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Survival and complication rates of tooth- and implant-supported restorations after an observation period up to 36 years

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Abstract

Background: Tooth- and implant-supported fixed dental prostheses are well-documented and aesthetic treatment alternatives, and after a comprehensive periodontal treatment, a protocol with a good long-term prognosis if the maintenance program is strictly followed.

Aim: To reexamine a pre-existing patient cohort in order to obtain estimated long-term survival and complication outcomes of fixed dental prostheses.

Materials and Methods: For this study, patients treated with fixed dental prostheses between 1978 and 2002 were reexamined between 2019 and 2020. The restorations were divided in single crowns and fixed dental prostheses supported by teeth (TSC, FPTDP) and implants (ISC, FPIDP). Survival and complication rates were obtained. Kaplan–Meier functions were used to model complication probabilities, and average hazard ratios of different strata were compared using weighted Cox regression.

Results: The mean observation time of 40 patients and 223 reconstructions was 20.3 (±9.7, 1.2–36.2) years. The estimated survival rates were 84% (CI: 77%–92%) for TSC, 63% (CI: 51%–79%) for FPTDP, 87% (CI: 71%–100%) for ISC, and 64% (CI: 34%–100%) for FPIDP after 25 years. Biological complications included carious lesions (10.6%), periodontitis (7.9%), and peri-implantitis (6.8%). Technical complications included chipping (20.2%) and loss of retention (10.8%).

Conclusion: Biological complications lead to abutment loss in more than two-thirds of cases, regardless of the type of abutment (tooth or implant). Technical complications are less associated with abutment loss than biological complications.

KEYWORDS
biological complications, dental implants, fixed dental prostheses, long-term survival rates, technical complications

Frank M. Bischof and Ayse A. Mathey contributed equally to the manuscript.

1 | INTRODUCTION

Patients with the need for oral rehabilitations often demand a fixed restoration. With the introduction of implants to dental medicine in the late 1980s, treatment planning in fixed prosthodontics changed considerably. As a result of improved surface characteristics, newer generations of implants have become more reliable compared with pioneer types of implants (Buser et al., 2012). In a well-maintained patient cohort, very high survival rates of implants at 10 years (98.8%) could be achieved (Buser et al., 2012). In addition, the estimated survival rate for metal-ceramic implant-supported fixed dental prostheses after 5 years was 98.3% (CI: 96.8%–99.1%) for single crowns (ISC) and 98.7% (CI: 96.8%–99.5%) for fixed dental prostheses (FPIDP) (Pjetursson et al., 2018; Sailer et al., 2018). For FPIDP, a survival rate of 95.5% was reported at 10.75 years, with a prosthetic success rate of 70.8% (Wittneben et al., 2014). The most common hardware complications were ceramic chipping (20.31%), occlusal screw loosening (2.57%), and loss of retention (2.06%). Implants in strategic positions may be used also to avoid abutment teeth with a doubtful prognosis for FDPs (Bragger et al., 2011). A comparison of the long-term survival of tooth-supported reconstructions (TSC and FPTDP) in the pre- and post-implant era in a private clinic setting indicated improved survival rates after the introduction of dental implants (Walton, 2015).

TSCs offer a possibility to preserve teeth with a considerable loss of substance caused by caries, abrasion, erosion, or trauma. In addition, multiple FPTDPs can be an alternative to implant placement, especially when a surgical procedure is contraindicated, that is, due to general medical health conditions, pharmaceutical contraindications or insufficient bone volume that would otherwise involve extensive augmentation procedures. SCs and FPTDPs have several advantages compared with removable partial dentures: a favorable aesthetic outcome (Limones et al., 2020; Wittneben et al., 2018), improved proprioception and masticatory function, higher maximum bite force as well as a better food comminution (Goncalves et al., 2013; Liedberg et al., 2004). Implant-supported restorations show equivalent survival rates to FPTDPs (Pjetursson et al., 2015; Pjetursson, Sailer, et al., 2007; Wittneben et al., 2014). With the implementation of digital workflows in implant dentistry, treatment and manufacturing of implant-supported restorations were further simplified and appear to be more cost efficient (Joda & Bragger, 2015). Although technical complications such as abutment and screw loosening are frequently observed with ISC, this treatment modality offers the advantage of a prosthetic design with shorter units and, consequently, a lower overall treatment risk (Albrektsson et al., 2012). Biological and aesthetic complications can be limited by patient selection, comprehensive care, and a regular maintenance program (Monje et al., 2016; Roccuzzo et al., 2018).

Metal-ceramic restorations in particular demonstrate excellent mechanical properties compared with first generation all-ceramic FPTDPs (Lopez-Suarez et al., 2018). The most recent generation of all-ceramic materials, however, shows similar results compared with metal-ceramic materials regarding biological and technical complications over 6.65 years (±1.14) (Forrer et al., 2020). The potentially increased loss of tooth structure due to preparation (Edelhoff & Sorensen, 2002) and the need for an optimal oral hygiene have to be taken into consideration for the treatment planning. Complications of abutment teeth for fixed restorations are categorized as biological (e.g., secondary caries, loss of vitality, periodontal disease, and abutment tooth fracture) or technical (e.g., ceramic chipping or fracture, framework fracture, and loss of retention).

The latest systematic reviews compared metal-ceramic TSCs or FPTDPs and all-ceramic restorations. Survival and complication rates were estimated for 5 years. Loss of vitality, abutment tooth fracture, and caries appeared to be the most frequent biological complications for TSCs (Sailer et al., 2015), whereas for FPTDPs, loss of vitality, caries, and periodontal disease occurred most frequently (Pjetursson et al., 2015). Ceramic chipping and ceramic fracture were the most common technical complications (Pjetursson et al., 2015; Sailer et al., 2015). The estimated survival rate for TSC was 94.7% (CI: 94.1%–96.9%) after 5 years (Sailer et al., 2015) and 88.7% after 10 years (Schmidlin et al., 2010). For multiple-unit FPTDPs, the estimated survival rate was 94.4% (CI: 91.2%–96.5%) after 5 years (Pjetursson et al., 2015), 74.4%–90.4% after 10 years (Alsterstal-Englund et al., 2021; Bart et al., 2012; Bragger et al., 2011), and 80.5%–85% after 15 years (Bart et al., 2012; Walton, 2002, 2003).

For even longer observation periods, however, only limited information is available and outcomes with metal-ceramic TSC and FPTDP are still scarce (Walton, 2013). Treatment planning must take into account the expected longevity and complication rates of the various treatment options. Therefore, the aim of this study was to reexamine a patient cohort that had participated at a first clinical examination in 2005 (Bragger et al., 2011).

In addition, comparisons should be made between different subgroups: cemented versus screw-retained ISC and FPIDP, all-ceramic versus metal-ceramic reconstructions, abutment teeth with or without endodontic pretreatment or with post/core, and reconstructions with or without cantilever extension.

1.1 | Hypotheses

The following null hypotheses were stated:

- No statistically significant differences were expected when comparing different FDP regarding the survival and complication rates;
- No statistically significant differences were expected when comparing screw-retained reconstructions and cemented implant-supported reconstructions;

- No statistically significant differences were expected when comparing tooth-supported reconstructions with and without endodontic pretreated abutments;
- No statistically significant differences were expected when comparing reconstructions with and without cantilever extensions.

2 | MATERIALS AND METHODS

2.1 | Patient cohort

In order to obtain survival and complication rates of fixed dental prostheses over extended observation periods, a retrospective clinical reexamination was planned. Participants of a previous clinical and radiographic examination in 2005 were to be contacted and invited for a second examination in 2019/2020. These patients were originally recruited based on the presence of two sets of a complete periodontal and radiographic examinations obtained before and after comprehensive periodontal and, if indicated, prosthodontic treatment. They had been examined in 2005 after mean observation periods ranging from 0.8 to 26.4 years (Bragger et al., 2011, Schmidlin et al., 2010). The detailed characterization of the patient cohort was described earlier (Matuliene et al., 2008). After completion of the comprehensive dental treatment, the patients were enrolled in a supportive periodontal care (SPC) program, either at the University Clinic of Bern or at a private practice. The recall interval was determined based on the periodontal findings and individual risk factors according to Lang and Tonetti (2003).

Of the 199 patients examined in 2005, 84 had received 175 FDPs, and 64 had received 168 SCs (Bragger et al., 2011; Schmidlin et al., 2010): 121 were FPTDP, 24 FPIDP, 30 FPTIDP as well as 129 TSC and 39 ISC. Of the 199 participants in the first study, 84 patient charts could be retrieved from the clinic's archive and these patients were invited for a second examination. The patients' charts were complete including the sets of periodontal and radiographic documents obtained at the beginning and the end of the active treatment as well as those from the first reexamination in 2005.

After giving informed written consent, 40 patients could be clinically and radiographically reexamined between August 2019 and September 2020. The remaining 44 patients were either too frail to be reexamined, had moved away, were no longer interested in participating, or had died. The local ethics committee approved the study protocol (Kantonale Ethikkomission Bern 2018-01877), and it was conducted according to the revised principles of the Helsinki Declaration.

2.2 | Clinical examination

First, the general state of health was assessed by a questionnaire. The clinical examination consisted of the recording of existing teeth, implants, and reconstructions as well as the applied prosthetic materials (porcelain-fused to metal or all-ceramic) and the type of reconstruction (SC and/or multiple-unit FDP). For multiple-unit FDPs, the number of units including abutments and the presence of cantilever extensions were recorded.

A complete periodontal status including bleeding on probing (BoP) was carried out. Furthermore, all abutment teeth were tested on vitality (CO_2 test positive or negative). The marginal fit of the reconstructions was probed and categorized as not detectable or detectable without or with a secondary caries lesion. Periapical radiographs were taken to identify endodontic treatments, posts, possible periapical lesions, and/or vertical bone defects of the abutment teeth or implants. Additionally, the type of retention (cemented or screw-retained) was recorded for the implant-supported reconstructions.

2.3 | Evaluation of complications

All patient files were screened for information about the delivery date and the pretreatment of the abutment teeth (none, endodontic treatment, post, post and core). Moreover, all complications which occurred between the delivery and the examination date were categorized as technical and/or biological following a subcategorization. Technical complications included the presence of chipping, loss of retention (loosening of the occlusal screw for ISC and FPIDP, decementation for TSC and FPTDP), ceramic and/or framework fracture as well as fracture of the implant or fracture of the abutment screw. Chipping was categorized on a scale of 0 to 5 (no chipping, hardly visible, visible without functional relevance, esthetically relevant in anterior segment, functionally relevant in posterior segment, massive chipping). All technical complications were evaluated at the level of the restoration. Biological complications included caries at abutment teeth, periodontitis (pocket probing depth ≥6 mm and BoP+), peri-implantitis (clinical signs of inflammation, bleeding on probing and/or suppuration, increased probing depths and/or recession of the mucosal margin in addition to radio-graphic bone loss compared with previous examinations) (Berglundh et al., 2018), and horizontal or vertical fracture of the abutment tooth. All biological complications were evaluated at the level of the tooth or implant substructure. Complications leading to the extraction of the abutment tooth or to the loss/explantation of the implant as well as to the loss of the original SC or FDP were defined as failure.

2.4 | Categories of reconstructions

Reconstructions were classified into five categories: SCs with either tooth or implant abutments (TSC, ISC), and FPDs with either tooth or implant or combined tooth and implant abutments (FPTDP, FPIDP, FPTIDP). Furthermore, the multiple-unit FPDs were classified according to the presence or absence of cantilevers, and the number of units (three units and four or more units, respectively).

2.5 | Statistical analysis

Descriptive data were summarized for each of the five categories of reconstructions using median (25%–75%-quantiles) and frequencies (%) depending on data distribution.

Kaplan–Meier functions were used to model survival and complication probabilities. Probability estimates as well as 95%-CI at 5, 10, 15, 20, and 25 years were calculated by interpolation of Kaplan–Meier functions. At each time point, the number of events, the number of censoring, and the number at risk were summarized.

The data were assessed in two ways: First, all abutments were considered, and second, the reconstructions were considered as a unit. For the abutments, two main groups (abutment tooth and abutment implant) were then evaluated along with demographic covariates (age and gender) and with covariates of the specific subgroups of abutment teeth and implants. The different subgroups (metal-ceramic vs. all-ceramic; cemented vs. screw-retained for ISC and FPIDP; vital abutment vs. endodontic pretreatment vs. post/core for TSC and FPTDP; cantilever extension present vs. cantilever extension not present) were coded numerically. Second, the five groups of reconstructions (TSC, FPTDP, ISC, FPIDP, and FPTIDP) were assessed along with demographic covariates and again with covariates on subgroup-level as described above. Average hazard ratios of categories and levels were compared using weighted Cox regression (Schemper et al., 2009). Note that weighted Cox regression allows the assessment of survival behavior even when Kaplan–Meier curves cross, that is, when the proportional hazards assumption is violated. Also, as some patients had more than one reconstruction, weighted cox regression was applied using patient clusters to eliminate the impact of repeated measurements.

All analyses in this report were performed with the statistics software R (R foundation for statistical computing, Vienna, Austria, version 4.0.2).

The data were reported in compliance with the STROBE checklist.

3 | RESULTS

3.1 | Patient characteristics, observation time, and number of included reconstructions

Out of the 199 patients examined in 2005, 84 had received FDPs and 64 had received SCs (Bragger et al., 2011; Schmidlin et al., 2010). Forty patients were clinically reexamined between August 2019 and September 2020 (11 patients received SCs only, 12 patients received FDPs only, and 17 patients received both, SCs and FDPs). The remaining 44 patients were either too frail to be reexamined, had moved away, were not interested in participating, or had died. Of the 40 patients reexamined, 21 were female.

The mean age of the patients at the time of the most recent examination was 64 years (range 51–78 years). The mean observation time of all restorations was 20.3 (range 1.2–36.2) years. The mean observation time of FPTDPs was 22.8 years (range 5–36.2), of FPIDPs 12.2 years (range 1.2–29.4), of TSCs 21.6 years (range 3–35.6), and of ISC 15 years (range 1.5–31.6).

Of the 343 original reconstructions (168 SCs according to Schmidlin et al., 2010 and 175 FDPs according to Bragger et al., 2011), 223 reconstructions were reexamined. This included 107 TSC, 36 ISC, 53 FPTDP, 19 FPIDP, and 8 FPTIDP (Table 1). Ten tooth-supported reconstructions and 19 implant-supported reconstructions had a cantilever extension. Forty-three-unit FDPs and 40 ≥ four-unit FDPs were examined.

3.2 | All reconstructions (TSC, FPTDP, ISC, FPIDP, FPTIDP)

The global test for comparing the hazard ratios of the five reconstruction types showed no difference, the *p*-value was not statistically significant ($p = .053$) (Figure 1a,b). Furthermore, weighted Cox regression showed no difference in global average hazard ratios for combined technical complications between the five types over the entire observation period with $p = .16$ (Figure 2a,b).

3.3 | Tooth-supported reconstructions (TSC, FPTDP)

3.3.1 | Survival/failure

Over the first 10 years, FPTDP showed a survival rate of 93% (CI: 86%–100%), which continuously decreased (at 15 years: 86% CI: 77%–96%, at 20 years: 75% CI: 64%–88%, at 25 years: 63% CI: 51%–79%, at 30 and 35 years: 56% CI: 43%–74%). In contrast to this finding, the survival rate of TSC remained more stable during the observation period (at 10 years: 91% CI: 86%–97%, at 15 years: 91% CI: 86%–97%, at 20 years: 84% CI: 77%–92%, at 25 years: 84% CI: 77%–92%, at 30 years: 82% CI: 74%–91% and at 35 years: 69% CI: 47%–91%) (Figure 1b, Table 2).

Covariate analysis showed a higher survival for glass–ceramic TSC compared with metal-ceramic TSC after 18 years ($p < .001$) (Figure 3).

3.3.2 | Biological complications

Over the entire observation period, 74 (21.6%) of all 342 abutments (teeth and implants) showed a biological complication, of which 64 (25.2%) involved tooth abutments. Over the observation period, 27 carious lesions, 20 probing depth ≥5 mm, 16 loss of vitality, and 14 abutment fractures were diagnosed (Table 3).

The covariate analysis showed a statistically significant effect of the endodontic pretreatment. Endodontically treated abutment teeth with or without post or post and core showed higher probability of having a complication compared with vital tooth abutments ($p = .03$ for TSC and $p < .001$ for FPTDP, respectively) (Figure 4).

TABLE 1 Distribution of reconstructions and number of reconstructions examined per patient.

Patient No.	FPTDP	FPIDP	FPTIDP	TSC	ISC	Total
1	2	–	–	–	–	2
2	2	1	–	–	–	3
3	1	–	1	–	1	3
4	4	–	1	1	5	11
5	2	–	–	–	–	2
6	–	–	–	2	–	2
7	2	–	–	4	1	7
8	–	–	1	–	1	2
9	2	–	–	1	2	5
10	–	–	–	1	–	1
11	–	–	–	1	–	1
12	5	2	–	3	1	11
13	1	–	–	–	1	2
14	1	–	–	–	–	1
15	–	1	–	6	–	7
16	2	1	–	4	–	7
17	1	–	–	28	–	29
18	–	–	–	2	–	2
19	1	–	–	–	–	1
20	–	–	–	9	1	10
21	–	–	–	–	1	1
22	1	1	1	–	–	3
23	–	–	–	2	–	2
24	3	4	1	1	1	10
25	2	1	1	2	2	8
26	–	–	–	1	2	3
27	–	–	–	23	5	28
28	–	–	–	2	–	2
29	3	–	–	–	–	3
30	–	1	–	–	–	1
31	1	–	–	1	3	5
32	–	5	–	–	4	9
33	2	–	–	7	2	11
34	–	–	–	1	2	3
35	5	1	–	4	–	10
36	1	–	–	–	–	1
37	1	1	–	1	–	3
38	4	–	–	–	–	4
39	2	–	–	–	1	3
40	2	–	2	–	–	4
	53	19	8	107	36	223
	23.8%	8.5%	3.6%	48.0%	16.1%	

Abbreviations: FPIDP, fixed partial implant-supported dental prostheses; FPTDP, fixed partial tooth-supported dental prostheses; FPTIDP, fixed partial tooth-implant-supported dental prostheses; ISC, implant-supported single crown; TSC, tooth-supported single crown.

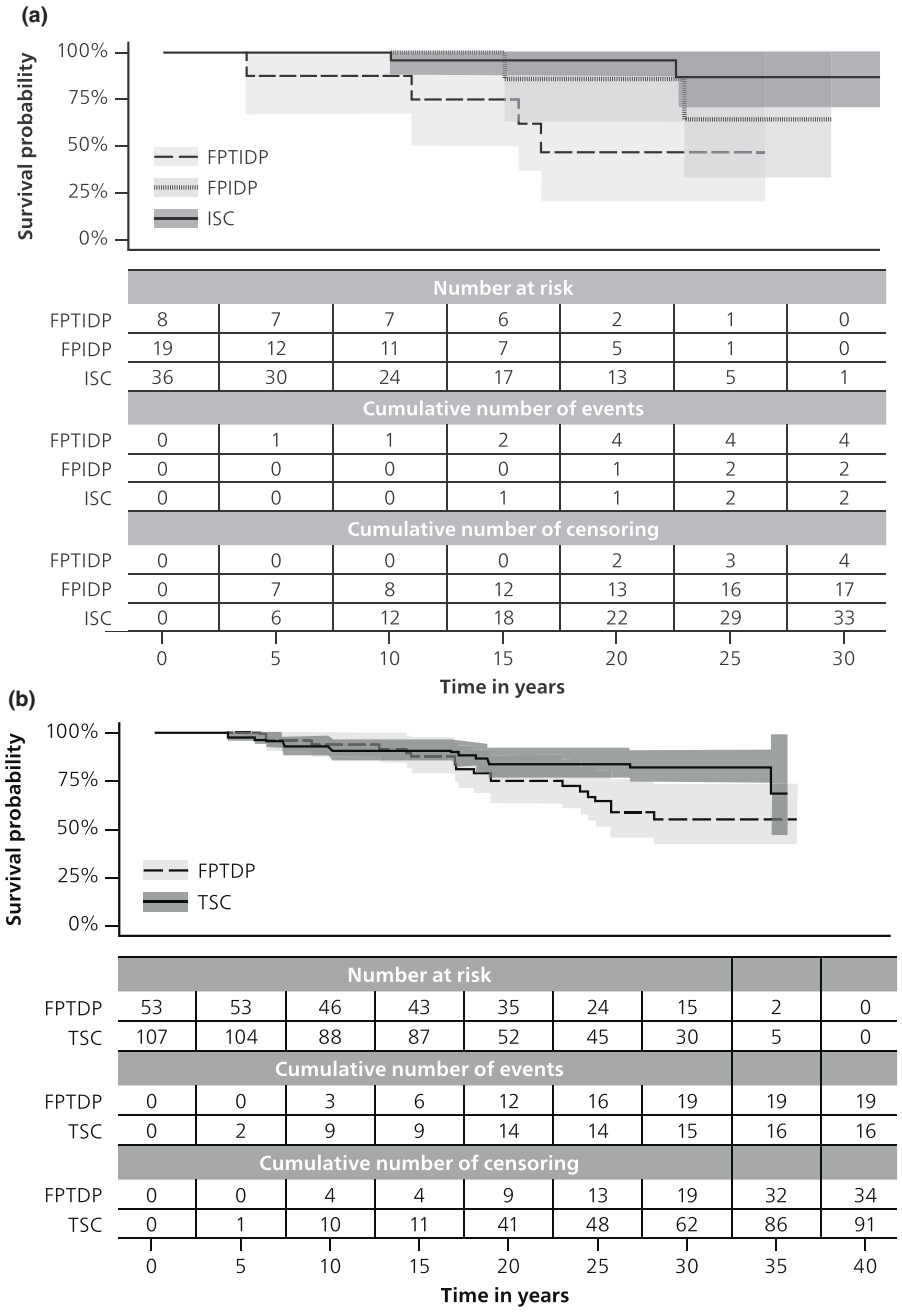

FIGURE 1 (a) Kaplan–Meier survival probabilities of different implant-supported restorations: $p = .053$, compared by weighted Cox regression. (b) Kaplan–Meier survival probabilities of different tooth-supported restorations: $p = .053$, compared by weighted Cox regression.

3.3.3 | Technical complications

Regarding the tooth-supported restorations, technical complications occurred in 34.0% of the FPTDP and 36.4% of the TSC. The following technical complications were observed: 35 chippings (ten for FPTDP and 25 for TSC), and 17 loss of retention (eight FPTDP and nine for TSC). The detailed numbers for the chipping subcategorization were found as follows: twelve TSC and five FPTDP in Grade 1, nine TSC and four FPTDP in Grade 2, one FPTDP in Grade 3, three TSC in Grade 4, and one TSC in Grade 5. Regarding the material used for the reconstructions, eleven TSC made of lithium disilicate were subjected to chipping (eight Grade 1 and three Grade 2). Furthermore, seven ceramic fractures resulted in the loss of the reconstruction (two for FPTDP and five for TSC). Framework fracture occurred only once in the TSC group (Table 4, Figure 2a).

3.4 | Implant-supported reconstructions (ISC, FPIDP)

3.4.1 | Survival/failure

Over the first 10 years, FPIDP showed a survival rate of 100%, which continuously decreased (at 15 years: 93% CI: 82%–100%,

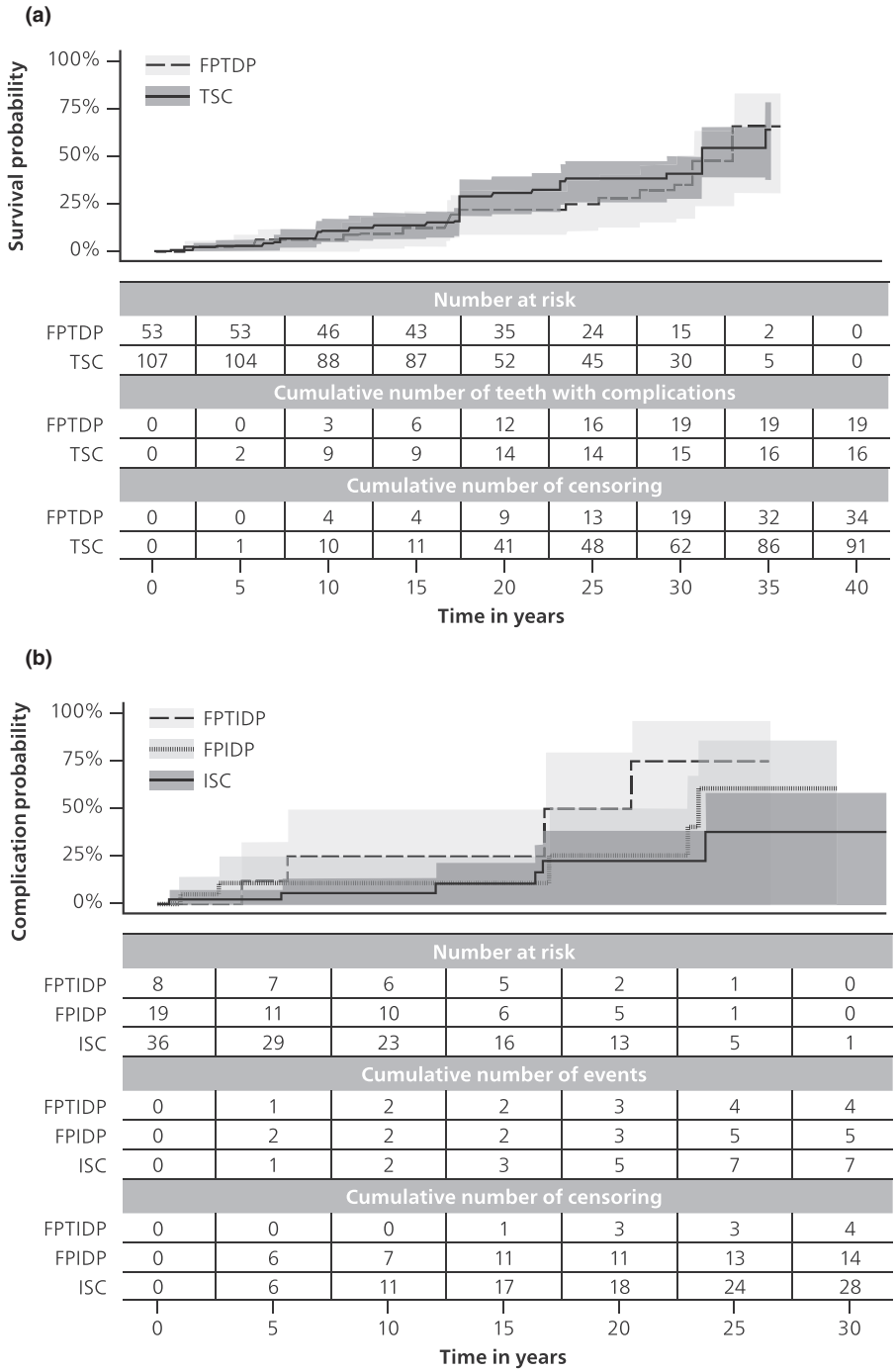

FIGURE 2 (a) Cumulative probability of different tooth-supported restorations for having any complication: $p = .16$, compared by weighted Cox regression. (b) Cumulative probability of different implant-supported restorations for having any complication: $p = .16$, compared by weighted Cox regression.

at 20 years: 86% CI: 63%–100%, at 25 years: 64% CI: 34%–100%). In contrast to this finding, the survival rate of ISC remained more stable at a high level during the observation period (at 10 years: 100%, at 15 years: 96% CI: 88%–100%, at 20 years: 96% CI: 88%–100%, at 25 years: 87% CI: 71–100, at 30 years: 87% CI: 71%–100%) (Figure 1a, Table 2).

The survival rates were statistically significantly higher for screw-retained ISC, FPIDP and FPTIDP combined compared with cemented reconstructions ($p < .001$) (Figure 5). The presence of cantilever extensions had no significant impact on the survival ($p = .19$).

3.4.2 | Biological complications

Over the entire observation period, 10 implants (11.4% overall) showed biological complications and six peri-implantitis cases were recorded (Table 3).

TABLE 2 Kaplan–Meier mean (95%-CI) survival estimates using interpolation.

Years	FPTIDP	FPIDP	ISC	FPTDP	TSC	Overall
5	81% (59–100%)	100% (100–100%)	100% (100–100%)	100% (100%–100%)	98% (96%–100%)	99% (97%–100%)
10	81% (59–100%)	100% (100–100%)	100% (100–100%)	93% (86%–100%)	91% (86%–97%)	93% (90%–97%)
15	69% (43–100%)	93% (82–100%)	96% (88–100%)	86% (77%–96%)	91% (86%–97%)	90% (86%–95%)
20	47% (21–100%)	86% (63–100%)	96% (88–100%)	75% (64%–88%)	84% (77%–92%)	82% (76%–88%)
25	47% (21–100%)	64% (34–100%)	87% (71–100%)	63% (51%–79%)	84% (77%–92%)	76% (69%–83%)
30	–	–	87% (71–100%)	56% (43%–74%)	82% (74%–91%)	72% (64%–80%)
35	–	–	–	56% (43%–74%)	69% (47%–91%)	63% (47%–80%)

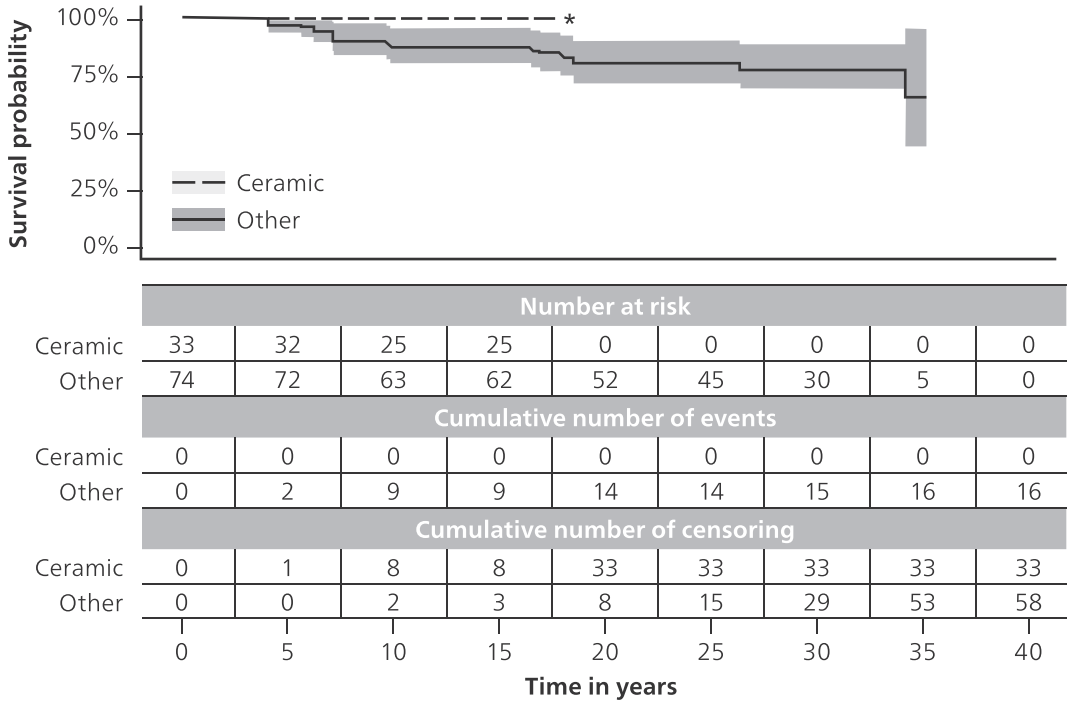

FIGURE 3 Kaplan–Meier survival probabilities of different materials: *$p < .001$, compared by weighted Cox regression.

Complication	Teeth	Implants	All abutments
No biological complications	190 (74.8%)	78 (88.6%)	268 (78.4%)
Any biological complications	64 (25.2%)	10 (11.4%)	74 (21.6%)
Caries	27 (10.6%)	–	27 (7.9%)
Periodontitis/peri-implantitis	20 (7.9%)	6 (6.8%)	26 (7.6%)
Abutment fracture	14 (5.5%)	4 (4.5%)	18 (5.3%)
Loss of vitality	16 (6.3%)	–	16 (4.7%)
Total	254 (100%)	88 (100%)	342 (100%)

TABLE 3 Number of biological complications by abutment type.

For implant abutments (ISC and FPIDP), the type of retention had a significant impact on biological complications. Cemented restorations showed a statistically significant higher probability of complications compared with screw-retained restorations ($p < .001$) (Figure 6).

Gender, age, material, and the presence of a cantilever did not influence biological complications.

3.4.3 | Technical complications

Over the entire observation period, five (26.3%) of the FPIDPs and seven (19.4%) of the ISCs showed complications. Complications included chipping (15.8% for FPIDPs and 13.9% for ISCs) and loss of retention (15.8% for FPIDPs and 5.6% for ISCs). The detailed numbers for loss of retention were two loosenings of the occlusal screw

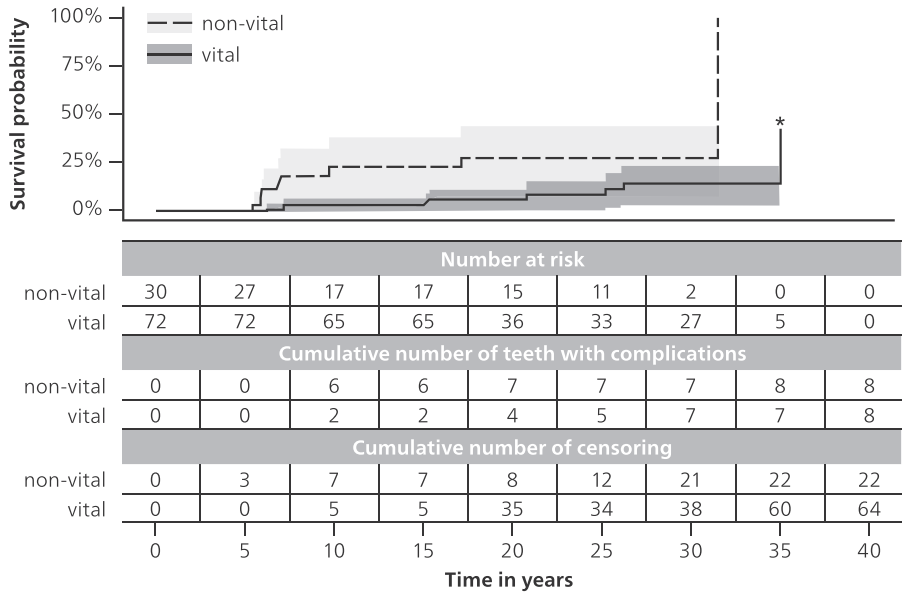

FIGURE 4 Cumulative probability of having a biological complication by endodontic pretreatment of tooth abutments: *$p = .03$ for TSC and $p < .001$ for FPTDP, compared by weighted Cox regression.

TABLE 4 Summary of frequencies of all technical complications by reconstruction.

Complication	FPTIDP	FPIDP	ISC
Total reconstructions	8 (100%)	19 (100%)	36 (100%)
No technical complication	4 (50.0%)	14 (73.7%)	29 (80.6%)
One complication	4 (50.0%)	4 (21.0%)	7 (19.4%)
Two or more complications	0 (0.0%)	1 (5.3%)	0 (0.0%)
Chipping	2 (25.0%)	3 (15.8%)	5 (13.9%)
Framework fracture	0 (0%)	0 (0%)	0 (0%)
Ceramic fracture	0 (0%)	0 (0%)	0 (0%)
Loss of retention	2 (25.0%)	3 (15.8%)	2 (5.6%)
Complication	**FPTDP**	**TSC**	**All reconstr.**
Total reconstructions	53 (100%)	107 (100%)	223 (100%)
No technical complication	35 (66.0%)	68 (63.6%)	150 (67.3%)
One complication	17 (32.1%)	38 (35.5%)	70 (31.4%)
Two or more complications	1 (1.9%)	1 (0.9%)	3 (1.3%)
Chipping	10 (18.9%)	25 (23.4%)	45 (20.2%)
Framework fracture	0 (0%)	1 (0.9%)	1 (0.5%)
Ceramic fracture	2 (3.8%)	5 (4.7%)	7 (3.1%)
Loss of retention	8 (15.1%)	9 (8.4%)	24 (10.8%)

(one ISC and one FPIDP with cantilever extension) four decementations (two FPIDP with cantilever extension, one FPIDP and one FPTIDP). The detailed numbers for the chipping subcategorization were found as follows: two ISC for Grade 2, three ISC and two FPIDP and one FPTIDP for Grade 4, one FPIDP and one FPTIDP for Grade 5. In the implant group, no fractures of framework or of the ceramic occurred (Table 4, Figure 2b).

In general, ceramic restorations tend to have more technical complications than metal-ceramic restorations (15/33 = 45.4% for ceramic vs. 11/74 = 14.8% for metal-ceramic after 18 years) ($p < .001$). In comparison with biological complications, technical complications had a smaller impact on the survival of the restoration.

3.5 | Tooth-implant supported reconstructions: Survival and complications

In contrast to the other types of reconstruction, FPTIDPs showed a lower survival rate from the beginning, which also continuously decreased (at 5 years: 81% CI: 59%–100%, at 10 years: 81% CI: 59%–100%, at 15 years: 69% CI: 43%–100%, at 20 years: 47% CI: 21%–100%, at 25 years: 47% CI: 21%–100%). The probability for having a technical complication was high for FPTIDP reconstructions (50%), although the *p*-value was not significant due to the small FPTIDP group size ($n = 8$). The only two fractures of the abutment screw and one implant fracture were observed in the FPTIDP group.

4 | DISCUSSION

4.1 | Patient cohort and observation time

The present study reports on the long-term survival of single crowns and fixed partial dentures supported by teeth or implants in a patient cohort that had been treated for periodontal disease and enrolled in

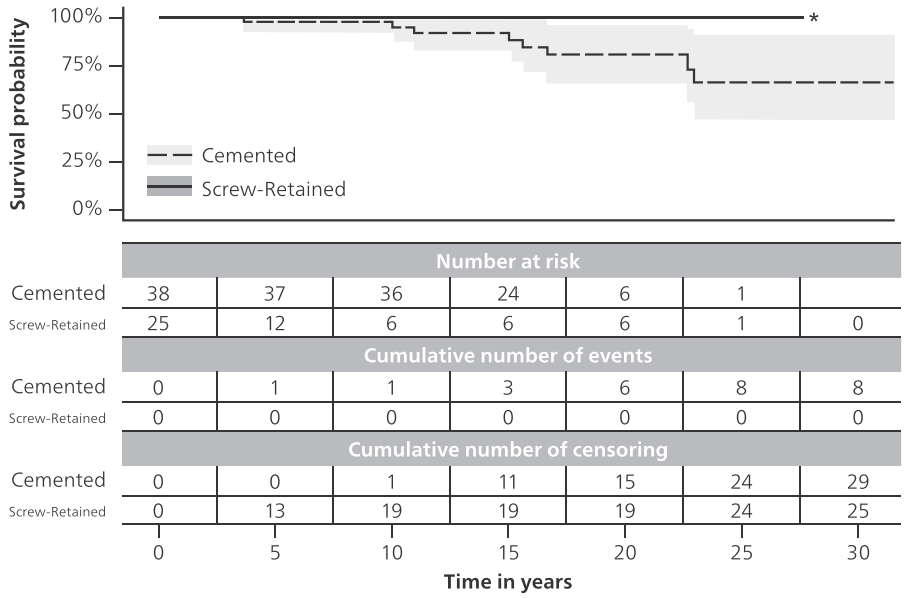

FIGURE 5 Kaplan–Meier survival probabilities for implant-supported restorations by type of retention: *$p < .001$, compared by weighted Cox regression.

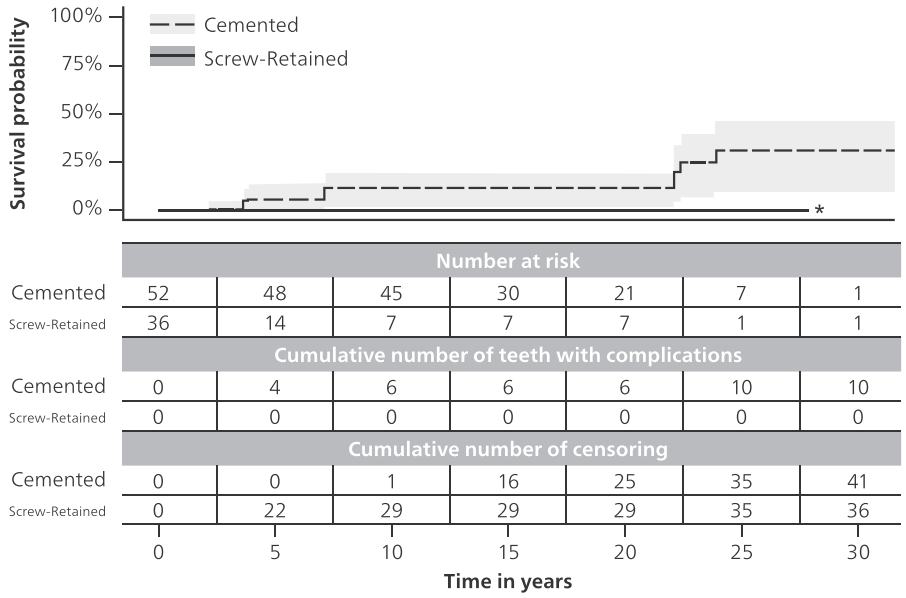

FIGURE 6 Cumulative probability of having a complication by type of retention: *$p < .001$, compared by weighted Cox regression.

a regular SPC program. Only few other studies are in a comparable range in terms of observation time. A high number of patients were lost to follow-up (56.3% for SCs and 65.5% for FPDs), and no information is available on the remaining patients of the original cohort (relocation, too frail for examination, deceased, etc.). Considering the long observation time and the cohort age in 2005 (62 years, 36.2–83.4 for FPDs; 46.8 years, 24–66.3 for SCs) (Bragger et al., 2011; Schmidlin et al., 2010), a high percentage of lost to follow-up had to be expected.

The long-term survival of the prosthetic reconstruction influences the patient's satisfaction with the treatment and the costs in hindsight (Walton, 2015). In particular for patients who are in need for prosthetic rehabilitations at a young age, the prognosis with various reconstruction types over extended observation periods are of utmost importance. A retrospective study observed tooth- and implant-supported fixed reconstructions of a patient cohort with birth defects (Krieger et al., 2009). The median age at delivery was 19.3 years (range 16.6–24.7 years). The survival rate of TSCs after 15.7 years (range 7.9–24.9 years) was 75%, which is substantially lower compared with the present study and can be justified by the type of birth defect which was mostly restored (amelogenesis/dentinogenesis imperfecta). Long-term data and the prognosis for tooth- and implant-supported fixed reconstructions are also applicable to insurances involved in funding these rehabilitations (Incici et al., 2009).

4.2 | Significance of supportive periodontal therapy

A standardized comprehensive treatment protocol and competent supportive periodontal treatment have been shown to be successful in maintaining stable periodontal conditions and retaining most teeth. Patients who finish periodontal treatment and do not comply regularly with maintenance have a sevenfold increase in tooth loss and an eightfold increase in implant loss compared with regular attenders (Ng et al., 2011; Roccuzzo et al., 2022).

Considerable re-treatment and extra costs are often involved and should be expected. A study calculated the direct life-time patient costs for supportive periodontal treatment. For periodontally compromised patients, a regular recall program is a cost-effective method of managing periodontal disease when compared with an approach that relies on replacing teeth with fixed reconstructions (Fardal et al., 2012).

4.3 | Tooth-supported restorations (FPTDP, TSC)

4.3.1 | Survival/failure

The estimated survival probability of tooth-supported single crowns was 69% (CI: 47%–91%) after an observation time of 36 years. A systematic review reported on 4663 metal-ceramic single crowns after a mean follow-up time of 7.3 years (Sailer et al., 2015). The estimated survival rate was 94.7% (CI: 94.1%–96.9%) after 5 years, which was slightly lower in comparison with the present study (98% after 5 years, CI: 96%–100%). Reasons for this may be the standardized comprehensive treatment protocol of the present patient cohort and the supportive periodontal treatment over the whole observation time. Moreover, the survival rate of TSC over 30 years was still 82% (CI: 74%–91%), which is proof for a predictable and reliable treatment option for teeth with the indication of an indirect restoration. Comparable numbers (85% survival rate) were also shown after an observation period of 25 years (Walton, 2013).

Regarding metal-ceramic FPTDPs, the survival rate in the present study was 56% after 36 years. Another systematic review summarized the survival and most frequent complication rates of 1796 metal-ceramic FDPs after a mean observation time of 7 years (Pjetursson et al., 2015). The 5-year survival rate was 94.4% (CI: 91.2%–96.5%), slightly lower than in the present report (100% after 5 years).

Consideration of initial treatment, specifically endodontic treatment with or without a post or post and core, negatively affected survival with a hazard ratio of 7.02 for tooth abutments supporting single crowns. Tooth abutments supporting fixed partial dentures had an even higher hazard ratio (8.29). The amount of maintained abutment walls was suggested to be the predominant factor for survival of endodontically treated teeth (ferrule effect), but most studies fail to show a post effect (Naumann et al., 2018).

4.3.2 | Biological complications

The accumulated risk for tooth abutments (TSC and FPTDP) to have any biological complication was 25.2%, which is higher compared with implant abutments, but no statistical significance was found between tooth and implant abutments ($p = .76$). A possible explanation for this finding might be the longer follow-up time and the higher number of tooth abutments examined. Additionally, tooth abutments are exposed to an increased risk of having biological complications compared with implants (e.g., caries and loss of vitality). Most frequently, abutment teeth were affected by caries or periodontitis. Furthermore, loss of vitality and abutment tooth fracture occurred. This finding does not correspond with the results of a systematic review, where loss of vitality and abutment fractures were the most common biological complications (Sailer et al., 2015). The high exposure time of the present study (mean 20.3 years, ±9.7, range 1.2–36.2) and thus the longer exposure to "biological risks" might be a possible reason as well as the increasing age of the study population (65 years, range 47–84) with a possible decrease of the manual ability to perform sufficient oral hygiene for the oldest part of the patient cohort.

The periodontal assessment of the same patient cohort in 2005 (Matuliene et al., 2008) described an increase of residual pocket probing depths (PPD) ≥ 5 mm from 4.1 to 5.4 sites between the end of active periodontal treatment and the reexamination in 2005 after a mean observation time of 11 years. PPD ≥ 5 mm was associated with a higher risk of tooth loss (OR 5.8 at site level), which might also explain the rate of periodontal complications.

4.3.3 | Technical complications

For single crowns, ceramic chipping was the most common technical complication, and all-ceramic restorations (lithium disilicate) showed significantly fewer ceramic chippings over the first 18 years compared with metal-ceramic (Table 4). This finding confirms the result of a meta-analysis that found chipping to be the most common technical complication for metal-ceramic restorations in general, but contradicts it when comparing metal-ceramic and lithium disilicate (Sailer et al., 2015). The number of all-ceramic reconstructions was significantly smaller compared with the number of metal-ceramic FDPs (33 vs. 74). Furthermore, there are no all-ceramic reconstructions beyond 18 years. This can be explained by the fact that metal-ceramic used to be, and still is, considered the gold standard for tooth- and implant-supported reconstructions. More recent publications report similar survival rates of most types of all-ceramic reconstructions to those reported for metal-ceramic reconstructions, both in anterior and posterior regions (Sailer et al., 2015). Thus, the use of all-ceramic restorations became more popular and scientifically justified in recent years.

The second most frequent technical complication was loss of retention. In relation to the observation period of 36 years, the numbers were very low, and the cementation of metal-ceramic

restorations seems not to be a primary issue, although conventional non-adhesive cements were mostly used.

4.4 | Implant-supported restorations (FPIDP, TSC)

4.4.1 | Survival/failure

In the present report, estimated survival rates for ISC and FPIDP were 87% (CI: 71%–100%) and 64% (CI: 34%–100%) after 25 years, respectively. Over the first 10 years, FPIDP showed a survival rate of 100%, as shown in a previous study with the same cohort (Bragger et al., 2011). Those results were similar to the findings of a systematic review that demonstrated a 5-year survival rate of 98.7% (CI: 96.8%–99.5%) for metal-ceramic FPIDPs. The implementation of a careful risk assessment prior to implant surgery and subsequent enrollment in a regular supportive periodontal therapy program may have positively influenced the survival of the implant reconstructions.

The following 15 years, the survival rates of FPIDPs decreased continuously (at 15 years: 93% CI: 82%–100%, at 20 years: 86% CI: 63%–100%, at 25 years: 64% CI: 34%–100%). A study investigating the long-term outcome of titanium dental implants over a 20-year follow-up period demonstrated an implant survival rate of 89.5% (Chappuis et al., 2013). A systematic review of Salvi et al. 2014 showed implant survival rates of 85.7%–99.2% over a mean observation period of 10 or more years (Salvi & Zitzmann, 2014).

Another systematic review showed an estimated 5-year survival rate of 98.3% (CI: 96.8%–99.5%) for metal-ceramic ISC (Sailer et al., 2015, 2018). In the present report, the survival rate of ISC remained stable on a high level during the observation period and was 87% (CI: 71%–100%) after 25 years. In a previous study investigating the same cohort, ISCs were lost in 5.1% (CI: 1.3%–9%) after 10 years (Schmidlin et al., 2010). The combined survival rate for 168 ISC and 127 FPIDPs was 95.5% after a mean observation period of 10.75 years (range: 8.4–13.5 years) (Wittneben et al., 2014).

4.4.2 | Biological complications

The cumulative risk for any biological complications was 11.4% for implants, with peri-implantitis being the most frequent complication (6.8%). The patient cohort of the present study comprised patients with a history of periodontitis, who attended an individual supportive periodontal therapy. Nevertheless, the increased risk of periodontally compromised patients for peri-implantitis (Roccuzzo et al., 2021; Schwarz et al., 2018) as well as the benefit of a regular SPC program (Roccuzzo et al., 2009) is well known. From a prosthetic point of view, a slim restorative angle in the emergence profile of the prosthetic suprastructure can reduce the initial marginal bone loss and perhaps improve the long-term prognosis of the implant (Katafuchi et al., 2018), particularly in patients with a history of periodontitis (Strauss et al., 2022). In addition, the restoration has to be accessible to perform an ideal oral hygiene (Serino & Strom, 2009).

The type of retention had a significant impact on biological complications. Cemented implant restorations showed a statistically significant higher probability of complications compared with screw-retained restorations ($p < .001$). Potential cement residues can trigger inflammation in the peri-implant soft tissue and present an additional risk factor for the overall treatment (Serino & Hultin, 2019; Wittneben et al., 2017).

Gender, age, and the material did not influence biological complications. For implant-supported FDPs with cantilever, the covariate analysis also showed no increased risk for complications, which is consistent with previous studies, where 30 implant-supported fixed dental prostheses with cantilever extensions over an observation period of 13.3 (±2.7) years were examined (Aglietta et al., 2009; Schmid et al., 2021). A systematic review focusing on cantilevered FPIDPs reported estimated survival rates of 98.4% for the implants and 99.2% for the rehabilitations (Storelli et al., 2018).

4.4.3 | Technical complications

Over the entire observation period, the cumulative risk for technical complications was 26.3% for FPIDPs and 19.4% for ISCs. Technical complications included chipping (15.8% for FPIDPs and 13.9% for ISCs) and loss of retention (15.8% for FPIDPs and 5.6% for ISCs). In the implant group, no fractures of framework or of the ceramic occurred. In a retrospective study investigating the long-term outcomes of implant-supported reconstructions, ceramic chipping occurred with a probability of 20.31% and loss of retention with a probability of 2.06% after 10 years (Wittneben et al., 2014).

The probability for having a technical complication was high for FPTIDP reconstructions (50%), although, due to the small group size, not statistically significant. Former investigations reported a 10-year survival of 77.8% (CI: 66.4%–85.7%) for FPTIDPs (Pjetursson, Bragger, et al., 2007).

The cumulative risk of biological complications after 10 years was 17.6%. The cumulative risk of technical complications after 10 years was estimated to be 13.5% (Schmidlin et al., 2010).

4.5 | Limitations

- The clinical relevance/meaningfulness of the obtained data from this cohort needs to be interpreted with caution in light of the fact that a dropout rate (lost to follow-up) of 56.3% for SCs and 65.5% for FDPs was observed.
- The ISC and FPIDP as well as the FPTIDP groups were underpowered compared with the tooth-supported reconstructions.
- The observation time of all restorations was up to 36 years (mean 20.3 years) with a broad range of 1.2–36.2 years.

- Many different clinicians and technicians were involved in the fabrication of the reconstructions, and different designs were pooled.
- The number of all-ceramic reconstructions was significantly smaller compared with the number of metal-ceramic reconstructions (33 vs. 74).

5 | CONCLUSION

With regard to the findings of this retrospective study, the following clinically relevant conclusions can be drawn:

- When following a patient cohort over 10, 20, and up to 30 years, a considerable dropout rate has to be expected, reducing the statistical power.
- The tooth-supported reconstructions that could be evaluated showed survival rates of at least 75% after 20 years. Implant-supported reconstructions showed survival rates of at least 86% after 20 years.
- Associated risk factors for more failures could be endodontic pretreatment for teeth and cementation of the suprastructure for implants.
- Regardless of the type of abutment (tooth or implant), the occurrence of biological complications can lead to the loss of the abutment in more than two-thirds of all complications.
- Technical complications tend to be less associated with abutment loss than biological complications.

AUTHOR CONTRIBUTIONS

Frank M. Bischof: Writing – original draft; investigation. **Ayse A. Mathey:** Investigation; writing – original draft. **Alexandra Stähli:** Writing – review and editing; project administration. **Giovanni E. Salvi:** Conceptualization; writing – review and editing; methodology. **Urs Brägger:** Conceptualization; writing – review and editing; supervision; methodology.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest related to this study.

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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