.001$). The probability of having fracture/delamination of veneering material was significantly higher than those of having framework fracture and other problems respectively ($Ps < 0.05$). The obvious heterogeneity in the follow-up time periods among the included studies precluded performing a meta-analysis.

Funding sources

Details of funding and conflict of interest were not stated in 5 studies [19, 21-24]. The County Council of Västerbotten, the Swedish National Board of Health and Welfare, and the Finnish Dental Association Alloponia supported two studies [18, 20]. Two studies reported the absence of existing conflict of interest, with no funding received or commercial interest present [25, 26].

Strength of clinical recommendation

The SORT grading system was used to assess the quality of the included studies. SORT assesses the clinical evidence based on the quantity, quality, and consistency of included studies, and grades the overall strength of clinical recommendation derived from the systematic review accordingly as either strong (A), moderate (B), or weak (C).

The findings of the studies included in the systematic review were consistent. However, the lack of a diverse, population-representative patient cohort, and the heterogeneity of study-designs, patient-FRC FDP allocation, follow-up periods, operator-details, assessment protocols, and reporting of outcomes limits the quality of the evidence from these trials. As such, all included studies were graded as level-2 with limited quality evidence. Consequently, the systematic review's overall strength of clinical recommendation was considered moderate or 'B'.

Discussion

The first systematic review of the evidence supporting the use of FRC FPDs, published in 2005, included 26 case reports and case series, and 6 cohort studies with up to 4 years follow-up periods [15]. The review concluded that the clinical documentation of FRC FPDs was generally poor due to the absence of randomised control trials, comparing FRC FPDs to conventional alternatives. Furthermore, it highlighted a lack of long-term cohort studies to provide good evidence for their use in replacement of missing teeth [15]. The more recent 2009 systematic review included 15 peer reviewed papers, reporting 13 cohort studies, all of which were published in the preceding 15 years [16]. The review estimated the overall survival of FRC FPDs to be 73% at 4.5 years. The included studies involved the placement of 435 FRC FPDs in three hundred and forty patients. The largest included study reported a patient sample size of 39 participants receiving 83 FRC FPDs [31]. Similarly to the previous systematic reviews, the current systematic review did not identify any randomised controlled trials involving the placement of FRC FPDs in comparison to conventional FPDs or RBBs. In contrast, the current systematic review included 9 cohort studies, all of which were published within the preceding 7 years, and reporting the placement of 592 FRC FPDs in 463 patients. Included studies had larger sample sizes with longer follow-up periods. The largest included study within the current review involved the placement of FRC FPDs in 134 patients [25]. Moreover, there was a clear and significant improvement in the overall survival of FPDs with 94.4% estimated survival at 4.8 years, when compared to the 2009 systematic review. Moreover, the location of the FRC FPDs did not impact the survival of FRC FPDs, whether replacing anterior or posterior teeth.

Further comparison between our review and previous systematic reviews identified differences between studies included in both reviews in relation to the most common location of FPDs and preferred types of retainers, framework and veneering resin composite materials. The studies included in the van Heumen et al. systematic review mainly relied on inlay-retention, which accounted for 52% (*n*= 227/ 435) of all delivered FPDs. Conversely, surface retainers were only used in 20% (*n*= 87/ 435) of all FPDs [16]. Moreover, 73% (*n*= 227/ 312 bridges with reported location) of FPDs replaced missing posterior teeth. The most commonly used materials were unidirectional R-glass fibers for the FPD framework (Vectris Pontic™; Ivoclar Vivadent, NY, USA) and an indirect hybrid resin composite (Targis Dentin™; Ivoclar Vivadent, NY, USA) [16]. In contrast, studies included in the current review demonstrated preference to using surface retainers in comparison to inlay retainers for retention of FPDs at 63% and

26%, respectively. Additionally, 64% of delivered FPDs replaced missing anterior teeth. E-glass fiber-reinforced framework and microhybrid veneering resin composite were the materials of choice for fabrication of FPDs in the majority of included studies.

The cavity preparation for FRC FPD retainers seems to have a limited effect upon the performance of FRC FPDs. Anteriorly, when comparing FRC FPDs with no abutment preparation to those with shallow and deep cavity preparations, Aktas et al. did not identify any significant differences in fracture strength between different designs [32]. The study did however observe significantly lower fracture strength for cantilever-design FRC FPDs. Posteriorly, when comparing inlay-retained FPDs with large box designs versus small ones, and boxes prepared using conventional inlay burs versus ones prepared using ultrasonic tips (small and large), Ozcan et al. demonstrated that there were no significant differences in fracture strength between the different box sizes or preparation techniques [33]. These *in-vitro* findings support the clinical outcomes reported in the studies included in this review, indicating no significant differences in survival based upon retainer design [18, 20, 26].

In contrast, the compatibility of materials used for fabrication of FRC FPDs is cardinal for the survival of such prostheses. As previously mentioned, studies included in the van Heumen et al. review mainly relied upon the Vectris Pontic/ Targis Dentin system [16]. Vectris requires the application of a silane coupling agent to create a bond with the di-methacrylate-based Targis composite. However, such a bond is relatively prone to failure [34]. The upgraded UDMA matrix based microfilled Adoro veneering composite seems to be more compatible with silanated Vectris framework, reporting less veneer fractures [35], and improved aesthetics [36]. Furthermore, Tanoue et al. reported that when reinforced with unidirectional pre-impregnated glass fiber, microhybrid resin composite demonstrates higher flexural and shear bond strengths (355.8 MPa and 28.1 Mpa respectively) when compared to microfilled resin composite (271.2 MPa and 18.7 MPa) [37]. Accordingly, it has been postulated that the 0.012-7 µm filler of microhybrid resin composite was more compatible for bonding with the 10µm diameter glass fibers [37]. Thereby, advances in material composition and compatibility may explain the noted significant improvement in FRC FPD performance within the studies included in the present systematic review.

Regarding the performance of FRC FPDs, when all reported unfavourable events (major/ unrepairable failures, and minor/ repairable failures) were considered, fracture and/or delamination of veneering composite constituted the majority of FRC FPD failures, at 41% (*n*= 56/ 137 events), followed by FPD debonding (one retainer or both), at 24% (*n*= 33/ 137 events).

USHPS evaluation of FRC FPDs, in-regards to prosthesis adaptation, colour match, marginal discolouration and surface roughness, indicated clinically satisfactory performance in all FPDs placed in four studies [19, 22, 23, 26]. However, Izgi et al. reported 8 FPDs with clinically unacceptable pontics [21], while Frese et al. identified unacceptable surface staining in one FPD [24].

Five studies confirmed a clinically acceptable biological response following placement of FRC FPDs when periodontal health, caries, and post-operative hypersensitivity were assessed at recall. Wolff et al. and Frese et al. reported all FPDs as presenting clinically acceptable periodontal outcome and the majority of prostheses being either clinically excellent or good [22, 24]. Izgi et al. also reported similar results with only a few cases presenting with bleeding on probing and slight inflammation and probing depths not exceeding 2 mm [21]. Postoperative hypersensitivity or caries relating to the FRC FPD abutments rarely occurred, with 4 studies reporting single cases of recurrent caries and no reports of hypersensitivity [20-22, 26].

Two studies investigated patients' response to FRC FPDs. Malmstrom et al. demonstrated a high patient satisfaction when assessed by visual analogue scale (VAS) [38], with a mean score >80mm, in-regards to prosthesis appearance, colour, chewing ability and overall satisfaction at 2-year recall [26]. Similarly, Wolff et al., in their up to 5-year follow-up study, reported clinically excellent and good patient-perception in 86% and 10% of FPDs, respectively [22].

FRC FPDs can be considered a prosthetic alternative, to conventional CM RBBs, that is metal-free and consequently more aesthetic, and cost-efficient and comparable performance. The survival of CM RBBs has been reported to be 88% at 5 years from a systematic review of 17 studies [39]. The most frequently reported technical complication experienced by RBBs is that of debonding. In contrast, FRC FPDs included in the present review experienced fracture/delamination of veneering material as the main mode of failure. The quality of evidence supporting FRC FPDs, however, is still limited in-comparison to CM RBBs. Interestingly, a recent literature review attempted to estimate the success of CM RBBs, FRC FPDs, and all-ceramic RBBs (AC RBB) at 3 years [40]. The study concluded that FRC FPDs enjoyed the highest success rate at 88.5%, versus 82.8% and 77.5% for CM RBBs and AC RBBs, respectively.

Moreover, FRC FPDs can also offer a medium-term, minimally invasive and aesthetic treatment alternative to metal-ceramic and all-ceramic conventional FPDs. Pjetursson et al. in their systematic review, investigating the survival rate of metal-ceramic and all-ceramic tooth supported FDPs, reported a 5-year survival rate for metal-ceramic FDPs of 94.4% compared to 86.2% – 90.4% for all-ceramic FDPs [41].

Regarding the failure mode of FRC FPDs, fracture and/or debonding of the veneering resin composite remains the most common mode of failure. A number of *in-vitro* studies have proposed modifications to the FRC FPD design in order to overcome these disadvantages. The addition of one short unidirectional FRC bar, in the pontic area, at 90° to the main FRC FPD framework, offers additional support to the pontic's cusps [42] . Moreover, increasing the occlusal thickness of the pontic to 2.5 – 4 mm or using an acrylic denture tooth or a glass ceramic pontic can also improve the load-bearing capacity of FRC FPDs [43, 44].

The findings of this systematic review indicate that robust long-term clinical performance in the form of well designed prospective, randomised control studies, conducted on a large cohort of patients, with a clear and detailed assessment and reporting of outcomes, remains lacking for FRC FPDs. However, findings of this review, and the moderate strength of clinical recommendation also demonstrate that FRC FPDs do offer a medium-term management alternative, for replacing missing single anterior and posterior teeth. Such restorations appear to offer a reliable, minimally invasive, aesthetic, cost-efficient way to restore missing single teeth with predictable clinical performance, and patient oriented outcomes. As such, FRC FPDs should no longer be considered as experimental, temporary, or short-term treatment modalities. Moreover, the versatility of their fabrication techniques, whether direct or indirect, varying retention options through surface, inlay or hybrid retainers, and their capacity to be easily repaired *in-situ*, are all considered major advantages supporting the use of FRC FPDs.

Conclusion

Current clinical studies of FRC FPDs demonstrate high overall survival with predictable performance outcomes when used as a medium-term management alternative for replacing single anterior or posterior teeth in patients. Further research is required to identify the viability of FRC FPDs as a long-term treatment option.

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Conflict of interest

There was no conflict of interest present during the undertaking of this study. The study did not receive any internal or external funding.

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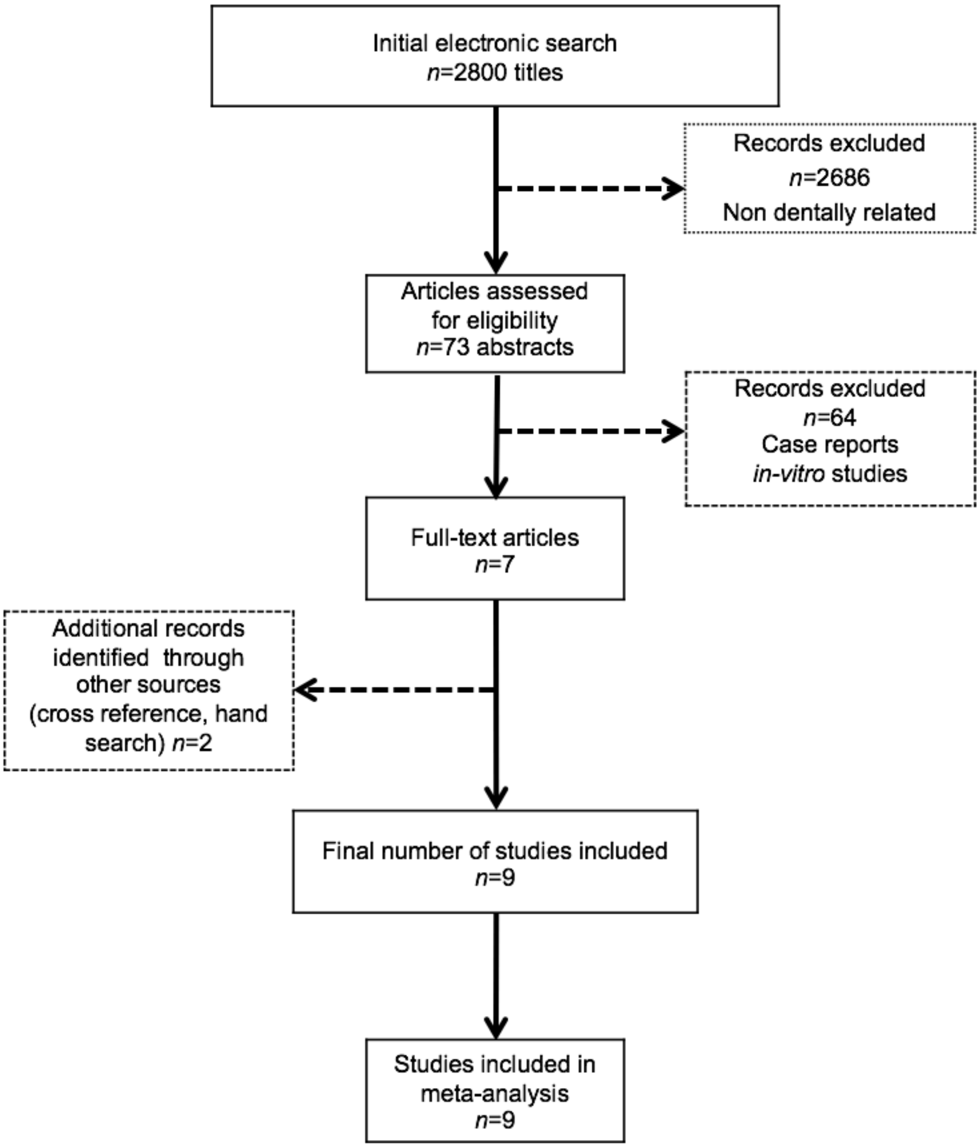


Figure 1: Flow-chart of the selection of studies for the systematic review of the longevity of 3-unit FRC FPD in patients

Table 1 Search strategy used for PubMed

1	Search ((((composite) AND fibre-reinforced) OR fibre reinforced) OR fiber-reinforced) OR fiber reinforced
2	Search (((fixed partial dentures) OR fixed partial prosthesis) OR fixed partial prostheses) OR FPD) OR bridges
3	Search ((#1 and #2)) Filters: Publication date from 2007/01/01 to 2015/12/31, Humans, English

Table 2: Details of studies included in the systematic review. Fixed Partial Dentures (FPDs). *Seven patients were not clinically examined at recall.*

Study	Type	Patients	Follow-up	Drop-out (%)
van Heumen, 2009	Retrospective	52 pts (13-64y/o)	5 - 9yrs	23% (n=14 FPDs)
Cenci, 2010	Retrospective	13 pts (39 - 62 y/o)	Upto 8 years	0
van Heumen, 2010	Retrospective	77 pts (12 - 78 y/o)	4.5 - 8.9yrs	13% (n=12 FPDs)
Wolff, 2011	Retrospective	29 pts (mean age 39.45y/o)	2 months - 5.3 years	0
Izgi, 2011	Prospective Cohort	10 pts (age= unclear)	16 months - 3.3 years	0
Spinas, 2013	Retrospective	30 pts (13 - 17y/o)	5yrs	0
Frese, 2014	Retrospective	24 pts (15 - 60y/o)	3.5 - 6.3yrs	0*
Kumbuloglu, 2015	Prospective Cohort	134 pts (16-68y/o)	Upto 7.5yrs	0
Malmstrom, 2015	Prospective Randomised	94 pts 18-80 y/o)	2 yrs	22% (n=30/ 167 FPDs)

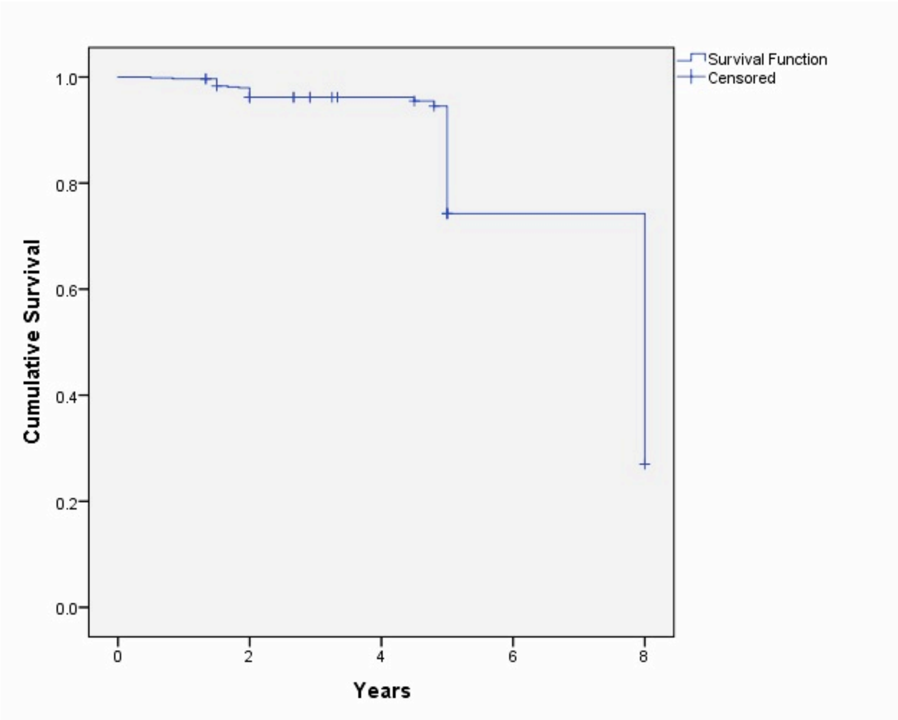
Table 3: Data extracted from studies included in systematic review. Maxilla (Max); mandible (Man); fixed partial denture (FPD); surface retained (SR); inlay retained (IR); hybrid retained (HR); reported Kaplan Meier survival estimate (KM).

Study	Location	FPDs/ Retention	Abutments	Technique	Framework	Composite resin	Bonding protocol	Operator details	Assessment criteria	Survival rates
van Heumen, 2009	Anterior (Max=57, Man=3)	n=60. SR (n=48/60), and HR (n=12/60)	Two	Indirect	Stick	Flowable resin (unclear). Veneering: Sinfony Artglass	Compolute, Twin-look, and Panavia	6 experienced operators	Clinical examination of periodontal status, caries, wear, discolouration, fractures and dislodgements	KM= 64% at 5yrs
Cenci, 2010	Posterior (Max/Man =unclear)	n=22 IR	Two	Indirect	Ribbond	Tertic Ceram Veneering: Durafill; Renamel	Rely X ARC	1 experienced operator	Modified USPHS	KM= 34.2% at 8yrs
van Heumen, 2010	Posterior (Max=4, Man=46)	n= 96. SR (n=31/96), HR (20/96), and IR (45/96)	Two	Indirect	Stick	Flowable resin (unclear). Veneering: Sinfony; Artglass	Compolute, Variolink, Twin-look, and Panavia	6 experienced operators	Clinical examination of periodontal status, caries, wear, discolouration, fractures and dislodgements	KM=78 % at 5yrs
Wolff, 2011	Anterior (Max=12, Man=12),	n=32. SR n=11. IR, n=21.	Two (n=25);	Indirect and Direct	everStick C&B	Unclear	Optibond FL	8 specialist operators	Modified USPHS/ Ryge	KM= 74.4%

	and Posterior (Max= 3/ Man=5)		One (n=7)								at 1.5yrs
Izgi, 2011	Posterior (Max=10, Man=4)	n=14 IR	Two	Direct	everStick C&B, (n=7/14) and Ribbond, (n=7/14)	Flowable resin: Ionosit-Baseliner. Vennering: Ecusit-Composite	Clearfil SE Bond	Unclear	Modified USPHS	KM= 71.4% at 2.9yrs for everStick 3.3yrs for Ribbond
Spinas, 2013	Anterior (Max=32)	n=32 SR	Two	Indirect	Vectris	Veneering: SR Adoro	One Coat Bond and Permamix Smartix Dual	1 operator	Modified USPHS	94% (n=30/32) after 5yrs
Frese, 2014	Anterior (Max=11, Man=13)	n=24. SR, n=13/24. IR, n=11/24	Two (n=20); One (n=4)	Indirect and Direct	everStick C&B	Flowable resin: Tetric Flow. Veneering: Herculite XRV; Enamel HFO plus; Tetric Evo Ceram	Optibond FL	Unclear	Modified USPHS and periodontal evaluation. 7pts not available for clinical examination	KM= 85.6% after 4.5yrs
Kumbulogl u, 2015	Anterior (Max=112 , Man=63)	n=175 SR	Two	Indirect	everStick C&B	Flowable resin: Grandio Flow.	RelyX ARC, Bifix DC, Variolink II, Multilink	1 operator	Technical and biological assessment	KM= 97.7% at 4.8yrs

						Veneering: Dialog				
Malmstrom, 2015	Anterior (Max=51, Man=12). Posterior (Max= 48, Man=26)	n=137(*at follow-up*). SR, n=63. IR, n=29. HR, n=45	Two	Direct	everStick C&B, (n=66) and Ribbond, (n=71)	Flowable resin: Tetric Flow. Veneering: Tetric Ceram or Esthet.X	Optibond solo total-etch	6 postgraduate residents	Modified USPHS	93% (n=127/137) at 2 yrs

Artglass; Twinlook (Heraeus Kulzer, Dormagen, Germany)
Sinfony; Compolute; Scotch Bond; Rely X ARC (3M ESPE, MN, USA)
Panavia; Clearfil SE Bond (Kurary, Okayama, Japan)
OptiBond FL; OptiBond Solo; Herculite XRV (KerrHawe, CA, USA)
Ecusite-Composite; Ionosite-Baseliner; Smartix Dual (DMG, Hamburg, Germany)
Enamel HFO plus; Tetric Evo Ceram; Tetric Flow; Variolink II; Multilink (Ivoclar Vivadent, Schaan, Liechtenstein)
One Coat Bond (Coltene-Whaledent, Altstätten, Switzerland)
Esthet X (Dentsply-Caulk, DE, USA)
Dialog (Schütz Dental, Rosbach, Germany)
Grandio Flow, Bifix DC (VOCO, Cuxhaven, Germany)



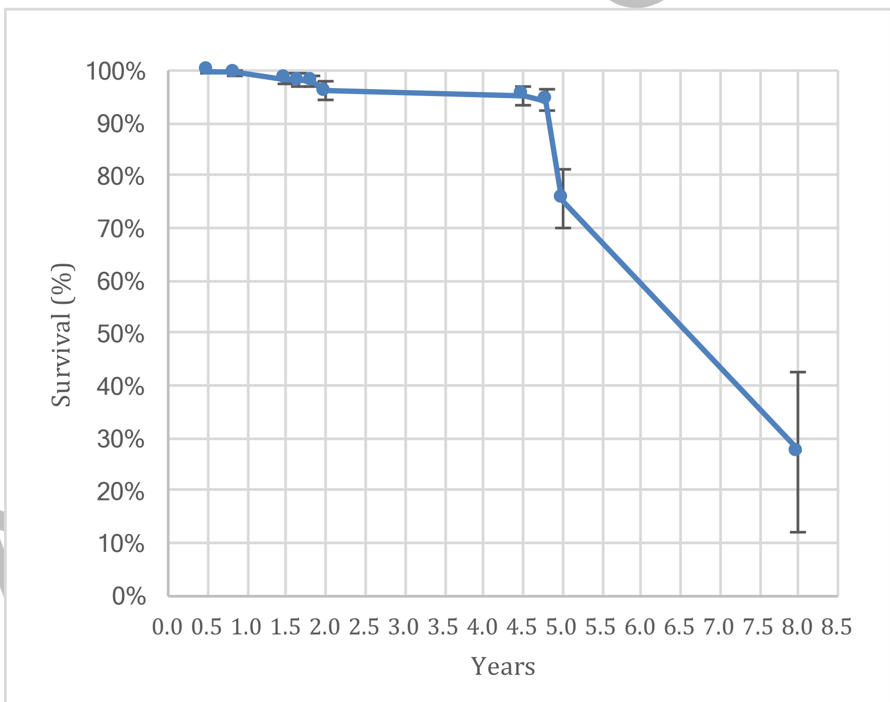


Figure 2a: Cumulative survival rate of fiber reinforced composite fixed partial dentures (FRC FPDs) included in the review (*n* =592). Figure 2b. Overall survival of fiber reinforced composite fixed partial dentures (FRC FPDs) included in the review (*n* = 592) with vertical bars indicating 95% confidence intervals.

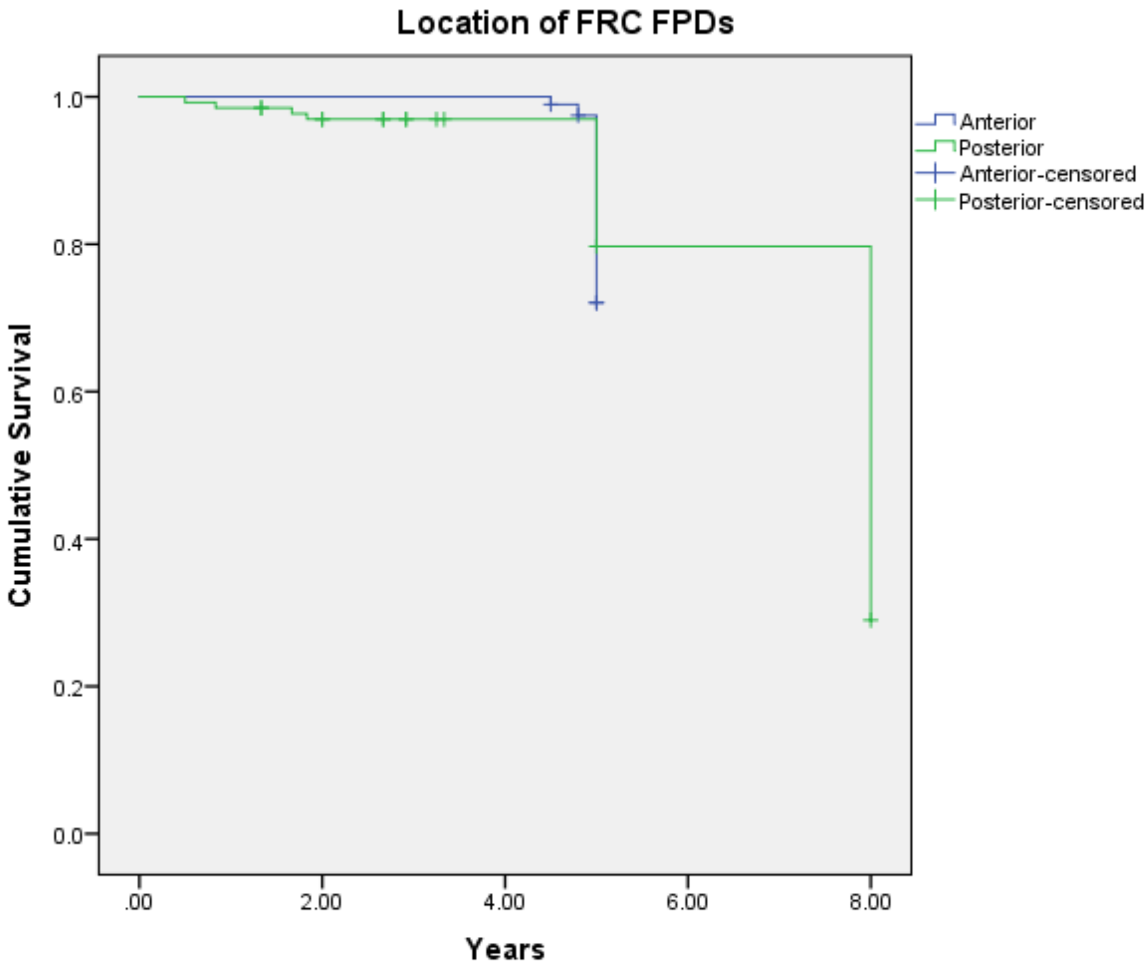


Figure 3: Cumulative survival rate of fiber reinforced composite fixed partial dentures (FRC FPDs) dependent on location included in the review (*n* = 423, two studies excluded). No statistically significance difference was found between the FRC FPDs in terms of location (*P* = 0.278).

Table 4. Survival table for fiber reinforced composite fixed partial dentures (FRC FPDs) included in the review (*n* =592).

Time (Year)	Survival probability at the time point	95% confidence interval
0.5	99.8%	99.5% - 100.0%
0.8	99.7%	99.2% - 100.0%
1.5	98.3%	97.3% - 99.3%
1.7	98.1%	97.0% - 99.2%
1.8	97.9%	96.8% - 99.1%
2.0	96.1%	94.6% - 97.7%
4.5	95.4%	93.7% - 97.2%
4.8	94.4%	92.5% - 96.5%
5.0	75.5%	68.8% - 79.7%
8.0	27.5%	11.9% - 42.1%

Table 5. Survival table for fiber reinforced composite fixed partial dentures (FRC FPDs) in anterior (*n* =291) and posterior (*n* = 132) locations.

Tooth location	Time (Year)	Survival probability at the time point	95% confidence interval
Anterior	4.5	99.0%	97.8% - 100.0%
	4.8	97.5%	95.6% - 99.3%
	5.0	72.1%	63.2% - 80.9%
Posterior	0.5	99.2%	97.8% - 100.0%
	0.8	98.5%	96.4% - 100.0%
	1.7	97.7%	95.2% - 100.0%
	1.8	96.9%	94.0% - 99.9%
	5.0	79.7%	72.6% - 86.8%
	8.0	29.0%	12.8% - 45.2%