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Clinical and radiographic outcomes of implant-supported zirconia fixed dental prostheses with cantilever extension: A proof-of-principle study with a follow-up of at least 1 year

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Abstract

Objectives: To test the reliability of full zirconia implant-supported fixed dental prostheses with cantilever extension (FDPCs) after at least 1 year of function.

Materials and Methods: Thirty-five patients in need of implant-supported single unit crowns (SUC) and FDPCs in posterior areas were enrolled. After implant placement, patients were rehabilitated with screw-retained full-zirconia FDPCs. Implant survival rate, pocket probing depth (PPD), presence/absence of bleeding on probing (BoP), and presence/absence of mechanical/technical complications were recorded. Mesial and distal radiographic marginal bone levels (mBLs) from baseline (i.e., recall appointment 3–6 months after implant loading [T0]) to the follow-up examination (i.e., latest recall appointment after at least 12 months after T0 [T1]), were calculated.

Results: Thirty patients with 34 FDPCs (31 SUCs and 3 FDPs) supported by 37 implants were available for analysis after a mean loading time of 2.6 ± 1.5 years (range: 13–87 months). No implants were lost. MBLs and mean PPD values did not change statistically significantly from T0 to T1 from 0.92 mm ± 0.42 to 0.96 mm ± 0.38 (95% CI: −0.07/0.17; $p = .418$) and from 2.99 mm ± 0.70 to 3.27 mm ± 0.71 (95% CI: −0.11/0.68; $p = .25$) respectively. Peri-implant mucositis was diagnosed in 22 cases. Screw-loosening and zirconia chipping occurred 1× in 4 patients.

Conclusion: Within the limitations of the present proof-of-principle study, the use of full-zirconia FDPCs in posterior areas seems a valid and safe short-term treatment option.

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

Andrea Roccuzzo and Michele Morandini contributed equally to this study and share first author position.

1 | INTRODUCTION

The long-term reliability of implant-supported fixed dental prostheses (FDPs) is nowadays not a matter of debate thanks to the wide body of evidence supporting such rehabilitative solutions (Duong et al., 2022; French et al., 2019; Jung et al., 2012; Roccuzzo et al., 2022). Nevertheless, in the last decade, scientific interest focused on treatment options aimed to reduce surgical invasiveness (Romandini et al., 2022), patient morbidity (Hof et al., 2014) and consequent financial costs (Karlsson et al., 2022). More specifically, among all available treatment options, the use of implant-supported FDPs with cantilever extension has been proposed (Halg et al., 2008) and its reliability in terms of implant-survival and success rates have been widely documented, as demonstrated by the many systematic reviews published on this topic (Freitas da Silva et al., 2018; Romeo & Storelli, 2012; Storelli et al., 2018; Zurdo et al., 2009). This treatment modality has been proposed both for the anterior and posterior sites. Indeed, in the anterior area, the use of cantilever extensions has been implemented in cases of a limited mesiodistal gap in order to prevent the placement of two adjacent implants often resulting in compromised aesthetics (Roccuzzo et al., 2020; Van Nimwegen et al., 2017) and the late onset of peri-implant diseases (Roccuzzo, Imber, et al., 2023). With respect to the posterior sites, cantilever extensions have been mainly adopted to avoid more invasive surgical interventions such as lateral maxillary sinus floor elevation (Aglietta et al., 2012). On this topic, following the recommendation of the 5th Consensus Conference of the European Association of Osseointegration (EAO) underlying the need for long-term data, (Hammerle et al., 2018) two recent publications with a follow-up of at least 10 years reported positive clinical and radiographic outcomes in terms of implant survival and peri-implant marginal bone level changes, despite increased risk for technical/mechanical complications (Schmid et al., 2020, 2021). At present, the whole available evidence on such type of reconstructions has been obtained on porcelain fused-to-gold alloys (Roccuzzo, Fanti, et al., 2023; Thoma et al., 2021) which have been widely replaced by zirconia as the material of first choice for implant-supported fixed dental reconstructions without cantilever extensions (Pjetursson et al., 2018). Therefore, it seems reasonable and of clinical significance to implement such material also in the fabrication of FDPs with cantilever extension.

Hence, this proof-of-principle study aimed to test the reliability of implants supporting full-zirconia FDPs with cantilever extension after at least 1 year of function.

2 | MATERIALS AND METHODS

The study protocol was submitted to and approved by the Ethical Committee of the Canton of Bern (KEK), Switzerland (Nr.: 2018-01877). The investigation was conducted according to the revised principles of the Helsinki Declaration (2013), and signed informed consent was obtained from each patient before entering the study. The trial was registered at ClinicalTrials.gov (NCT05676268). Data reporting was performed according to the STROBE guidelines.

2.1 | Study design and population

The present study was designed as a prospective, single-center proof-of-principle study with at least 12 months of follow-up.

Subjects attending or referred to the Department of Periodontology at the University of Bern, Bern, Switzerland, for periodontal treatment and implant therapy were consecutively screened for recruitment. Following screening by one investigator (G.E.S.), patients were enrolled between 2018 and 2020 based on the assessment of the following criteria:

2.2 | Inclusion criteria

- Male and female 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 care (SPC) program;
- Patients without clinical signs of bruxism and/or oral parafunctions;
- Implant placement in pristine bone without augmentation procedures;
- Implant placement with transcrestal sinus floor elevation with a minimum residual bone height of 5–6 mm;
- Need of replacement of two adjacent teeth in the posterior area (i.e. premolars/molars) in both jaws;
- Implants supporting one mesial/distal cantilever extension with a mesiodistal length of 6–7 mm.

2.3 | Exclusion criteria

- Systemic diseases that could interfere with the treatment outcome (e.g., uncontrolled diabetes mellitus, chemotherapy, etc.);
- Implant placement with sinus floor elevation by means of a lateral window;
- Implants with a length <8 mm and with an endosseous diameter <3.5 mm;
- Full-Mouth Plaque Score (FMPS) >25%;
- Full-Mouth Bleeding Score (FMBS) >25%;
- Cigarette smoking >10 cig./day'

2.4 | Surgical phase

At the completion of the active periodontal treatment (i.e., Step III) (Sanz et al., 2020), 35 patients underwent implant placement according to a standard surgical procedure (Buser et al., 2000). Solid-screw

implants with a sand-blasted and acid-etched (SLA Active) surface with an endosseous diameter of 4.1 or 4.8 mm, a length of 8, 10, or 12 mm, a shoulder diameter of 4.8 or 6.5 mm and a supracrestal machined neck with a height of 1.8 or 2.8 mm (Straumann Dental Implant System, Institut Straumann AG), were placed in maxillary and mandibular posterior areas.

2.5 | Prosthetic phase

Following transmucosal placement and healing of 3–6 months, (Type 4-C placement and loading) (Gallucci et al., 2018), impressions were taken at fixture level by means of the open-tray technique using a polyether material (Impregum, 3 M Espe, Seefeld, Germany) to fabricate a screw-retained full-zirconia SUC or FDP. All restorations were fabricated in the same Dental Laboratory (Zahnmanufaktur Zimmermann & Mäder, Bern, Switzerland) by the same experienced dental technician, using identical materials and technical procedures. After try-in and a careful check of the occlusal contacts and lateral guidance to minimize the risks of premature contacts, the reconstructions were torqued at 35 N/cm. Finally, the access screw channel was filled with sterilized PTFE tape and sealed with light-cured composite. All surgical and prosthetic phases were performed by registered periodontist staff members following the same surgical and prosthetic workflows.

2.6 | Supportive periodontal/peri-implant care (SPC) program and follow-up examination

At the completion of the rehabilitation phase, all patients were enrolled in tailored in-house SPC program according to their calculated risk with a recall interval ranging from 3 to 6 months (De Ry et al., 2021). Patients were invited for a follow-up examination after at least 12 months after prosthesis delivery which was performed prior to the planned SPC session (T1).

2.7 | Outcomes measures

For the record and analysis of the investigated outcomes, two different time points were defined:

- T0: first recall appointment after prosthesis delivery (i.e., baseline – 3–6 months after implant loading).
- T1: follow-up examination (i.e., follow-up visit – at latest recall appointment after at least 12 months after baseline).

2.8 | Clinical and radiographic examination

Evaluation of the clinical and radiographic parameters was performed at baseline (T0) and at the latest follow-up at least 12 months (T1) following completion of therapy before the latest planned SPC appointment. Moreover, at both time points, 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 were performed.

The following clinical parameters were recorded at the implant-site by the same calibrated experienced examiner (A. St.) using a graduated manual periodontal probe (PCP-UNC 15; Hu-Friedy®). The applied probing force ranged from 0.15 to 0.25 N.

- Plaque index (PII) (O'Leary et al., 1972);
- BoP, evaluated dichotomously with either presence/absence of bleeding within 30 s following probing;
- Suppuration on probing (SoP), with either presence/absence of suppuration after probing;
- Peri-implant pocket probing depth (PPD), measured from the mucosal margin to the bottom of the probable peri-implant sulcus and evaluated at four sites per implant (i.e., mesial, distal, oral, and buccal);
- Presence of buccal peri-implant soft tissue deficiency of at least 2 mm.

In addition, for each patient, the following full-mouth periodontal parameters were recorded:

- Full-mouth plaque score (FMPS) (O'Leary et al., 1972): percentage of tooth/implant sites revealing the presence of dental biofilms;
- Full-mouth bleeding score (FMBS) (Lang et al., 1986): percentage of tooth/implant sites revealing the presence of bleeding on probing.

2.9 | Radiographic assessment

The radiographic assessment was performed following the methodology proposed by Schmid et al. (Schmid et al., 2020, 2021). Analogue non-standardized and non-individualized intraoral radiographs were obtained using the paralleling technique (Updegrave, 1951). The radiographs (Kodak Ultraspeed DF 58 – Eastman Kodak CompanySA) 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. Following identification of the mesial and distal edge of the implant shoulder, a line was drawn between these two points and used as landmark. 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). 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. In addition, the following linear measurements were calculated: the overall length of the reconstruction, the length of the cantilever extension, and height of the connector (Figure 1).

All positive values were defined as bone loss while bone gain was defined by negative values. All radiographic measurements were assessed in duplicate by two blinded and calibrated examiners (M.M. and J.C.I).

2.10 | Assessment of peri-implant health and diseases

Peri-implant health and diseases were assessed according to the definitions of the consensus report of the 2017 World Workshop on the classification of periodontal and peri-implant diseases and condition (Salvi et al., 2022). More specifically, 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 the presence of 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 remodeling (Heitz-Mayfield & Salvi, 2018). Finally, 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 remodeling (Schwarz et al., 2018).

2.11 | Assessment of mechanical/technical complications

Mechanical/technical complications were assessed as events according to Salvi and Brägger (Salvi & Bragger, 2009) and reported as percentages of the total number of patients, implants, and restorations. Mechanical risks comprise a complication/failure of a prefabricated component caused by mechanical forces such as an implant or abutment fracture while technical risks are related to a complication/failure of the laboratory-fabricated restoration or its materials such as occlusal screw-loosening/fracture, framework fracture and ceramic chipping.

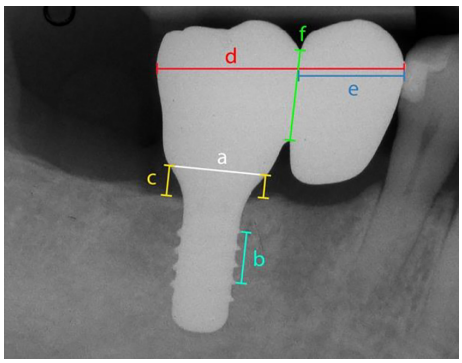

FIGURE 1 Radiographic reference points and lines used to measure linear peri-implant marginal bone levels of the fixed dental prostheses with cantilever extension. Implant Shoulder (white line [a]); linear distance between implant threads (3 × 1.25 mm = 3.75 mm) (light blue [b]); mesial and distal linear distances at implant site adjacent to and distant from cantilever extension (yellow lines [c]); length of the reconstruction (red lines [d]); length of the cantilever extension (dark blue line); height of the connector (green line [f]).

2.12 | Data analysis

Descriptive statistics were expressed using means (±SD) and ranges for continuous and absolute and relative frequencies (%) for categorical variables. Additionally, 95% confidence intervals were calculated for mean differences in clinical and radiographic parameters between time points and sites (i.e., adjacent, and distant to the cantilever extension). Distribution of quantitative measures was assessed using Shapiro–Wilk's test. Paired *t*-tests were used to assess changes of BL, PD, and BoP through time and between sites. A calculated intra-class correlation coefficient (ICC) ≥.94 for all radiographic parameters provided a very high level of reproducibility of the performed measurements. Corrections for within-cantilever implant dependence were not performed since most of cantilevers involved only one implant. All the tests were two-tailed. The significance level of reference was set at $p < .05$.

3 | RESULTS

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

3.1 | Patients' characteristics

Of the 35 patients originally included in this study, 30 patients (18 males and 12 females) (drop-out rate: 14%) with a mean age of 67.7 ± 9.2 years completed the follow-up examination and were available for analysis. Five patients were unwilling to attend the follow-up examination. Three male and three female patients were smokers (i.e., <10 cigarettes/day). Patients were rehabilitated with 37 dental implants and restored with 31 SUCs (i.e., one implant) and 3 FDPs (i.e., two implants) with one mesial/distal cantilever extension. The mean follow-up period was 31.1 ± 18.1 months. FMPS and FMBS were 14.2 ± 5.3% and 9.5 ± 5.6%, respectively.

3.2 | Implant characteristics

Twenty-six implants (70.3%) had a diameter of 4.1 mm while 11 (29.7%) implants had a diameter of 4.8 mm. The majority of implants were placed in the maxilla (i.e., $n = 27$; 79.4%) and in the premolar

TABLE 1 Demographic and clinical characteristics at patient, reconstruction, and implant-level. Number (%) or mean ± standard deviation (range).

	Total	One-implant	Two-implants
N patients	30	27	3
Gender			
Male	18 (60.0)	16 (59.3)	2 (66.7)
Female	12 (40.0)	11 (40.7)	1 (33.3)
Age (years)	67.7 ± 9.2 (42–84)	67.5 ± 9.6 (42–84)	70.0 ± 5.6 (65–76)
Smoking			
No	24 (80.0)	22 (81.5)	2 (66.7)
Yes	6 (20.0)	5 (18.5)	1 (33.3)
Follow-up (months)	31.1 ± 18.1 (13–87)	30.8 ± 17.8 (13–87)	34.0 ± 24.6 (16–62)
FMPS (%)	14.2 ± 5.3 (4–25)	14.3 ± 5.5 (4–25)	13.3 ± 2.9 (10–15)
FMBS (%)	9.5 ± 5.6 (1–20)	9.6 ± 5.9 (1–20)	9.3 ± 1.2 (8–10)
N reconstructions	34	31	3
Jaw			
Maxilla	27 (79.4)	24 (77.4)	3 (100)
Mandible	7 (20.6)	7 (22.6)	0 (0)
Material			
Zirconia mono	8 (23.5)	7 (22.6)	1 (33.3)
Zirconia Multi-layered	26 (76.5)	24 (77.4)	2 (66.7)
Extension			
Mesial	24 (70.6)	22 (71.0)	2 (66.7)
Distal	10 (29.4)	9 (29.0)	1 (33.3)
Length of reconstruction	15.6 ± 4.7 (8.7–29.2)	15.0 ± 4.4 (8.7–29.2)	22.1 ± 2.5 (19.2–23.7)
Length of cantilevers	6.3 ± 1.3 (3.0–8.3)	6.2 ± 1.3 (3.0–8.3)	6.9 ± 1.1 (5.7–7.9)
Height of connector	6.8 ± 1.5 (4.3–11.6)	6.7 ± 1.4 (4.3–11.6)	7.7 ± 1.8 (6.5–9.7)
N implants	37	31	6
Position			
Premolar	23 (62.2)	18 (58.1)	5 (83.3)
Molar	14 (37.8)	13 (41.9)	1 (16.7)
Implant type			
Regular Neck (RN)	30 (81.1)	24 (77.4)	6 (100)
Wide Neck (WN)	7 (18.9)	7 (22.6)	0 (0.0)
Diameter			
4.1 mm	26 (70.3)	21 (67.7)	5 (83.3)
4.8 mm	11 (29.7)	10 (32.3)	1 (16.7)
Length			
8 mm	9 (24.3)	6 (19.4)	3 (50.0)
10 mm	24 (64.9)	21 (67.7)	3 (50.0)
12 mm	4 (10.8)	4 (12.9)	0 (0.0)
Opposite dentition			
Teeth	26 (70.3)	24 (77.4)	2 (33.3)
Implants	11 (29.7)	7 (22.6)	4 (66.7)

area ($n = 23$; 62.2%). Concomitant with implant placement, 10 adjunctive surgical procedures (i.e., transcrestal sinus floor elevation) were performed. Finally, no simultaneous lateral bone augmentation was performed.

3.3 | Prosthesis characteristics

The mean function period of the FDPCs was of 31.1 ± 18.1 months with a range from 13 to 87 months. All FDPCs were screw-retained.

TABLE 2 Linear BL radiographic distances (mean ± SD) at T0, T1 and changes T1–T0 at implant-level in the SUCs group (a) and FDPs (b). Mean ± SD. (95% CI) and results from paired *t*-test (a).

	T0	T1	Difference T1–T0	*p*-Value
N implants	34	34	34	
Overall mean	0.92 ± 0.42	0.96 ± 0.38	0.05 ± 0.34 (−0.07 0.17)	.418
Adjacent site to the cantilever extension	0.94 ± 0.46	0.98 ± 0.46	0.04 ± 0.35 (−0.08 0.16)	.497
Distant site to the cantilever extension	0.89 ± 0.48	0.95 ± 0.38	0.06 ± 0.43 (−0.09 0.20)	.459
p-value	0.549	0.655	0.826	
	T0	**T1**	**Difference T1–T0**	
N implants	3	3	3	
Overall mean	1.04 ± 0.22	0.85 ± 0.35	−0.19 ± 0.45	
Adjacent site to the cantilever extension	1.06 ± 0.27	1.04 ± 0.38	−0.02 ± 0.63	
Distant site to the cantilever extension	0.96 ± 0.11	0.64 ± 0.19	−0.33 ± 0.08	

Thirty-one reconstructions were SUCs while 3 were FDPCs. The cantilever extensions were located 26× on the mesial and 11× on the distal aspect of the reconstructions, respectively. Most of the reconstructions were located in the upper jaw ($n = 27$; 79.4%). With respect to the material, 8 reconstructions (23.5%) were fabricated with monolitic zirconia while the majority were fabricated with multi-layered zirconia ($n = 26$; 76.5%).

Twenty-six (70.3%) reconstructions had as opposite antagonist natural teeth, while in 11 (29.7%) of cases implant-supported single unit crowns were present. No removable dental prostheses were present in the dentitions opposing the FDPCs.

3.4 | Biological, technical, and mechanical complications

All installed implants were present in the oral cavity at the follow-up examination yielding an implant survival rate of 100%. With respect to peri-implant diseases, none of the implants was diagnosed with peri-implantitis, while peri-implant mucositis was detected in 22 cases. All other implants (40.5%) were diagnosed with peri-implant health. The only recorded technical complications were screw-loosening (2×) and chipping (2×) which occurred once in 4 patients.

3.5 | Radiographic outcomes

Overall, no statistically significant differences in mBL from 0.92 mm ± 0.42 at baseline to 0.96 mm ± 0.38 at follow-up was observed neither in the SUCs group ($n = 31$) (95% CI: −0.07/0.17; $p = 0.418$) nor in the FDPCs ($n = 3$) (95% CI: −0.07/0.17; $p = .418$). The calculated mean mBL differences at implants adjacent to the cantilever extension were 0.04 mm ± 0.35 and −0.02 mm ± 0.63 respectively ($p > .05$). The evaluation of the mBL changes at implant sites distant from the cantilever extension yielded a change from 0.89 mm ± 0.48 at baseline to 0.95 mm ± 0.38 at follow-up (95% CI: −0.09/0.2; $p = .459$). The mean calculated length of the prosthesis was 15.6 mm ± 4.7 (range: 8.7–29.2), of the cantilever extension 6.3 mm ± 1.3 (range: 3.0–8.3), and of the height of the connector 6.8 mm ± 1.5 (range: 4.3–11.6). A summary of the radiographic measurements is reported in Table 2a,b.

3.6 | Clinical outcomes

Mean PPD changed from 2.99 mm ± 0.70 at baseline to 3.27 mm ± 0.71 at follow-up (95% CI: −0.11/0.68; $p = .250$). Mean PPD at implant sites adjacent to the cantilever extension changed from 3.04 mm ± 0.73 at baseline to 3.29 mm ± 0.83 at follow-up (95% CI: −0.18/0.68; $p = .123$), while at implant sites distant from the cantilever extension, mean PPD changed from 2.93 mm ± 0.77 at baseline to 3.25 mm ± 0.74 at follow-up (95% CI: −0.09/0.74; $p = .148$). A comparable trend was observed in the FDPCs group. Details of the peri-implant clinical measurements are reported in Tables 3a,b and 4.

4 | DISCUSSION

The present study evaluated the reliability of full zirconia implant-supported fixed dental prostheses with cantilever extensions (FDPCs) after at least 1 year of function. The obtained short-term results indicated that implants supporting SUCs and FDPs in posterior areas of both jaws yielded a 100% survival rate and were characterized by negligible marginal bone level changes and very few technical complications (i.e. screw-loosening [2×] and chipping [2×]) after a mean follow-up of 2.6 ± 1.5 years (Figures 2–4).

Although the use of cantilever extension has been historically associated with an increased risk for implant loss (Rangert et al., 1995) and implant fracture (Halg et al., 2008), our results corroborated several long-term clinical studies (Aglietta et al., 2012; Romeo et al., 2009; Schmid et al., 2021) reporting survival rates exceeding 95%, but also documenting implant fracture of narrow diameter implants (i.e., 3.3 mm in diameter) as a catastrophic event (Halg et al., 2008; Roccuzzo et al., 2022). Consequently, in the present study, the use of narrow-diameter implants was avoided, to eliminate the risk of such

TABLE 3 Clinical parameters at implants adjacent to and distant from the cantilever extension in the SUCs group (a) and FDPs (b). Mean ± SD. (95% CI) and results from paired *t*-test (a).

	T0	T1	Difference T1–T0	*p*-Value
N implants	34	34	34	
Overall mean	2.99 ± 0.70	3.27 ± 0.71	0.29 ± 1.13 (−0.11 0.68)	.250
Adjacent site to the cantilever extension	3.04 ± 0.73	3.29 ± 0.83	0.25 ± 1.24 (−0.18 0.68)	.123
Distant site to the cantilever extension	2.93 ± 0.77	3.25 ± 0.74	0.32 ± 1.19 (−0.09 0.74)	.148
p-Value	0.199	0.707	0.645	
	T0	**T1**	**Difference T1–T0**	
N implants	3	3	3	
Overall mean	2.92 ± 0.34	3.33 ± 0.54	0.42 ± 0.66	
Adjacent site to the cantilever extension	2.92 ± 0.38	3.25 ± 0.66	0.33 ± 1.01	
Distant site to the cantilever extension	2.92 ± 0.38	3.42 ± 0.52	0.50 ± 0.25	

TABLE 4 Bleeding on probing (BoP) scores at implants adjacent to and distant from the cantilever extension in the SUCs group (a) and FDPs (b). Mean ± SD. (95% CI) and results from paired *t*-test (a).

	T0	T1	Difference T1–T0	*p*-Value
N implants	34	34	34	
Overall mean	19.1 ± 18.5	18.4 ± 15.5	−0.7 ± 26.5 (−9.9 8.5)	.872
Adjacent site to cantilever	16.2 ± 26.7	25.0 ± 28.2	8.8 ± 39.8 (−5.1 22.7)	.205
Distant site to cantilever	22.1 ± 28.0	11.8 ± 21.5	−10.3 ± 36.5 (−23.0 2.4)	.109
p-value	0.402	0.059	0.051	
	T0	**T1**	**Difference T1–T0**	
N implants	3	3	3	
Overall mean	8.3 ± 12.9	8.3 ± 12.9	0.0 ± 15.8	
Adjacent implant to cantilever	8.3 ± 14.4	16.7 ± 14.4	8.3 ± 14.4	
Distant implant to cantilever	8.3 ± 14.4	0.00 ± 0.00	−8.3 ± 14.4	

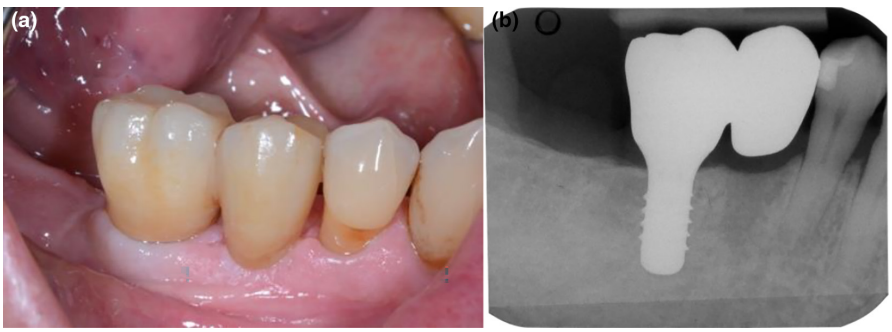

FIGURE 2 Clinical (a) and radiographic (b) scenarios of a 4.8 mm WN tissue level implant placed in region 46. A single-unit crown (SUC) with a mesial cantilever extension was delivered to replace teeth 46 and 45.

complication. With respect to the implant length, it should be emphasized that all implants included in the present investigation were at least 8 mm long. The clinical choice of avoiding short implants to support a cantilever extension was recently suggested by Thoma et al., 2021 who reported a 5-year implant survival rate of 84.2% for 6-mm implants with a cantilever extension in posterior areas (Thoma et al., 2021).

When focusing on the peri-implant marginal bone level changes, our results are in accordance with previous preclinical (Lima et al., 2019) and clinical investigations (Kim et al., 2014; Wennstrom et al., 2004) which failed to document detrimental effects of cantilever extensions on peri-implant marginal bone level changes, irrespective of the location (i.e., adjacent or distant to the extension). Very recently, differences in radiographic bone density based on implant location (i.e., maxilla vs. mandible) were documented after 5 years of loading suggesting a higher susceptibility to overload of maxillary implants (Gil et al., 2022). These findings could not be confirmed in the present investigation, probably due to the shorter follow-up and the different implant lengths.

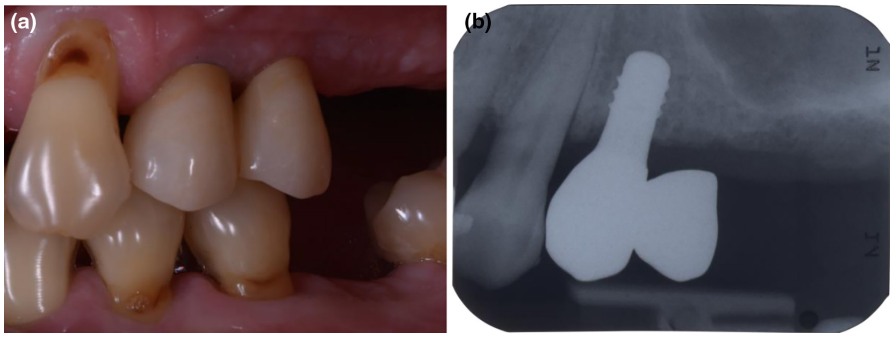

FIGURE 3 Clinical (a) and radiographic (b) scenarios of a 4.8 mm RN tissue level implant placed in region 24. A single-unit crown (SUC) with a distal cantilever extension was delivered to replaced teeth 24 and 25.

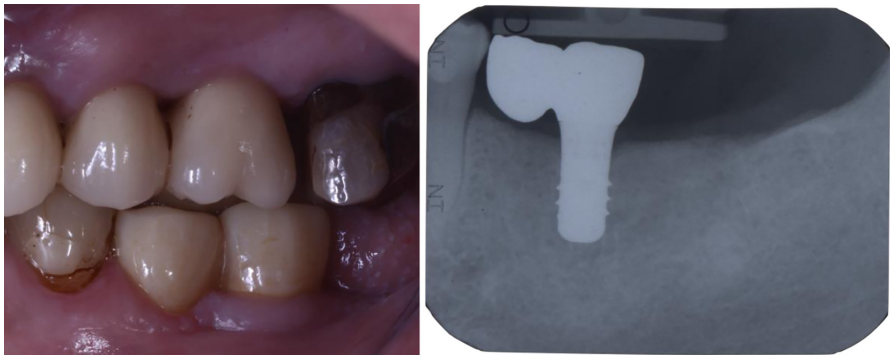

FIGURE 4 Clinical and radiographic appearance of a RN 4.8 tissue level (TL) implant placed in region 36. A single-unit crown (SUC) with a mesial cantilever extension was performed to replace teeth 36 and 35.

TABLE 5 FMPS and FMBS (%) of the 30 patients who reached the latest follow-up. Mean ± SD. (95% CI) and results from paired *t*-test.

	T0	T1	Difference T1–T0	*p*-Value
N patients	30	30		
FMPS (%)	14.2 ± 5.3	15.1 ± 6.8	0.8 ± 5.7 (−1.3 2.9)	.413
FMBS (%)	9.5 ± 5.6	10.4 ± 6.7	0.8 ± 5.7 (−1.2 3.0)	.415

History of periodontal disease has been widely documented as a major risk factor for the development of peri-implant diseases (Carra et al., 2022; Kordbacheh Changi et al., 2019; Roccuzzo et al., 2022). All partially edentulous patients included in this cohort had been previously treated for periodontal disease and subsequently enrolled in regular SPC including early diagnosis and treatment of peri-implant diseases, as documented by the low FMPS and FMBS at both time points (Table 5). When focusing on the mean PPD and BoP scores at implant sites, the outcomes failed to reveal statistically significant changes between T0 and T1, thus providing direct evidence of healthy peri-implant conditions. Consequently, in order to minimize the number of installed implants in periodontitis-susceptible patients and reduce the risk of later onset of peri-implantitis (Roccuzzo, Imber, et al., 2023), the use of FDPCs should be considered. However, since peri-implant diseases are mainly detectable after many years of loading, the obtained short-term results should be interpreted with caution.

An increased risk for mechanical/technical complications of FDPCs has been documented. Schmid and co-workers reported a 34.6% loss of retention (Schmid et al., 2020) while Thoma and co-workers accounted for a technical complication rate of 64.2% (Thoma et al., 2021). One difference with the previously mentioned studies is that in the present investigation, only screw-retained restorations were used, yielding 2 events of screw loosening and 2 minor zirconia chippings. On this aspect, it should be pointed out that in both cases of screw-loosening, the prostheses were located in the maxillary premolar area with a distal cantilever extension. Therefore, although all FDPCs were delivered to patients not displaying signs of bruxism and oral parafunctions at baseline and a careful occlusal control to avoid any contact on the cantilever extension was performed, these complications may indicate that minimal premature contacts might have developed over time having a detrimental impact on the reconstruction. Hence, it is of paramount importance, especially in the long term to carefully check and eventually correct the static and dynamic relationships of SUCs and FDPs during SPC. Another important aspect that should be mentioned is that the use of this prosthetic protocol was able to reduce treatment time and costs as well as invasiveness of surgical procedures as demonstrated by the 8 external sinus floor elevations that could be avoided in 22 patients. The present study has some limitations including the relatively small sample size, the short-term follow-up (i.e., 2.6 ± 1.5 years), the lack of a control group as well as the assessment of patient's reported outcome measures (PROMs). However, it must be underlined that this is, to the best of the authors' knowledge, the first study that clinically tested the reliability of implant-supported zirconia FDPCs. Consequently, the obtained results are unique and will serve as a benchmark for future randomized clinical trials.

5 | CONCLUSIONS

Within the limitations of the present proof-of-principle study, the use of full-zirconia implant-supported FDPs with cantilever extension in posterior areas of the maxilla and mandible seems a valid short-term treatment option in terms of implant survival rate, marginal bone level changes and incidence of technical/mechanical complication rates.

AUTHOR CONTRIBUTIONS

A.R. and G.E.S. conceived the idea and led the writing, A.R., M.M., A.St, and J.C.I collected, analyzed, interpreted the data, and contributed to the writing, and A.S. critically revised the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no potential conflict of interest with respect to this study. A.R. and M.M. were the recipients of a 3-year scholarship from the Clinical Research Foundation (CFR) for the Promotion of Oral Health, Brienz, Switzerland, and A.R. was the recipient of a 1-year scholarship from the International Team of Implantology (ITI). J.C.I. was the recipient of a 1-year scholarship from the Osteology Foundation.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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