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Clinical and radiographic outcomes of implant-supported fixed dental prostheses with cantilever extension. A retrospective cohort study with a follow-up of at least 10 years

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Abstract

Aim: To report the clinical and radiographic outcomes of implant-supported fixed dental prostheses with cantilever extensions (FDPCs) after a function time ≥10 years.

Material and methods: Patients with FDPCs in posterior areas were clinically and radiographically re-evaluated. Mesial and distal radiographic marginal bone levels (mBLs) from baseline (i.e. delivery of FDPC) to the follow-up examination were calculated and compared between implant surfaces adjacent to and distant from the cantilever extension. Implant survival rate, pocket probing depth (PPD), presence/absence of bleeding on probing (BoP) and presence/absence of mechanical/technical and biological complications were recorded.

Results: Twenty-six patients with 30 FDPCs supported by 60 implants were re-evaluated after a mean loading time of 13.3 ± 2.7 years (range: 10–18.6 years). One diameter-reduced implant carrying a cantilever extension fractured, yielding a patient-based survival rate of 96.2% (95% CI: 0.95/1.0). The mean marginal bone level change was not statistically significantly different from baseline to follow-up (1.2 mm ± 0.9 to 1.6 mm ± 1.7; 95% CI: −0.1/0.9; $p > .05$). The mean PPD changed statistically significantly from 3.4 mm ± 0.7 to 3.7 mm ± 0.7 (95% CI: 0.04/0.6; $p = .02$). Loss of retention occurred ≥ 1x in 9 patients (34.6%, 95% CI: 0.44/0.83). At follow-up, peri-implant health was diagnosed in 12 (46.2%), peri-implant mucositis in 7 (26.9%) and peri-implantitis in 7 (26.9%) patients, respectively.

Conclusion: Despite a high rate of loss of retention, the use of implant-supported FDPCs in posterior areas represents a reliable long-term treatment option with a high implant survival rate and minimal peri-implant bone level changes irrespective of the location of the cantilever extension.

KEYWORDS

biological complications, bone loss, cantilever extension, dental implants, fixed dental prostheses, technical complications

1 | INTRODUCTION

Despite the large amount of evidence documenting the successful long-term use of osseointegrated dental implants to support fixed dental prostheses (FDPs) (Hämmerle et al., 2018; Morton et al., 2018), the scientific interest for alternative implant-supported prosthetic solutions aiming at reducing patient's morbidity (i.e. FDPs with cantilever extension) increased, as demonstrated by the number of systematic reviews published on this topic (Aglietta et al., 2009; Romeo & Storelli, 2012; Van Nimwegen et al., 2017; Zurdo et al., 2009). In particular, the use of cantilever extensions has been adopted when a limited mesio-distal gap prevented the placement of two adjacent implants (Roccuzzo et al., 2020) or to overcome more extensive surgical procedures such as maxillary sinus floor elevation (Aglietta et al., 2012). Moreover, even-though the replacement of two adjacent missing teeth both in the maxillary and mandibular anterior areas with an implant-supported cantilever extension has been documented to be a reliable treatment option in terms of clinical, radiographic and aesthetic outcomes (Roccuzzo et al., 2020; Tymstra et al., 2011), some questions remain on the use of cantilever extensions in posterior edentulous areas where loading forces may jeopardize marginal bone levels or even implant survival. In addition, although results from two retrospective studies with a 5-year follow-up failed to report increased risks in terms of survival and success rates (Hälg et al., 2008; Wennström et al., 2004), there is lack of evidence on the long-term follow-up (i.e., at least 10 years) of biological and technical complications around implants supporting cantilever extensions.

A retrospective study reported positive results in terms of implant survival rate and minimal clinical and radiographic changes around FDPs with cantilever extension with a mean loading time of 5.6 years (Aglietta et al., 2012).

Based on available evidence from the 5th Consensus Conference of the European Association of Osseointegration (EAO), the concept of implant-supported fixed dental prostheses (FDPs) with cantilever extension can be recommended as a reliable treatment option with high survival rates of FDPs and implants. Clinicians and patients, however, should be aware of the fact that this recommendation is based on a limited number of studies with a short to medium follow-up (Hämmerle et al., 2018).

Long-term observation periods are needed to verify whether or not these positive outcomes can be maintained. Therefore, the aim of this retrospective study was to investigate the survival and success rates of implants supporting FDPs with cantilever extensions after at least 10 years of function.

2 | MATERIAL AND METHODS

The study protocol was submitted to and approved by the Ethical Committee of the Canton of Bern, Switzerland (Kantonale Ethikkommission, KEK, Nr.: 2018-01877). The investigation was conducted according to the revised principles of the Helsinki Declaration, and a signed informed consent was obtained from each patient before beginning of the study.

2.1 | Patient selection

Partially edentulous patients comprehensively treated between November 1999 and March 2009 at the Department of Periodontology, University of Bern, Switzerland, were invited to participate in the follow-up examination.

The following inclusion criteria were applied:

- patients aged ≥18 years
- patients with systemic health or controlled medical conditions
- patients with healthy or treated periodontal conditions• patients enrolled in regular supportive periodontal therapy (SPT)
- patients without clinical signs of bruxism and/or oral parafunctions
- 2 osseointegrated dental implants in the canine or posterior areas of maxilla and mandible following transmucosal placement and healing of 3-6 months
- tissue level solid-screw implants with a sand-blasted and acid-etched (SLA) surface with an endosseous diameter of 3.3, 4.1 or 4.8 mm, a length of 8, 10 or 12 mm, a shoulder diameter of 4.8 mm and a supracrestal machined neck with a height of 1.8 or 2.8 mm (Straumann® Dental Implant System, Institut Straumann AG, Basel, Switzerland)
- porcelain fused-to-gold alloy FDPCs
- utilization of prefabricated titanium abutments
- cemented (3M™ ESPE Ketac™ Cem, Seefeld, Germany) or screw-retained fixed dental prostheses with a mesial or distal cantilever extension (FDPCs)
- cantilever extension corresponding to 1 premolar unit (i.e., 6–7 mm)
- absence of occlusal contacts or guidance on the cantilever extension at baseline
- opposing dentition consisting of natural teeth or fixed or removable prosthetic restorations
- availability of a periapical radiograph at baseline (i.e. FDPC delivery)
- availability of PPD measurements (mm) taken at baseline at 4 sites/implant with a graduated Michigan periodontal probe (Deppeler SA, Rolle, Switzerland)
- availability of BoP measurements (%) (Lang et al., 1986) taken at baseline at 4 sites/implant with a graduated Michigan periodontal probe (Deppeler SA, Rolle, Switzerland).

The following exclusion criteria were applied:

- untreated or active periodontal diseases
- immediate implant placement (i.e., Type I implant placement according to Hämmerle et al., 2004)
- FDPCs in the aesthetic zone (i.e., replacement of maxillary or mandibular incisors)
- FDPCs supported by hollow-screw and hollow-cylinder implants

2.2 | Clinical examination at follow-up

A comprehensive clinical examination including an update of the medical history, soft tissue examination, assessment of periodontal, dental (i.e., caries control) and endodontic (i.e., vitality control) conditions and assessment of occlusion and articulation was performed at follow-up. Subsequently, a periapical radiograph was obtained by means of the parallel long-cone technique (Updegrave, 1951) ≥10 years following baseline (i.e., FDPC delivery). PPDs and BoP scores were assessed at 4 sites/implant (i.e., mesial, distal, oral and buccal) by one experienced examiner (E.S.) with a graduated Michigan periodontal probe (Deppeler SA, Rolle, Switzerland).

Implant survival was defined as presence of the implant in the oral cavity at follow-up and reported as percentage.

2.3 | Radiographic examination at follow-up

Analog radiographs from intraoral dental films (Kodak Ultraspeed DF 58 - Eastman Kodak Company, New York, USA) were scanned and digitized using Microtek TMA 1600 and Microtek ScanPotter (settings on Mac OS X: 1600 dpi, Diafilm, Format.tif). Subsequently, each radiographic image was calibrated and evaluated by means of the software ImageJ (National Institutes of Health, Bethesda, MD, USA). Based on the fact that all patients were rehabilitated with Straumann Tissue Level implants, the known distance between two implant threads (e.g. 1.25 mm) × 3 (1.25 mm × 3 = 3.75 mm) was used to calibrate the radiographs (Figure 1, green lines). Following identification of the mesial and distal edge of the implant shoulder (IS), a line was drawn between these two points and used as landmark (Figure 1, white lines). Measurements of the mesial and distal bone levels were taken from these 2 points perpendicular to the connecting line to the first bone-to-implant contact (BIC) (Figure 1, red, blue and pink lines).

In order to accurately identify the true radiographic linear distance IS-BIC, the height of the supracrestal machined neck (i.e., 2.8 mm for standard implants and 1.8 mm for standard plus implants) was subtracted from the measured values. All negative values were defined as bone gain while bone loss was defined by positive values. All radiographic measurements were taken in duplicate by one experienced examiner (M.M.) not involved in any part of the treatment and follow-up examination.

2.4 | Assessment of peri-implant health and diseases

Peri-implant health and diseases were assessed according to the consensus report of the World Workshop on the classification of periodontal and peri-implant diseases and conditions (Berglundh et al., 2018). Peri-implant health was characterized at the clinical level by the absence of signs of soft tissue inflammation, for example absence of bleeding on gentle probing (BoP) and suppuration (Araujo & Lindhe, 2018). Peri-implant mucositis was defined as presence of

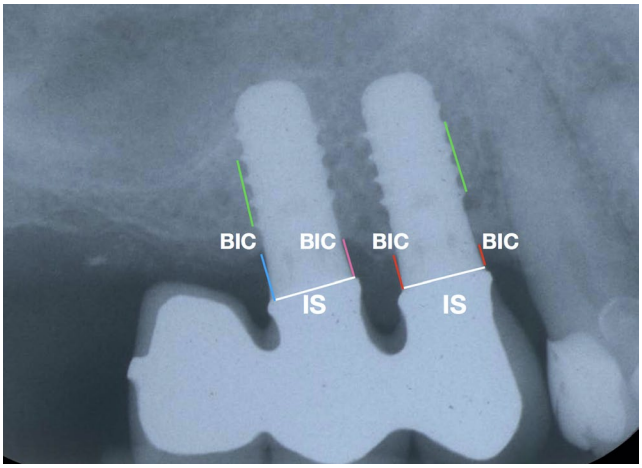

FIGURE 1 Radiographic reference points and lines used to measure linear peri-implant marginal bone levels of the fixed dental prosthesis (FDP) with cantilever extension. IS: Implant Shoulder BIC: radiographic Bone-to-Implant Contact Linear distance between implant threads (3 × 1.25 mm = 3.75 mm) (green) Implant without cantilever extension: Mesial and distal linear distances IS-BIC (red) Implant with cantilever extension: Linear distance IS-BIC distant from cantilever extension (pink) Implant with cantilever extension: Linear distance IS-BIC adjacent to cantilever extension (blue)

BoP and/or suppuration with or without increased probing depth compared to previous examinations in conjunction with the absence of bone loss beyond crestal bone level changes resulting from initial bone remodelling (Heitz-Mayfield & Salvi, 2018). Peri-implantitis was defined by the presence of BoP and/or suppuration, increased probing depths compared to previous examinations and presence of bone loss beyond crestal bone level changes resulting from initial bone remodelling (Schwarz et al., 2018).

2.5 | Assessment of mechanical/technical complications

Mechanical/technical complications were assessed as events according to Salvi and Brägger (2009) and reported as percentages of the total number of patients, implants and restorations.

Mechanical risks comprised a complication/failure of a prefabricated component caused by mechanical forces such as implant or abutment fracture while technical risks were related to a complication/failure of the laboratory-fabricated restoration or its materials such as occlusal screw-loosening/fracture, framework fracture and ceramic chipping.

Data are reported in compliance with the STROBE checklist.

2.6 | Data analysis

The primary outcome variable was the bone level change calculated as a mean of the mesial and distal measurements and expressed in mm as mean BL (mBL) ± standard deviation (*SD*).

TABLE 1 Patient, FDPC and implant characteristics

Patient Nr.	Gender	Mean age at follow-up (years)	Smoking status at follow-up	Location of implants (cantilever) according to FDI	Endosseous implant diameter (mm)	Adjunctive surgical procedure	Follow-up (months)
1	F	83	NO	44,45 (46)	3.3/3.3	NO	194
2	M	68	NO	(45) 46,47	4.1/4.8	NO	127
3	F	77	NO	24,25 (26)	3.3/4.1	NO	177
4	M	84	NO	(23) 24,26	4.1/4.8	SFE	155
5	F	58	NO	44,45 (46)	3.3/4.1	NO	192
6	F	72	NO	14,15 (16)	4.1/4.1	SFE	129
				24,25 (26)	4.1/4.1	SFE	129
7	M	59	NO	24,25 (26)	3.3/4.1	NO	123
8	M	70	YES	14,15 (16)	4.1/4.8	SFE	205
				24,25 (26)	4.1/4.8	NO	205
9	F	72	NO	13,14 (15)	3.3/4.1	NO	202
10	F	72	NO	37,36 (35)	4.1/4.1	NO	135
11	M	65	NO	14,15 (16)	4.1/4.1	NO	125
12	M	75	NO	14,15 (16)	4.1/4.1	NO	130
13	F	73	NO	23, 24 (25)	4.1/4.1	Contour GBR	148
14	F	63	NO	(34) 35,36 (37)	4.1/4.8	NO	165
15	M	85	YES	24,25 (26)	4.1/4.1	SFE	128
16	F	72	NO	(14) 15,16	4.1/4.1	NO	173
17	F	65	NO	14,15 (16)	4.1/4.1	NO	145
18	M	70	NO	13,14 (15)	4.1/4.1	SFE	138
19	F	75	NO	(44) 45,46	4.1/4.1	Contour GBR	120
20	F	82	NO	(13) 14,15 (16)	4.1/4.1	SFE	157
				24,25 (26)	4.1/4.1	SFE	157
21	F	72	YES	(23) 24,25 (26)	4.1/4.8	Contour GBR	219
				14,15 (16)	4.1/4.8	Contour GBR	205
22	F	72	NO	24,25 (26)	4.1/4.1	SFE	145
23	M	84	NO	14,15 (16)	4.8/4.8	NO	126
24	M	68	YES	24, 25 (26)	4.1/4.1	NO	155
25	M	67	NO	(35) 36,37	4.1/4.1	NO	223
26	M	63	NO	24, 25 (26)	3.3/4.1	NO	148

Abbreviations: F, Female; FDI, World Dental Federation Tooth-Numbering System; FDPC, Fixed Dental Prosthesis with Cantilever extension; GBR, Guided Bone Regeneration; M, Male; SFE, Sinus Floor Elevation.

The clinical parameters PPD and BoP were expressed as overall mean of the mesial, distal, buccal and oral implant sites as well as of implants adjacent to and distant from the cantilever extension, respectively. PPD was expressed in mm ± *SD* while bleeding on probing (BoP) scores were reported as mean percentages (%) ± *SD*. Distribution of the quantitative measurements was assessed using the Shapiro–Wilk test.

Survival rates of implants and restorations as well as rates of biologic and technical complications were reported in %.

All differences were assessed using the paired Student t test. The 95% confidence intervals of the differences were calculated, and all tests were two-tailed with a significance level set at alpha <0.05. The data analysis was performed using a commercially available statistical software package (PRISM®; Version 7.0a GraphPad Software, Inc., San Diego, CA, USA).

3 | Results

The characteristics of the patients, the implants and the FDPCs are summarized in Table 1.

3.1 | Patient characteristics

Twenty-six patients (12 males and 14 females) with a mean age of 72.2 ± 7.2 years at follow-up treated in the Department of Periodontology, University of Bern, Switzerland, between November 1999 and March 2009 with 2 implants and at least 1 cantilever extension were included.

Three male and 1 female patient were smokers (i.e., ≥5 cigarettes/day) at time of follow-up. Patients were rehabilitated with 60 dental implants and restored with 30 metal-ceramic FDPCs (Figures 2, 3).

3.2 | Implant characteristics

Seven implants (11.7%) had a diameter of 3.3 mm, 44 (73.3%) implants a diameter of 4.1 mm and 9 (15%) implants a diameter of 4.8 mm.

Concomitant with implant placement, 13 minor adjunctive surgical procedures were performed (i.e., transcrestal sinus floor elevation $n = 9$; contour guided bone regeneration $n = 4$).

3.3 | Characteristics of the FDPCs

The FDPCs were in function for a mean of 13.3 ± 2.7 years (159.3 ± 32.2 months) with a range from 10 to 18.6 years. All but one FDPCs were cemented. The cantilever extensions were located 6× on the mesial, 21× on the distal and 3× on the mesial and distal aspect of the FDPC, respectively. Seven FDPCs were located in the posterior mandible while 23 FDPCs were located in the posterior maxilla. Twenty-seven FDPCs supported 1 mesial or distal cantilever extension corresponding to 1 premolar unit while 3 FDPCs carried 1 mesial and 1 distal cantilever extension corresponding to 2 premolar units.

In 14 patients, the opposing dentition consisted of implant-supported FDPs, and in the remaining 12 patients, the antagonists were natural teeth. No removable dental prostheses were present in the dentitions opposing the FDPCs.

FIGURE 2 Clinical buccal view of the fixed dental prosthesis (FDP) shown in Figure 1

FIGURE 3 Clinical occlusal view of the fixed dental prosthesis (FDP) shown in Figure 2

3.4 | Implant survival and success

After 11.3 years (i.e. 136 months), one patient suffered from loss of a diameter-reduced (i.e. 3.3 mm) implant due to fracture. Therefore, a patient-based survival rate of 96.2% (95% CI: 0.95/1.0) could be achieved. At follow-up, peri-implant health was diagnosed in 12 (46.2%), peri-implant mucositis in 7 (26.9%) and peri-implantitis in 7 (26.9%) patients, respectively.

3.5 | Mechanical/technical complications

The most frequent technical complication was loss of retention (i.e. debonding) observed ≥1× in 9 patients (34.6%, 95% CI: 0.44/0.83). Out of these 9 patients, 5 patients experienced loss of retention 1×, 3 patients 2× and 1 patient 6×, respectively. The only screw-retained FDPC was excluded from the analysis.

The remaining technical complications (i.e. abutment fracture, ceramic chipping and screw loosening) occurred 1× in 3 patients. Mechanical and technical complications are summarized in Table 2.

3.6 | Changes in radiographic marginal bone levels

The assessment of the linear radiographic measurements by two examiners yielded a Cohen's kappa coefficient of 0.72 across all radiographs.

No statistically significant change in mBL from 1.2 mm ± 0.9 at baseline to 1.6 mm ± 1.7 at follow-up was observed (95% CI: −0.1/0.9; $p > .05$). The mean mBL at implants adjacent to the cantilever extension increased from 1.2 mm ± 0.8 at baseline to 1.4 mm ± 0.9 at follow-up (95% CI: −0.1/0.5; $p > .05$). The peri-implant mBL at implants distant from the cantilever extension displayed a statistically significant increase from 1.3 mm ± 1.0 at baseline to 1.9 mm ± 1.7 at follow-up (95% CI: 0.1/1.1; $p = .02$). The evaluation of the mBL changes at implant sites adjacent to the cantilever extension yielded a statistically significant increase from 0.9 mm ± 0.9 at baseline to 1.3 mm ± 0.9 at follow-up (95% CI: 0.1/0.7; $p = .01$) whereas a mBL change from 1.3 mm ± 0.8 at baseline to 1.4 mm ± 0.9 at follow-up was observed at implant sites distant from the cantilever extension (95% CI: −0.2/0.4; $p > .05$). In 7 patients with peri-implantitis, mBL changed from 1.1 mm ± 0.6 at baseline to 2.9 mm ± 2.5 at follow-up ($p > .05$).

A summary of the mBL changes is provided in Table 3.

3.7 | Changes in clinical parameters

The overall PPD changed statistically significantly from 3.4 mm ± 0.7 at baseline to 3.7 mm ± 0.7 at follow-up (95% CI: 0.04/0.6; $p = .02$). Mean PPD at implant sites adjacent to the cantilever extension increased statistically significantly from 3.3 mm ± 0.7 at baseline to 3.6 mm ± 0.7 at follow-up (95% CI: 0.05/0.6; $p = .02$) and from 3.4 mm ± 0.7 at baseline to 3.8 mm ± 0.9 at follow-up (95% CI: 0.1/0.7; $p = .01$) at implants sites distant from the cantilever extension. In 7 patients with peri-implantitis, PPDs changed from 3.6 mm ± 1.1 at baseline to 4.6 mm ± 0.5 at follow-up ($p > .05$).

No statistically significant differences between baseline and follow-up examinations were observed with respect to BoP scores (95% CI: −7.9/10.3; $p > .05$). In 7 patients with peri-implantitis, BoP scores changed from 17.9% ± 12.2 at baseline to 46.4% ± 46.6 at follow-up ($p > .05$).

One implant in 1 smoking patient displayed suppuration at the follow-up examination.

The clinical parameters are summarized in Table 4.

4 | Discussion

The aim of the present study was to report the clinical and radiographic outcomes of implant-supported fixed dental prostheses with a mesial or distal cantilever extension (FDPCs) after a follow-up of least 10 years. The results indicated that implants supporting FDPCs in posterior areas of maxilla and mandible yielded a 96.2% survival rate and were associated with minimal marginal bone level changes after a mean time in function of 13.3 ± 2.7 years. The most frequent complication was loss of retention recorded at least 1× in 9 patients. It should be noted that FDPCs were delivered to patients not displaying signs of bruxism and oral parafunctions at baseline.

TABLE 2 Mechanical and technical complications reported on patient, FDPC and implant level

Mechanical/technical complication	Patient-based events ($n = 26$) (%)	FDPC-based events ($n = 30$) (%)	Implant-based events ($n = 60$) (%)
Implant fracture	1 (3.8)	1 (3.3)	1 (1.7)
Abutment fracture	1 (3.8)	1 (3.3)	1 (1.7)
Framework fracture	0 (0)	0 (0)	0 (0)
Ceramic chipping	1 (3.8)	1 (3.3)	n.a.
≥1× loss of retention	9 (34.6)	9 (30.0)	n.a.
Screw loosening	1 (3.8)	1 (3.3)	1 (1.7)
Screw fracture	0 (0)	0 (0)	0 (0)

n.a, not applicable.

TABLE 3 Linear radiographic distances IS-BIC (mm) (mean ± *SD*) of implant-supported FDPCs

	Linear distance IS-BIC at baseline	Linear distance IS-BIC at follow-up	Mean difference ± *SD* (95% Confidence Interval)	*p* value
Overall mean ± SD linear distance IS-BIC (mm)	1.2 ± 0.9	1.6 ± 1.7	0.4 ± 0.3 (−0.1 to 0.9)	ns*
Implants with cantilever extension: Mean ± SD of mesial and distal linear distances IS-BIC (mm)	1.2 ± 0.8	1.4 ± 0.9	0.2 ± 0.1 (−0.1 to 0.5)	ns*
Implants without cantilever extension: Mean ± SD of mesial and distal linear distances IS-BIC (mm)	1.3 ± 1.0	1.9 ± 1.7	0.6 ± 0.7 (0.1–1.1)	.02
p value *	ns*	ns*		
Implants with cantilever extension: Mean ± SD of linear distance IS-BIC adjacent to cantilever extension (mm)	0.9 ± 0.9	1.3 ± 0.9	0.4 ± 0.2 (0.1–0.7)	.01
Implants with cantilever extension: Mean ± SD of linear distance IS-BIC distant from cantilever extension (mm)	1.3 ± 0.8	1.4 ± 0.9	0.1 ± 0.1 (−0.2 to 0.4)	ns*
p value *	ns*	ns*		

Abbreviations: BIC, radiographic Bone-to-Implant Contact; FDPC, Fixed Dental Prosthesis with Cantilever extension; IS, Implant Shoulder; SD, Standard Deviation.

*Paired Student's *t* test.

High survival rates of implant-supported FDPCs were reported both in prospective and retrospective studies (Storelli et al., 2018). In particular, a 100% survival rate in 45 patients with 166 implants supporting FDPCs in posterior areas was reported after a follow-up of 8 years (Romeo et al., 2009). In a study with a mean follow-up of 5 years, 2 implants with a 3.3 mm diameter supporting FDPCs fractured after 2.5 and 3.8 years, respectively (Hälg et al., 2008). In the present study, the only diameter-reduced implant (i.e. 3.3 mm) supporting a cantilever extension was lost due to fracture after 11.3 years of loading yielding a patient-based survival rate of 96.2%. This survival rate (i.e. 96.2%) compares favourably with an estimated 5–10-year survival rate of 99.2% reported in a recent systematic review (Storelli et al., 2018).

In the study by Aglietta et al. (2012), no implant loss was reported in 21 patients with 42 implants supporting FDPCs after a mean follow-up of 5.6 years. It should be noted, however, that in the study by Aglietta et al. (2012) implants with a diameter of 3.3 mm were excluded. Hence, it may be safe to avoid the use of reduced-diameter implants supporting FDPCs in posterior areas.

In the present study, a tendency to an increased marginal bone loss was observed around implant sites adjacent to and distant from the cantilever extension. These results are comparable with those reported in two long-term retrospective cohort studies with similar design (Aglietta et al., 2012; Wennström et al., 2004). The mean overall change of 0.4 mm in marginal bone levels observed between baseline and follow-up at implant sites adjacent to the cantilever extension was, however, 4.5x smaller compared with that of 1.8 mm at implant sites diagnosed with peri-implantitis in the present study. Hence, these results are in accordance with those of previous studies failing to report detrimental effects of cantilever extensions on peri-implant marginal bone level changes (Aglietta et al., 2012; Freitas da Silva et al., 2018; Hälg et al., 2008; Romeo et al., 2009; Wennström et al., 2004; Zurdo et al., 2010).

A history of treated periodontitis has been reported to be a risk for the development of peri-implant diseases (Derks et al., 2016; Karoussis et al., 2003; Kordbacheh Changi et al., 2019; Roccuzzo et al., 2010, 2012). All partially edentulous patients enrolled in the present study presented a history of treated periodontitis and were enrolled in regular SPT including early diagnosis and treatment of peri-implant diseases. The mean PPD and BoP scores at implants supporting FDPCs revealed minor changes between baseline and follow-up examination. These increases in PPD and BoP scores were associated with the development of peri-implant mucositis and peri-implantitis and cannot be related to the presence of cantilever extensions. Hence, in order to reduce the number of implants and minimize the risk of developing peri-implant diseases in periodontally compromised patients, the use of FDPs with cantilever extensions should be considered (Hardt et al., 2002; Ong et al., 2008; Sgolastra et al., 2015).

In the present study, all but one FDPCs were cemented. Loss of retention occurred at least 1× in 9 patients over a mean period of 13.3 years. The rate of 34.6% loss of retention observed in the present study was considerably higher when compared with the 5–10-year cumulative rate of loss of retention of 5.22% defined as unscrewing of occlusal screws and debonding (Storelli et al., 2018). Nevertheless, in the present study, loss of retention occurred without jeopardizing the survival rates of implants and FDPCs. Although at time of cementation none of the cantilever extensions were in occlusion or guidance with the opposing dentition, it cannot be excluded that occlusal patterns changed over time leading to premature contacts on the cantilever extensions. Hence, in order to minimize loss of retention, inspection

TABLE 4 Clinical parameters at implants adjacent to and distant from the cantilever extension, respectively

	Baseline	Follow-up	Mean Difference ± *SD* (95% Confidence Interval)	*p* value
Overall mean PPD ± *SD* (mm)	3.4 ± 0.7	3.7 ± 0.7	0.3 ± 0.1 (0.04–0.6)	.02*
Mean PPD ± *SD* at implants adjacent to the cantilever extension (mm)	3.3 ± 0.7	3.6 ± 0.7	0.3 ± 0.1 (0.05–0.6)	.02*
Mean PPD ± *SD* at implants distant from the cantilever extension (mm)	3.4 ± 0.7	3.8 ± 0.9	0.4 ± 0,1 (0.1–0.7)	.01*
p value *	ns*	ns*		
Overall mean BoP ± *SD* (%)	17.3 ± 22. 4	18.5 ± 27.5	1.2 ± 4.6 (−7.9 to 10.3)	ns*
Mean BoP ± *SD* at implants adjacent to the cantilever extension (%)	16.2 ± 23. 7	17.0 ± 29.3	0.8 ± 4.9 (−8.8 to 10.4)	ns*
Mean BoP ± *SD* at implants distant from the cantilever extension (%)	18.8 ± 21. 1	20.5 ± 25. 5	1.7 ± 4.3 (−6.7 to 10.2)	ns*
p value *	ns*	ns*		

Abbreviations: BoP, Bleeding on Probing; FDPC, Fixed Dental Prosthesis with Cantilever extension; PPD, Pocket Probing Depth; *SD*, Standard Deviation.

*Paired Student's *t*-test.

and correction of the static and dynamic relationships of FDPCs should also be part of the maintenance care program.

Incidences of mechanical/technical complications were reported to be higher in implant-supported FDPs with cantilever extensions when compared with those without extensions (Aglietta et al., 2009; Brägger et al., 2011; Kreissl et al., 2007; Salvi & Brägger, 2009). Nevertheless, delivery of FDPCs in posterior areas in the present study reduced treatment time and costs as well as invasiveness of surgical procedures, as indicated by the fact that in 19 patients 23 external sinus floor elevations could be avoided.

The retrospective design of the present study represents a limitation, and hence, the findings should be interpreted with caution. Furthermore, the lack of a control group of FDPs without cantilever extension makes comparisons of the obtained results impossible. The lack of standardization and of exact intra-examiner reproducibility of the radiographic measurements as well as the assessment of the clinical parameters over a period of time ranging from 10 to 18.6 years represents an additional limitation in terms of clinical significance. Moreover, the authors were unable to provide reasons and numbers of subjects lost to follow-up and acknowledge that this may represent a major limitation of the present study.

For the reasons outlined above, the present results do not allow any generalizability to a population-based setting and preclude from external validity (Walton & Layton, 2018).

In conclusion, despite 34.6% of patients experiencing loss of retention, the use of implant-supported FDPs with a cantilever extension of one premolar unit in posterior areas represents a reliable long-term treatment option with a high implant survival rate and minimal peri-implant bone level changes irrespective of the location of the cantilever extension.

CONFLICTS OF INTEREST

The authors do not report any conflicts of interest related to the present study.

AUTHOR CONTRIBUTIONS

A.R. funding secondly is the recipient of a 3-year scholarship from the Clinical Research Foundation (CFR) for the Promotion of Oral Health, Brienz, Switzerland. E.S., A.R. and M.M. collected and analysed the data. C.A.R. analysed the data and contributed to the writing. A.S. contributed to the writing. G.E.S. conceived the idea and led the writing.

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REFERENCES

Aglietta, M., Iorio Siciliano, V., Blasi, A., Sculean, A., Brägger, U., Lang, N. P., & Salvi, G. E. (2012). Clinical and radiographic changes at implants supporting single-unit crowns (SCs) and fixed dental prostheses (FDPs) with one cantilever extension. A retrospective study. *Clinical Oral Implants Research*, *23*(5), 550–555. https://doi.org/10.1111/j.1600-0501.2011.02391.x

Aglietta, M., Siciliano, V. I., Zwahlen, M., Brägger, U., Pjetursson, B. E., Lang, N. P., & Salvi, G. E. (2009). A systematic review of the survival and complication rates of implant supported fixed dental prostheses with cantilever extensions after an observation period of at least 5 years. *Clinical Oral Implants Research*, *20*(5), 441–451. https://doi.org/10.1111/j.1600-0501.2009.01706.x

Araujo, M. G., & Lindhe, J. (2018). Peri-implant health. *Journal of Clinical Periodontology*, *45*(Suppl 20), S230–S236. https://doi.org/10.1111/jcpe.12952

Berglundh, T., Armitage, G., Araujo, M. G., Avila-Ortiz, G., Blanco, J., Camargo, P. M., & Zitzmann, N. (2018). Peri-implant diseases and conditions: Consensus report of workgroup 4 of the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions. *Journal of Clinical Periodontology*, *45*(Suppl 20), S286–S291. https://doi.org/10.1111/jcpe.12957

Brägger, U., Hirt-Steiner, S., Schnell, N., Schmidlin, K., Salvi, G. E., Pjetursson, B., & Lang, N. P. (2011). Complication and failure rates of fixed dental prostheses in patients treated for periodontal disease. *Clinical Oral Implants Research*, *22*(1), 70–77. https://doi.org/10.1111/j.1600-0501.2010.02095.x

Derks, J., Schaller, D., Hakansson, J., Wennström, J. L., Tomasi, C., & Berglundh, T. (2016). Effectiveness of implant therapy analyzed in a Swedish population: Prevalence of peri-implantitis. *Journal of Dental Research*, *95*(1), 43–49. https://doi.org/10.1177/0022034515608832

Freitas da Silva, E. V., Dos Santos, D. M., Sonego, M. V., de Luna Gomes, J. M., Pellizzer, E. P., & Goiato, M. C. (2018). Does the presence of a cantilever influence the survival and success of partial implant-supported dental prostheses? Systematic review and meta-analysis. *International Journal of Oral and Maxillofacial Implants*, *33*(4), 815–823. https://doi.org/10.11607/jomi.6413

Hälg, G. A., Schmid, J., & Hämmerle, C. H. (2008). Bone level changes at implants supporting crowns or fixed partial dentures with or without cantilevers. *Clinical Oral Implants Research*, *19*(10), 983–990. https://doi.org/10.1111/j.1600-0501.2008.01556.x

Hämmerle, C. H., Chen, S., & Wilson, T. G. Jr (2004). Consensus statements and recommended clinical procedures regarding the placement of implants in extraction sockets. *The International Journal of Oral & Maxillofacial Implants*, *19*(Suppl):26–28.

Hämmerle, C. H. F., Cordaro, L., Alccayhuaman, K. A. A., Botticelli, D., Esposito, M., Colomina, L. E., Wachtel, H. (2018). Biomechanical aspects: Summary and consensus statements of group 4. The 5(th) EAO Consensus Conference 2018. *Clinical Oral Implants Research*, 29(Suppl 18), 326–331. https://doi.org/10.1111/clr.13284

Hardt, C. R., Gröndahl, K., Lekholm, U., & Wennström, J. L. (2002). Outcome of implant therapy in relation to experienced loss of periodontal bone support: a retrospective 5- year study. *Clinical Oral Implants Research*, *13*(5), 488–494. https://doi.org/10.1034/j.1600-0501.2002.130507.x

Heitz-Mayfield, L. J. A., & Salvi, G. E. (2018). Peri-implant mucositis. *Journal of Clinical Periodontology*, *45*(Suppl 20), S237–S245. https://doi.org/10.1111/jcpe.12953

Karoussis, I. K., Salvi, G. E., Heitz-Mayfield, L. J., Brägger, U., Hämmerle, C. H., & Lang, N. P. (2003). Long-term implant prognosis in patients with and without a history of chronic periodontitis: a 10-year prospective cohort study of the ITI Dental Implant System. *Clinical Oral Implants Research*, *14*(3), 329–339. https://doi.org/10.1034/j.1600-0501.000.00934.x

Kordbacheh Changi, K., Finkelstein, J., & Papapanou, P. N. (2019). Peri-implantitis prevalence, incidence rate, and risk factors: A study of electronic health records at a U.S. dental school. *Clinical Oral Implants Research*, *30*(4), 306–314. https://doi.org/10.1111/clr.13416

Kreissl, M. E., Gerds, T., Muche, R., Heydecke, G., & Strub, J. R. (2007). Technical complications of implant-supported fixed partial dentures in partially edentulous cases after an average observation period of 5 years. *Clinical Oral Implants Research*, *18*(6), 720–726. https://doi.org/10.1111/j.1600-0501.2007.01414.x

Lang, N. P., Joss, A., Orsanic, T., Gusberti, F. A., & Siegrist, B. E. (1986). Bleeding on probing. A predictor for the progression of periodontal disease? *Journal of Clinical Periodontology*, *13*(6), 590–596.

Morton, D., Gallucci, G., Lin, W. S., Pjetursson, B., Polido, W., Roehling, S., & Zhou, W. (2018). Group 2 ITI Consensus Report: Prosthodontics and implant dentistry. *Clinical Oral Implants Research*, *29*(Suppl 16), 215–223. https://doi.org/10.1111/clr.13298

Ong, C. T., Ivanovski, S., Needleman, I. G., Retzepi, M., Moles, D. R., Tonetti, M. S., & Donos, N. (2008). Systematic review of implant outcomes in treated periodontitis subjects. *Journal of Clinical Periodontology*, *35*(5), 438–462. https://doi.org/10.1111/j.1600-051X.2008.01207.x

Roccuzzo, A., Jensen, S. S., Worsaae, N., & Gotfredsen, K. (2020). Implant-supported 2-unit cantilevers compared with single crowns on adjacent implants: A comparative retrospective case series. *Journal of Prosthetic Dentistry*, *123*(5), 717–723. https://doi.org/10.1016/j.prosdent.2019.04.024

Roccuzzo, M., Bonino, F., Aglietta, M., & Dalmasso, P. (2012). Ten-year results of a three arms prospective cohort study on implants in periodontally compromised patients. Part 2: clinical results. *Clinical Oral Implants Research*, *23*(4), 389–395. https://doi.org/10.1111/j.1600-0501.2011.02309.x

Roccuzzo, M., De Angelis, N., Bonino, L., & Aglietta, M. (2010). Ten-year results of a three-arm prospective cohort study on implants in periodontally compromised patients. Part 1: implant loss and radiographic bone loss. *Clinical Oral Implants Research*, *21*(5), 490–496. https://doi.org/10.1111/j.1600-0501.2009.01886.x

Romeo, E., & Storelli, S. (2012). Systematic review of the survival rate and the biological, technical, and aesthetic complications of fixed dental prostheses with cantilevers on implants reported in longitudinal studies with a mean of 5 years follow-up. *Clinical Oral Implants Research*, *23*(Suppl 6), 39–49. https://doi.org/10.1111/j.1600-0501.2012.02551.x

Romeo, E., Tomasi, C., Finini, I., Casentini, P., & Lops, D. (2009). Implant-supported fixed cantilever prosthesis in partially edentulous jaws: A cohort prospective study. *Clinical Oral Implants Research*, *20*(11), 1278–1285. https://doi.org/10.1111/j.1600-0501.2009.01766.x

Salvi, G. E., & Brägger, U. (2009). Mechanical and technical risks in implant therapy. *International Journal of Oral and Maxillofacial Implants*, *24*(Suppl), 69–85.

Schwarz, F., Derks, J., Monje, A., & Wang, H. L. (2018). Peri-implantitis. *Journal of Clinical Periodontology*, *45*(Suppl 20), S246–S266. https://doi.org/10.1111/jcpe.12954

Sgolastra, F., Petrucci, A., Severino, M., Gatto, R., & Monaco, A. (2015). Periodontitis, implant loss and peri-implantitis. A meta-analysis. *Clinical Oral Implants Research*, *26*(4), e8–e16. https://doi.org/10.1111/clr.12319

Storelli, S., Del Fabbro, M., Scanferla, M., Palandrani, G., & Romeo, E. (2018). Implant supported cantilevered fixed dental rehabilitations in partially edentulous patients: Systematic review of the literature. Part I. *Clinical Oral Implants Research*, *29*(Suppl 18), 253–274. https://doi.org/10.1111/clr.13311

Tymstra, N., Raghoebar, G. M., Vissink, A., & Meijer, H. J. (2011). Dental implant treatment for two adjacent missing teeth in the maxillary aesthetic zone: a comparative pilot study and test of principle. *Clinical Oral Implants Research*, *22*(2), 207–213. https://doi.org/10.1111/j.1600-0501.2010.02017.x

Updegrave, W. J. (1951). The paralleling extension cone technique in intraoral dental radiography. *Oral Surgery, Oral Medicine and Oral Pathology*, *4*, 1250–1261.

Van Nimwegen, W. G., Raghoebar, G. M., Tymstra, N., Vissink, A., & Meijer, H. J. A. (2017). How to treat two adjacent missing teeth with dental implants. A systematic review on single implant-supported

two-unit cantilever FDP's and results of a 5-year prospective comparative study in the aesthetic zone. *Journal of Oral Rehabilitation*, *44*(6), 461–471. https://doi.org/10.1111/joor.12507

Walton, T. R., & Layton, D. M. (2018). Intra- and inter-examiner agreement when assessing radiographic implant bone levels: Differences related to brightness, accuracy, participant demographics and implant characteristics. *Clinical Oral Implants Research*, *29*(7), 756–771. https://doi.org/10.1111/clr.13290

Wennström, J., Zurdo, J., Karlsson, S., Ekestubbe, A., Gröndahl, K., & Lindhe, J. (2004). Bone level change at implant-supported fixed partial dentures with and without cantilever extension after 5 years in function. *Journal of Clinical Periodontology*, *31*(12), 1077–1083. https://doi.org/10.1111/j.1600-051X.2004.00603.x

Zurdo, J., Romão, C., & Wennström, J. L. (2009). Survival and complication rates of implant-supported fixed partial dentures with cantilevers: a systematic review. *Clinical Oral Implants Research*, *20*, 59–66. https://doi.org/10.1111/j.1600-0501.2009.01773.x

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