DENTAL MATERIALS XXX (XXXX) XXX–XXX

Available online at www.sciencedirect.com

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Longevity of immediate rehabilitation with direct metal-wire reinforced composite fixed partial dentures

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A R T I C L E I N F O

Article history:
Received 29 March 2022
Received in revised form 4 May 2022
Accepted 5 June 2022

Keywords:
Metal reinforced composites
Fixed partial dentures
Longevity
Long-term temporary solution
Resin-bonded bridge
Clinical performance
Survival

A B S T R A C T

Objectives: This study aimed to analyze the longevity of direct metal-wire reinforced composite fixed partial dentures (MRC-FPD) and factors influencing their survival and success.
Methods: Within one private practice 513 MRC-FPD were directly applied. The preparation of a proximal cavity in abutment teeth was not limited. MRC-FPD were reinforced by one to three metal-wires. At the last follow-up MRC-FPD were considered successful, if they were still in function without any need of therapy. MRC-FPD were considered as survived, if they were repaired or replaced. Multi-level Cox proportional hazard models were used to evaluate the association between clinical factors and time.
Results: Mean follow-up period (range) was 59(2–249) months. Seventy-three bridges did not survive (cumulative survival rate(CSR):86%) and further 129 bridges had received a restorative follow-up treatment (CSR:61%). AFR was 2.2% for survival and 8.6% for success. In multivariate analysis MRC-FPD with >1 wire showed a up to 2.3x higher failure rate than MRC-FPD with one wire($p \leq 0.023$). Dentist's experience in designing MRC-FDP ($p \leq 0.017$), patient's caries risk ($p \leq 0.040$) and bruxism ($p = 0.033$) significantly influenced the failure rate: the more experience, the lower caries risk and bruxism, the lower the failure rate.
Significance: For directly prepared metal-wire reinforced composite bridges high survival and moderate success rates were observed. MRC-FPD might, thus, be an immediate, short- and medium-term solution for replacing missing teeth. However, several factors on the levels of practice (dentist's experience in designing MRC-FDP), patient (bruxism, caries risk) and restoration (number of wires) were identified as significant predictors for the failure rate.
The study was registered in the German Clinical Trials Register (DRKS-ID: DRKS00021576).

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https://doi.org/10.1016/j.dental.2022.06.008

1. Introduction

In recent years reinforced composite fixed partial dentures have gained increasing interest as method for minimal-invasive, immediate and cost- effective rehabilitation of missing teeth [1,2]. Several studies reported (good) annual failure rates (AFR) between 17% after 1.5 years [3], 8% after 2 years [4], 5% after 3.5 years [5], 0.8% after 6 years [6] and even 1.6% after up to 9 years [7]. However, the direct fabrication of reinforced composite fixed partial dentures is supposed to be technique sensitive [8]. Operator skills, 'dentist profiles' [9] and practice organization may influence the longevity of the restorations. Furthermore, teeth have to accommodate not only vertical loads but also shearing forces [10]. In the last decades most studies, which analyzed reinforced composite fixed partial dentures concentrated on restorations with silanized fibre bundles. On the one hand glass fibre bundles allow excellent adhesion to the polymer matrix of the composite due to their silanization and resin-impregnation. They comply with esthetic requirements, transparency and camouflage [10]. On the other hand the resistance of fibre bundles are limited to tensile forces [10]. The absorption of shearing forces needs additional fibre bundles. Their geometrical placement is based on the expected forces and depends on the available space [7]. Furthermore the handling of the rigid fiber bundles in the oral cavity may be challenging [7].

Another strategy to reinforce composite bridges is the use of direct metal-wires, which have firstly been described more than 20 years ago [11] and are still used today [12,13]. To the best of our knowledge, publications about metal-reinforced bridges are limited to some case reports [12,13]. In contrast to glass fibre bundles, metal-wires absorb both tensile and torsional forces. This property allows the absorption of the occurring forces with one metal-wire only. In addition metal wires can be bent to an according shape before placing. Both features facilitate the intraoral designing of reinforced composite fixed partial dentures.

Since clinical studies on direct metal-wire reinforced composite fixed partial dentures (MRC-FDP) are lacking, the aim of this retrospective, single-center, practice-based, non-interventional, clinical study was, firstly, to explore the longevity of direct metal-wire reinforced composite fixed partial dentures for immediate rehabilitation and, secondly, to analyze the effect of various factors on restorative failures after up to 20 years of follow-up.

2. Materials & method

2.1. Study design

This study was a retrospective, single-center, practice-based, non-interventional, clinical study. Reporting follows STROBE guidelines for cohort studies [14]. The study has been registered in the German Clinical Trials Register (DRKS-ID: DRKS00021576). Assessment of the status of the restorations was done when patients attended for routine care or recall and as described in a former study for direct fiber reinforced fixed partial dentures (FRC-FPD) [7]. According to guidelines for good clinical practice (Clinical trials – Directive 2001/20/EC) [15] and the European guidelines for good clinical practice (CPMP/ICH/135/95) [16] this study was, therefore, not subject to Medical Ethical Committee approval.

2.2. Patient selection

The records from all patients of a private practice (W.W.) were searched for the presence of direct metal reinforced fixed partial dentures (MRC-FPD). Five-hundred thirteen MRC-FPD in 390 patients were found with an insertion date between April 1998 and December 2021.

Inclusion criteria were as followed:

- adhesively bonded direct metal reinforced fixed partial dentures (MRC-FPD) including
  - o anterior or posterior teeth
  - o lower or upper jaws
  - o bilateral abutments or cantilever
- MRC-FPD had to be inserted by W.W.

Exclusion criteria were as followed:

- indirect MRC-FPD
- no follow-up

2.3. Fabrication of the bridge

For all abutment teeth box-shaped occluso-proximal cavities were prepared to embed the wire (supplementary Fig. 1, supplementary Fig. 2). If possible the cavities of existing (composite) restorations were used for to preserve natural tissues. The cavities had an established dimension of 3 mm in length and depth while the width was defined by the metal wires with a diameter of 1.2 mm. All bridges were reinforced with at least one up to three metal wires. The constructions were slightly different for cantilever and conventional bridges and are illustrated in Fig. 1. For conventional bridges the metal wire was bent like a hanging rope between the abutment teeth. For cantilevers the wire was placed in a vertical or horizontal loop coming back to the abutment tooth. The wires were adjusted opposite to the antagonistic teeth. The free distance between the metal wire and the antagonistic teeth was at least 1 mm.

The cavities in the abutment teeth were prepared with diamond burs (e.g. Heico Diamant FG 831.314.012, Heico Switzerland AG, Steinach, Switzerland). Their dimension correlated to the scale of the wire and were approximatively 3 mm long to embed the wire mechanically. After bending and preparing some notches for retention, the metal wire was fixed and embedded in the abutment cavities with resin composite The insertion of additional wires was restricted to cases with a fracture due to insufficient vertical dimension. The wires were then placed side by side (not on top of each other)."

To achieve a tight fit of the composite material of the pontic to the gums, the used composit was allowed to flow to the gum and slightly cover it. The interproximal neck of the tooth was freed from composite using a straight explorer (e.g. Explorer S24, Deppeler SA, Rolle, Switzerland) and excessive composite along the oral and buccal side of the pontic was removed with a spatula (e.g. Spatula OP55, Deppeler). After

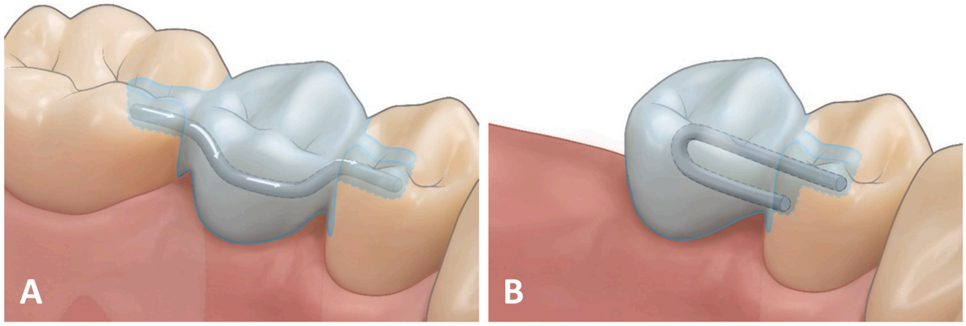

Fig. 1 – Occluso-oral view of a micro-invasive conventional (a) and cantilever (b) DFRC-FPD. The metal-wires are highlighted within the bridges.

curing the interproximal area was controlled with a polishing diamond bur (e.g. Komet Diamant FG 863.314.012, Komet, Lemgo, Germany) and the contact area of the pontic with the gum was rounded and controlled with a Proxoshape Diamond File of two grains (e.g. Intensiv Proxoshape Diamond File PS 2 red and yellow, Intensiv SA, Montagnola, Switzerland). At the end of the whole bridge was polished with a Greenie (e.g. Shofu Greenie FG Mini-Points 0414, Shofu Dental GmbH, Ratingen, Germany). In a second step the outer shape of the pontic as well as the occlusal surface of the FDP was formed. The free shrinking surfaces (vestibular, oral, occlusal, gingival) allowed an efficient completion of the pontic by one or two layers only. The occlusal surface was formed with a pragmatic stamp technique (DSO-technique) [17]. With this technique rubber dam is contra-indicated to allow a closed occlusion. After isolation of the antagonists with a lubricant (e.g. glycerin gel), appropriate moisture control was achieved using cotton rolls, suction device, and proper matrix wedge placement while a dental nurse facilitated the procedure at chair side. The occlusal part of the PFD was formed in one layer by closing the teeth in the uncured composite. After reopening the negative form of the antagonists was roughly formed and could be carefully reshaped. The curing was performed in reclosed occlusion. By this procedure a precise occlusion could be achieved. The articulation was carefully adapted after curing to avoid unfavorable sharing forces.

The final shaping was proceeded carefully to respect esthetic requests [18] as well as the prevention of occlusal overload (e.g. no occlusal pre-contacts). For this, different instruments were used: e.g. EVA Instruments were used to form and shape the convex bottom of the pontic. At the end of the preparation of the MRC-FDP – which lasted approximately one to two hours – the patient was advised in interproximal cleaning procedures. Occlusal contacts were controlled again in a follow-up appointment.

The described procedures were provided with a three-step etch and rinse adhesive system (Ultra-Etch, Ultradent Products, South Jordan, USA; Syntac classic, Ivoclar Vivadent, Schaan, Liechtenstein), a conventional composite material (Tetric EvoFlow or Tetric EvoCeram, Ivoclar Vivadent, Schaan, Liechtenstein) and an orthodontic metal wires with a diameter of 1.2 mm (remaloy® straight wires, round, hard, ø 1,20 mm, Dentaurum, Switzerland). The choice of these products followed the pragmatic approach that they all were used in the respective practice and are common products in Switzerland.

2.4. *Data extraction*

When patient attended for preparation of the MRC-FPD or for routine care and recall the following data were routinely collected:

- age, sex, risk of caries (high, moderate, low [classification was based on costs per year for direct restoration]), bruxism (yes, no [classification was based on costs for treatment of bruxism]) and number of teeth/restorations (per patient)
- dates of insertion, first repair or renewal, second repair or renewal and last follow-up of the MRC-FPD
- characteristics of the replaced tooth (Fédération Dentaire Internationale [FDI] notation system), extension of the bridge (uni- or bilateral), number of pontics (one or two), type of preparation (with one or two box–shaped proximal cavity), type of antagonist (periodontal supported, non-periodontal supported, no antagonist) and composite materials being used
- photographic images of the restored area and radiographs at start of and during observation period - if indicated

2.5. *Criteria for survival and success*

Clinical assessment of the status of the MRC-FPD was performed by the dentist who placed the restoration (W.W.) and took place during regular appointments. The observation period started with the insertion of the MRC-FPD.

2.5.1. *Survival*

The MRC-FPD was considered as a ‘survival’ if the type of restoration was still the same. Consequently, repair or replacement of the MRC-FPD was considered as survival. Whenever a different restoration type was inserted, an abutment tooth extracted or one of these treatments scheduled at the last check-up the MRC-FPD was defined as failure (primary endpoint).

Table 1 – Frequency, number of failures of teeth included in study and bivariate Cox proportional hazard regression analyses of time until failure by categories of each baseline characteristic for outcome success.

category	Teeth Frequency [n (%)]	Failures [n (%)]	p-value	HR	95% CI	Estimated Median success time	95% CI
overall	513 (100%)	202 (39%)				97.6	85.4–109.8
dentists' experience in designing DMRC-FPD [years]							
> 17	77 (15%)	40 (52%)		1.0	reference	117.9	94.4–141.4
> 10–17	223 (43%)	104 (47%)	**0.157**	1.3	0.9–1.9	86.2	75.7–96.6
< 10	213 (42%)	58 (27%)	**0.001**	2.1	1.4–3.3	44.5	38.2–50.8
patients' age [years]							
20–40	45 (9%)	9 (20%)		1.0	reference	164.9	121.5–208.4
40–60	190 (37%)	71 (37%)	**0.019**	2.3	1.1–4.6	95.3	80.8–109.9
> 60	278 (54%)	122 (44%)	**0.001**	3.3	1.7–6.6	78.3	64.3–92.4
number of restored teeth							
1	375 (73%)	149 (40%)		1.0	reference	94.8	82.6–107
2	106 (21%)	37 (35%)	0.618	0.9	0.6–1.3	108.8	79.4–138.2
3	23 (4%)	14 (61%)	**0.109**	1.6	0.9–2.7	56.7	32.5–80.9
4	9 (2%)	2 (22%)	0.873	0.9	0.2–3.6	51.1	35.3–66.9
number of abutment teeth							
1.0	86 (17%)	35 (41%)		1.0	reference	82.7	58–107.3
2.0	398 (78%)	160 (40%)	**0.076**	0.7	0.5–1	98.4	85.3–111.5
3.0	16 (3%)	6 (38%)	**0.102**	2.1	0.9–4.9	25.0	14.8–35.2
≥ 4	13 (3%)	1 (8%)	**0.059**	0.1	0–1.1	135.0	98.5–171.5
ratio of number of restored teeth to number of abutment teeth							
< 1	327 (64%)	127 (39%)		1.0	reference	96.3	83.5–109.1
1	143 (28%)	55 (38%)	0.455	1.1	0.8–1.5	106.7	81.6–131.8
> 1	43 (8%)	20 (47%)	**0.124**	1.4	0.9–2.3	61.2	42.1–80.2
extension of the bridge							
unilateral extension (mesial)	34 (7%)	16 (47%)		1.0	reference	65.9	38.4–93.3
unilateral extension (distal)	64 (12%)	31 (48%)	0.439	1.3	0.7–2.3	52.8	31.8–73.7
bilateriál extensions	415 (81%)	155 (37%)	**0.109**	0.7	0.4 – 1.1	103.6	90 – 117.3
number of used wires							
1	347 (68%)	115 (33%)		1.0	reference	103.1	89.7–116.4
2	152 (30%)	77 (51%)	**0.001**	1.6	1.2–2.2	77.0	59.6–94.5
≥ 3	14 (3%)	10 (71%)	**0.022**	2.1	1.1–4.1	42.6	25.3–60
typ of jaw							
upper jaw	299 (58%)	107 (36%)		1.0	reference	95.6	82.6–108.7
lower jaw	214 (42%)	95 (44%)	**0.208**	1.2	0.9–1.6	91.6	73.7–109.5
typ of the replaced tooth							
incisive	91 (18%)	30 (33%)		1.0	reference	93.9	61.6–126.2
canine	24 (5%)	8 (33%)	0.750	0.9	0.4–1.9	100.9	53.7–148.1
premolar	257 (50%)	107 (42%)	0.651	0.9	0.6–1.4	97.8	83.3–112.2
molar	141 (27%)	57 (40%)	0.825	1.1	0.7–1.6	80.3	64.9–95.7
number of teeth within the same jaw							
≤ 10	184 (36%)	78 (42%)		1.0	reference	74.0	58.8–89.2
> 10	329 (64%)	124 (38%)	**0.016**	0.7	0.5–0.9	104.7	89.7–119.7
number of teeth in the antagonistic jaw							
≤ 10	145 (28%)	68 (47%)		1.0	reference	70.3	54.3–86.3
> 10	368 (72%)	134 (36%)	**0.001**	0.6	0.5–0.8	106.4	91.5–121.2
DF-T							
≥ 20	21 (4%)	13 (62%)		1.0	reference	51.6	30.1–73.2
20–10	323 (63%)	138 (43%)	**0.063**	0.6	0.3–1	86.8	76.3–97.3
≤ 10	169 (33%)	51 (30%)	**0.038**	0.5	0.3–1	117.6	92.2–142.9
DMF-T							
≥ 20	277 (54%)	138 (50%)		1.0	reference	79.4	67.2–91.6
20–10	184 (36%)	56 (30%)	**0.001**	0.6	0.4–0.8	127.2	104.4–150
≤ 10	52 (10%)	8 (15%)	**0.193**	0.6	0.3–1.3	84.6	62–107.2
caries risk							
low	407 (79%)	140 (34%)		1.0	reference	109.7	95.5–123.9
moderate	96 (19%)	56 (58%)	**< 0.001**	2.2	1.6–3.1	50.7	37.7–63.8
high	10 (2%)	6 (60%)	**< 0.001**	4.4	1.9–10	24.6	4.9–44.3
bruxism							
no	178 (35%)	48 (27%)		1.0	reference	115.6	92.6–138.6

(continued on next page)

Table 1 – (continued)

category	Teeth Frequency [n (%)]	Failures [n (%)]	p-value	HR	95% CI	Estimated Median success time	95% CI
yes	335 (65%)	154 (46%)	**0.001**	1.7	1.2–2.3	86.0	73.6–98.4
type of antagonist							
periodontal supported	471 (92%)	187 (40%)		1.0	reference	95.2	82.5–107.9
non-periodontal supported	14 (3%)	6 (43%)	0.701	1.2	0.5–2.6	72.3	39.9–104.8
no antagonist	28 (5%)	9 (32%)	**0.207**	0.6	0.3–1.3	116.1	76.7–155.5

Factors associated with time until failure ($p < 0.25$; bold) in the separate models were entered in the multivariate Cox regression model (Table 2).

2.5.2. *Success*

When the restoration was still in function and never needed a (second) therapy, the MRC-FPD was defined as success. Whenever the restoration was replaced, repaired, re-cemented or scheduled for these treatments at the last check-up the MRC-FPD was defined as failure (secondary endpoint).

2.6. *Repair of MRC-FPD*

In case of a chipping fracture, a conventional repair filling was inserted after carefully cleaning and adequate conditioning of the remaining composite surface. For these repairs approximately half an hour was scheduled.

In case of a complete fracture, a new bridge was constructed according to the cause of the fracture: For caries, the bridge was anchored in the new filling. For an (i.e. eccentric) overload the bridge was constructed with an additional wire placed near the overloaded spot.

2.7. *Statistical analysis*

For descriptive purposes frequencies and percentages of measured baseline characteristics as well as frequencies and percentages of different failure types were tabulated. Statistical analysis was performed using SPSS (SPSS 26; SPSS, Munich, Germany). Time until no success and no survival was the dependent variable. Kaplan-Meier statistics and log-rank tests were used to calculate significant differences between the groups ($p < 0.05$). For Kaplan-Meier statistic the independent method was used to generate survival curves up to 20 years [19]. The annual failure rates (AFR) were calculated from life tables [15,20]. Crude associations between baseline characteristics and time until failure were calculated by fitting separate models for each baseline characteristic as the independent variable. Factors associated with time until no success and no survival ($p < 0.25$ [21,22]) in the separate models were entered in a multivariate Cox regression model.

3. Results

MRC-FPD were placed between 1998 and 2021. Five-hundred thirteen MRC-FPD in 390 patients were analyzed [follow-up period: mean (SD): 59 (58) months, median: 45 months, range: 2–249 months]. Drop-out rate was 0%. Further descriptive information of the included MRC-FPD can be found in Table 1. Eighty-six percent of the MRC-FPD (73 failures out of 513) were considered as survival (mean estimated survival time (95% CI): 182 (169–195) months) (supplementary table 1). Sixty-one percent of the MRC-FPD were considered as success (202 failures out of 513) within a mean estimated success time (95% CI) of 98 (85–110) months (Table 1). Annual failure rates for survival were 2.2% and for success 8.6%. The main reason for failure (non-survival) was the extraction of an abutment teeth ($n = 64$ out of 73) due to caries ($n = 37$) or periodontal reasons ($n = 27$).

3.1. *Cox regression analysis – bivariate analysis*

Crude bivariate associations between the different baseline characteristics and an increased time until failure are given in Table 1 (success) and supplementary table 1 (survival). Statistically significant predictors for success were dentist's experience in designing MRC-FPD, patients' age, number of restored teeth, number of abutment teeth, number of used wires, type of the jaw, number of teeth in the same jaw, number of teeth in the antagonistic jaw, DF-T, DMF-T, caries risk, bruxism, type of antagonist ($p < 0.25$).

Predictors being significant for success were also significant for survival, with two exceptions: the number of restored teeth and bruxism became non-significant predictors.

3.2. *Cox regression analysis – multivariate analysis*

The result of the non-clustered multivariate models including factors possibly associated with an increased failure rate in the bivariate models are shown in Table 2 (success) and appendix Table 2 (survival). In multivariate analysis the dentist's experience in designing MRC-FPD significantly influenced the longevity ($p = 0.001$; Table 2); the more experience, the lower the failure rate. DMRC-FDP in patients older than 60 showed a 2.2 times higher failure rate than DMRC-FDP in patients younger than 40 (HR: 2.2 (1.0–4.8); $p = 0.043$). Success was also influenced by the number of used metal-wires and caries risk; The use of one wire resulted in a significantly lower risk for failure than the use of two (HR: 1.8 (1.3–2.5); $p = 0.001$) or three wires (HR: 2.3 (1.1–4.7); $p = 0.023$) and failure rates for DMRC-FDP in patient with a moderate (HR: 1.9 (1.3–2.7); $p < 0.001$) or high caries risk (HR: 2.2 (0.9–6 +5.3); $p = 0.040$) was 1.9–2.2 times higher than in patient with a low caries risk (Table 2).

Table 2 – Multivariate Cox proportional hazard regression analyses of time until failure as function of baseline characteristics identified (for outcome success).

category	p-value	HR	95% CI
dentists' experience in designing DMRC-FPD [years]	0.002		
> 17		1.0	reference
> 10–17	0.203	1.329	0.9–2.1
< 10	**0.001**	2.161	1.4–3.4
patients' age [years]	0.066		
20–40		1.0	reference
40–60	0.169	1.707	0.8–3.7
> 60	**0.043**	2.224	1–4.8
number of restored teeth	0.846		
1		1.0	reference
2	0.964	0.974	0.3–3.1
3	0.745	1.401	0.2–10.7
4	0.618	1.943	0.1–26.4
number of abutment teeth	**0.040**		
1.0		1.0	reference
2.0	0.786	1.166	0.4–3.5
3.0	0.283	3.098	0.4–24.4
≥ 4	0.180	0.145	0–2.4
ratio of number of restored teeth to number of abutment teeth	0.940		
< 1		1.0	reference
1	0.796	1.163	0.4–3.7
> 1	0.900	1.155	0.1–11.1
extension of the bridge	0.183		
unilateral extension (mesial)		1.0	reference
unilateral extension (distal)	0.534	1.243	0.6–2.5
bilaterial extensions	0.439	0.737	0.3–1.6
number of used wires	**0.001**		
1		1.0	reference
2	**0.001**	1.781	1.3–2.5
≥ 3	**0.023**	2.301	1.1–4.7
typ of jaw			
OK		1.0	reference
UK	0.911	0.983	0.7–1.3
number of teeth within the same jaw			
≤ 10		1.0	reference
> 10	0.956	0.990	0.7–1.4
number of teeth in the antagonistic jaw			
≤ 10		1.0	reference
> 10	**0.029**	0.656	0.4–1
DFM-T			
≥ 20		1.0	reference
20–10	0.327	0.831	0.6–1.2
≤ 10	0.248	1.668	0.7–4
caries risk			
low		1.0	reference
moderate	**< 0.001**	1.875	1.3–2.7
high	**0.040**	2.178	0.9–5.3
bruxism			
no		1.0	reference
yes	**0.036**	1.486	1–2.2
type of antagonist			
periodontal supported		1.0	reference
non-periodontal supported	0.505	0.739	0.3–1.8
no antagonist	**0.022**	0.426	0.2–0.9

Bold p-values ($p < 0.05$) indicate factors strongly associated with a de- or increased failure rate.

Furthermore, patients with the signs of bruxism had a 1.5 times higher failure rate than patient without bruxism (HR: 1.5 (1.0–2.2); p = 0.036; Table 2). The respective Kaplan Meier success graphs according to the patient's caries risk and number of wires are presented in Fig. 2 and Fig. 3.

Predictors being significant for success were also significant for survival, with two exceptions. The predictors patient's age (p ≥ 0.641) and bruxism (p = 0.432) became non-significant for survival (supplementary table 2).

4. Discussion

The present retrospective clinical study investigated the longevity of direct metal reinforced composite fixed partial dentures for immediate rehabilitation. A total of 513 fixed partial dentures in 390 patients were inserted in a general practice environment and followed for up to 20 years. The overall high survival rates, are in accordance with available data on fiber reinforced FDP ([7]). Dentist's experience in designing MRC-FPD and the number of used wires were significant predictor for decreased time until failure for both success and survival. Furthermore, on patient's level the presence of bruxism and a high caries risk resulted in a decreased time until failure as well.

In restorative dentistry annual failure rates at 5–10 years below 6% are considered from a clinical perspective as satisfying [23]. Thus, the present study in private practice environments showed satisfying annual failure rates (AFR) for survival (2.2%) and slightly higher AFR for success (8.6%) after a mean observation time of 5 years. Furthermore, to the best of our knowledge the present study is the first study analyzing the longevity of fixed partial dentures being reinforced with metal-wires.

For fiber reinforced FPD a wide range of cumulative and annual failure rates have been reported after up to 8 years [3–7,24]. Almost all cited studies were university-based studies, one practice-based study only is available so far [7]. From that study, the definitions for success and survival were adopted and AFR differed only slightly from the present failure rates. Furthermore, the study location (practice- vs. university-based), the study design (retrospective vs. prospective), the study type (observational vs. interventional) and, consequently, the treatment protocol (shared decision making vs. study depending treatment decision) might influence failure rates. When comparing the present results with the results of university-based studies this has to be taken into account. Recently it was observed that the more the daily routine in private practice is transferred into a study design the higher the failure rates became [22,25,26]. The cause for this general findings are subject of further discussion.

From a clinical perspective the influence of the extension of the bridge and the type of the replaced tooth on the longevity is important to know. In the present study both parameters were analyzed and had no significant influence on the success and survival rates. This is in agreement with our previous study on FRC-FPD [7].

In the previous studies on fibre reinforced composite fixed partial dentures (FRC-FDP) invasive box-shaped preparations

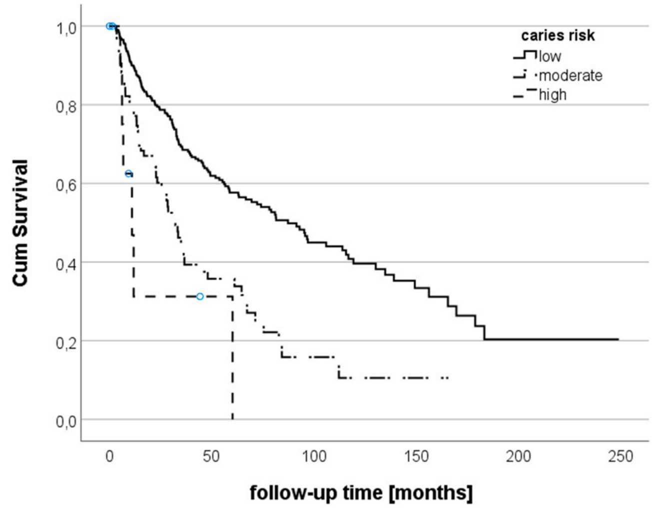

Fig. 2 – Kaplan-Meier success graphs for MRC-FPD according to the factor 'patient's caries risk'. MRC-FDP in patient with a moderate (HR: 1.9 (1.3–2.7); p < 0.001) or high caries risk (HR: 2.2 (0.9–6 +5.3); p = 0.040) showed a 1.9–2.2 times higher failure rate than in patient with a low caries risk.

in the abutment teeth were part of the concept for semi-direct or indirect FRC-FDP [3,6,27]. Only in a few studies box-shaped proximal cavities were limited to former existing restaurations and avoided in sound approximal surfaces to preserve intact enamel of the abutment teeth. In these cases the fiber bundles were directly bonded on the enamel surface of the abutment teeth (micro-invasive approach) [4,7]. In both studies the absence (or presence) of box-shaped cavities had no influence on the survival or success rates. In contrast, for MRC-FDP invasive box-shaped preparations (in relation to the required wire) are necessary to fix the wire. MRC-FDP are, therefore, more invasive when compared to the micro-invasive approach of FRC-FDP. However, when compared to the box-shaped approach of FRC-FDP, MRC-FDP are similar invasive but the designing is facilitated (as highlighted in the introduction). When compared with conventional bridges both metal- and fiber-reinforced FDP are much less invasive and in particular most of the enamel can be preserved.

The most important limitation of the present practice-based study is the fact, that all MRC-FDP have been fabricated and controlled by a single dentist. Previous studies on direct restorations observed the importance of the factor dentist for restoration survival [9,26,28–30]. As highlighted in the introduction operator skills, 'dentist profiles' [9] and practice organization may influence the longevity of the restorations. The fabrication of both, fiber- and metal- reinforced direct bridges are supposed to be technique sensitive [8]. Therefore, in the design of the present study the factor dentist was excluded in the present study. All MRC-FDP were inserted by one dentist (W.W.). The assessment of the status of the

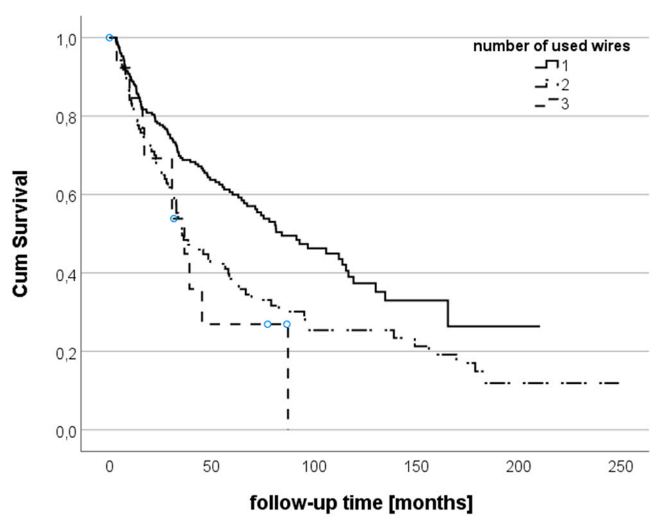

Fig. 3 – Kaplan-Meier success graphs for direct restorations according to the factor 'number of used wires '. The use of one wire resulted in a significantly lower risk for failure than the use of two (HR: 1.8 (1.3–2.5); p = 0.001) or three wires (HR: 2.3 (1.1–4.7); p = 0.023).

restorations was performed during normal recall appointments by the dentist who fabricated the MRC-FDP and not by a second blinded dentist. This, of course, might be a source of bias since the effect of the operators judging his own treatment outcome cannot be excluded. At time the first MRC-FDP was placed he had 31 years of dental experience and was well trained in handling direct composite restorations. However, the dentist's experience in designing MRC-FPD significantly influenced the failure rate in the present study; the more experienced, the lower the failure rate. Therefore, the factor dentist should be subject of future studies on MRC-FDP.

A recent systematic review [31] and a recent meta-analysis [23] revealed a significant effect on restoration survival for patient's caries risk level. Ten of 15 studies, analyzing amalgam, resin composite or sandwich single tooth restorations, observed a failure rate in high caries risk individuals which was 2.5–4.4 times higher than in low risk individuals [31]. However, definition of caries risk differed widely in the studies being included in the reviews. Previous studies used the history of new lesions over the study period [32,33], the age and the DMFT at the beginning of the study [15,21,34] or plaque and gingival indices [35]. In the present study for risk of caries the costs per year for direct restoration were used; the higher the costs the higher the caries risk. Although this is very pragmatic, the use of cost to define caries risk is rather unusual. Nonetheless, the present results are in agreement with previous findings. Consequently, patient's caries risk should not only be taken into account for single tooth restoration but also for direct composite FPR.

It has to be noted that the insertion of additional wires was restricted to cases in which a fracture has occurred due to insufficient vertical dimension or loads. Consequently, two or more wires were not used from the beginning, but after failure only. Therefore, (1) there is a selection bias for these cases, (2) the present finding that multiple wires have a higher failure rate than single wire FDP has to be interpreted with caution and (3) the number of wires should be investigated further.

In the present study bruxism had a significant negative influence on the success of MRC-FDP. This is also confirmed in the recent meta-analysis [23] and two systematic reviews on fixed partial dentures [36,37]. However, contradictory results were observed in the systematic review [31]. Three studies reported no effect of this variable on survival of inlay/onlay ceramic restoration. Three studies on amalgam, resin composite and partial-crowns observed a significant higher failure rate for patients with bruxism compared with patients without bruxism. Different definitions of bruxism and of failure might explain the contradictory results. This can also be seen in the present study. When the most common mechanical complication of fixed partial dentures in the reviews (chipping) [36,37] is redefined from failure to repairable survival (which is one of the difference between success and survival in the present study), bruxism changed from a significant to a non-significant predictor.

Regarding the retrospective power analysis, the analysis of the smallest subcategory to the reference category provided a power of $\geq$ 80% for the categories dentist's experience in designing MRC-FPD, patient's age, DFM-T and bruxism and a power of $\geq$ 65% for caries risk and number of teeth in the antagonistic jaw. For example, considering an α-error of 5% (multivariate analysis), a HR of 1.7 (being the HR between 'DMF-T $\leq$ 10' and 'DMF-T $\geq$ 20') and 52 patients in subcategory 'DMF-T $\leq$ 10' (ratio of 5.2) the analysis provided a power of 87.6%. Nonetheless, the present study may still be underpowered to detect moderate to clinically significant relative risks in some categories (e.g. "ratio of number of restored teeth to number of abutment teeth", "extension of the bridge"). Consequently, it might be speculated that with a larger sample size or with more failures the influence of some factors as (significant) predictor and the reliability of the present results would increase [38].

Within the limitation of the present practice-based study, direct metal-wire reinforced composite bridges showed high survival rates and moderate success rates after up to 20 years in private practice environment. MRC-FPD might, thus, be a valuable solution for an immediate, short- and medium-term replacement of missing teeth. However, several factors on the levels of practice (dentist's experience in designing MRC-FPD), patient (caries risk, bruxism) and restoration (number of wires) were significant predictors for the failure rate.

Funding

This study was funded by the authors and their institutions.

Acknowledgment

We thank Bernadette Rawyler for creating Fig. 1.

Informed consent

For this type of study, formal consent is not required.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.dental.2022.06.008.

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