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ORIGINAL ARTICLE

Clinical performance of monolithic zirconia crowns on titanium–zirconium reduced-diameter implants in the molar area: Interim data at three years of a randomized controlled trial

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Abstract

Aim: The aim of the present study was (i) to evaluate the clinical performance of reduced-diameter implants placed in the molar area and (ii) to test whether monolithic zirconia implant-supported crowns lead to similar clinical outcomes compared to porcelain-fused-to-metal crowns.

Materials and Methods: A total of 76 patients needing a single implant crown in the posterior region were recruited. All patients received a titanium–zirconium reduced-diameter implant (Straumann Roxolid, Tissue Level, Standard Plus, diameter 3.3 mm, regular neck) randomly allocated to receive either a (1) monolithic zirconia crown (test) or (2) porcelain-fused-to-metal crown (control). Implant survival, prosthetic outcomes, and patient-reported outcomes were assessed at crown delivery and after 3 years of follow-up. Marginal bone levels (MBL) as well as clinical parameters including probing depth (PD), bleeding on probing (BOP), and plaque levels (PCR) were also recorded.

Results: A total of 59 patients were available at the 3-year follow-up; 32 patients with a monolithic zirconia crown (TEST) and 27 patients with a porcelain-fused-to-metal crown (CONTROL). 14 implants (11 implant fractures/3 aseptic losses) were lost leading to an estimated implant survival rate of 80% ± 5.1% (95% CI 70.8%–90.8%). Prosthetic complications were limited to the control group and involved minor chippings.

Conclusions: This type of reduced-diameter implant to support single implant molar crowns in the molar area cannot be recommended. Monolithic zirconia crowns appear to be a viable option in the posterior region showing similar prosthetic outcomes to porcelain-fused-to-metal crowns.

KEYWORDS
implant crown, monolithic zirconia, reduced-diameter implants, survival

1 | INTRODUCTION

Replacing missing teeth in partially edentulous patients by placing dental implants into native bone or in combination with bone augmentation procedures is a predictable treatment modality (Hammerle et al., 2002; Jung et al., 2012). In healed molar sites, the edentulous alveolar ridge frequently shows a reduced bucco-oral dimension (Malo & de Araujo Nobre, 2011). If bone grafting is applied, morbidity and treatment costs increase, and healing time is prolonged (Coulthard et al., 2003). In these challenging clinical situations, reduced-diameter implants (diameter ≤3.5 mm) (Jung et al., 2018) may overcome these shortcomings (Davarpanah et al., 2000).

A recent systematic review on reduced-diameters implants revealed survival rates of 94.7 ± 5%, 97.3 ± 5% and 97.7 ± 2.3% for implants with diameters <3.0, 3–3.25 and 3.3–3.5 mm after 12–78, 12–63, and 12–109 months (Schiegnitz & Al-Nawas, 2018). Compared to standard diameter implants (>3.5 mm), the authors showed a statistically significant lower implant survival of implants with diameters <3.0 mm (Schiegnitz & Al-Nawas, 2018). Implants exhibiting diameters of 3–3.25 and 3.3–3.5 mm, however, showed no statistically significant difference in implant survival compared to standard diameter implants over a follow-up time of 12–78 months (Schiegnitz & Al-Nawas, 2018). Implants with diameters of 3.3–3.5 mm were placed in all regions including posterior sites. Still, long-term data and data on biological and technical complications of reduced-diameter implants are missing particularly in the posterior area. One reason might be that the indications to use reduced-diameter implants are restricted by the implant manufacturer.

To guarantee sufficient mechanical properties of reduced-diameter implants, implant materials have been adapted. In vitro studies demonstrated that the use of titanium–zirconium alloy (Ti–Zr: ≈15% Zr/≈85% Ti) in dental implants resulted in an increase of mechanical strength compared to pure titanium dental implants. (Kobayashi et al., 1995; Lee et al., 2016). The clinical performance of narrow-diameter Ti–Zr implants was investigated in two systematic reviews (Altuna et al., 2016; Iegami et al., 2017). Iegami et al. (2017) found no statistically significant differences in survival rates when Ti–Zr narrow-diameter implants and pure titanium narrow-diameter implants were compared after 1 year of clinical service nor when separately analyzed in posterior and anterior regions. Altuna et al. (2016) showed that narrow-diameter Ti–Zr implants had high survival and success rates (>95%) and marginal bone level (MBL) changes (<1 mm) similar to regular-diameter titanium implants up to 36 months. In edentulous mandibles, reduced-diameter Ti–Zi implants supporting removable complete dentures showed excellent clinical performance after 5 years (Muller et al., 2015).

Notwithstanding, the evidence on reduced-diameter implants supporting fixed prostheses is scarce and only short-term data are available (Altuna et al., 2016). A 1-year pilot study evaluated narrow-diameter Ti–Zr implants (3.3 mm) in unilateral edentulous atrophic mandibles. Each patient received two implants supporting 3-unit ceramo-metal fixed partial dentures. Implant as well as prosthesis survival rate were 100%, and no statistically significant differences of probing pocket depths and MBL between baseline and after 1 year were calculated (El-Sheikh & Shihabuddin, 2014). A 3-year split-mouth randomized clinical trial evaluated narrow (3.3 mm) and regular-diameter (4.1 mm) implants supporting single crowns in the posterior region. The authors found no statistically significant differences regarding MBL at implant placement, 1-year, and 3-year time intervals. Bleeding on probing (BOP) was present at 15% and 10% of narrow- and regular-diameter implants at 3-year follow-up. At the 3-year examination, the implant success rates were 95% and 100% for narrow- and regular-diameter implants (de Souza et al., 2018). The corresponding values for prosthesis success rates were 90% for narrow-diameter implants and 95% for regular-diameter implants (de Souza et al., 2018).

Given that the mid-term data on reduced-diameter implants to support fixed restorations is scarce, the aim of the present study was, therefore, (i) to evaluate the 5-year clinical performance of reduced-diameter implants placed in the molar area and (ii) to test whether monolithic zirconia implant-supported crowns lead to similar clinical outcomes compared to porcelain-fused-to-metal crowns. This paper aims to report the interim data at 3 years of follow-up.

2 | MATERIALS AND METHODS

2.1 | Study design

The present study was designed as a randomized controlled clinical study with two parallel study groups. The local ethical committee approved the clinical protocol (PB_2016-01977) and the study has been registered at ClinicalTrials.gov (NCT02272491). Prior to participation, an informed consent form was signed by all patients. Patients were treated in compliance with the current version of the Declaration of Helsinki. The study was conducted at the Clinic of Reconstructive Dentistry, University of Zurich, Switzerland. This article is reported following CONSORT (Moher et al., 2010).

2.2 | Study population

Partially edentulous patients presenting a single-tooth gap in the maxillary or mandibular molar region were recruited. At the date of inclusion, the subjects had to fulfill the following inclusion criteria:

- 18–80 years of age
- In need of an implant-supported crown at a single-tooth gap in the molar region
- Implant position allowing a screw-retained implant crown
- Presence of an antagonist

Exclusion criteria were the following:

- Insufficient bone volume for implant insertion
- No primary stability at implant insertion

- Bruxism (significant tooth wear visible)
- Pregnancy
- Known or suspected noncompliance, drug or alcohol abuse
- Full-mouth plaque score >30%
- Heavy smokers (more than 15 cigarettes per day)

2.3 | Implant placement

The placement of implants was planned as either type 3 (after 12–16 weeks) or type 4 (after >4 month) procedure (Hammerle et al., 2012). All surgeries were performed according to the implant manufacturer's instructions for the placement of Straumann® Tissue Level implants (Institut Straumann AG). Patients received antibiotics prior to surgery (2×625 mg Co-Amoxycillin) and nonsteroidal analgesics/antiphlogistics. The surgery was performed under local anesthesia. A mid-crestal incision and, if needed, a vertical releasing incision were performed. Mucoperiosteal flaps were reflected.

Titanium–zirconium reduced-diameter implants (Straumann® Standard Plus SLActive RN, Roxolid, 3.3 mm diameter; Institute Straumann AG) were used in all sites. All implants underwent transmucosal healing.

2.4 | Prosthetic procedures

The impression of the implants was taken 3–6 months after implant placement. At impression taking (digital or conventional), all subjects were randomly allocated to one of the two treatment modalities (monolithic zirconia crowns versus porcelain-fused-to-metal crown). The manufacturing of implant crowns was described in detail in the previous publication reporting the 1 year results (Muhlemann et al., 2020). In short, the monolithic zirconia crowns (Lava Plus, 3M, Seefeld) were fabricated by means of laboratory-based CAD followed by industrial-based CAM (Straumann® etkon; Institut Straumann AG). The zirconia crowns were individually stained and adhesively cemented onto the titanium base abutment (Straumann® RN Variobase with 1 mm mucosal height; Institut Straumann AG). The porcelain-fused-to-metal implant crowns (Straumann® RN synOcta cast gold abutment; Institut Straumann AG) were manufactured by means of the lost-wax technique using high noble gold (V-Classic; Cendres Métaux) followed by ceramic layering (Creation CC Willi Geller; Klema). Each implant crown was screw-retained with the implant-specific torque of 35 Ncm. The screw access hole was filled with Teflon tape and sealed with a composite filling (Muhlemann et al., 2020). The occlusal concept allowed occlusal contacts but no eccentric contacts at implant crown delivery. No nightguards were provided for the patients.

2.5 | Clinical examination and outcome measures

Baseline (BL) examinations were performed 1–2 weeks after crown insertion and the follow-up was completed 3 years later (3y-FU). Three calibrated operators performed all clinical examinations. Before the study, operators were calibrated by a calibration meeting and by conjointly conducting clinical examinations in pilot patients. Technical, biological, and radiographic outcomes, and adverse events (according to ISO 14155:2011) were assessed at BL and at 3y-FU. Clinical pictures of the implant crown and the neighboring dentition were taken at each visit.

2.6 | Technical outcomes

Technical complications included fracture of the veneering ceramic, fracture of the crown, fracture of the abutment, fracture of the abutment screw, loosening of the abutment screw, loss of occlusal filling, decementation of crown from titanium base abutment, and implant fracture. Prosthetic parameters were evaluated using modified USPHS (United States Public Health Service) (Table 1) (Muhlemann et al., 2020).

2.7 | Biological outcomes

At six sites around each study implant and at the mesial and distal dentition periodontal parameters were recorded including probing pocket depth, BOP score (Ainamo & Bay, 1976), plaque control record (PCR; O'Leary et al., 1972). At the mid buccal aspect of the study implant and the neighboring teeth, the width of the keratinized mucosa (KM) was measured.

2.8 | Radiographic outcomes (MBL)

Standardized periapical digital radiographs (Digora Optime; Soredex) were taken at BL and at the 3y-FU by means of the paralleling technique using a rim holder directing the X-ray beam perpendicular to the implant axis. The radiographs were imported into an open-source image software (ImageJ; National Institutes of Health). The radiographs were assessed by an independent and calibrated investigator. The distance between the implant shoulder and the first bone to implant contact was measured at the mesial and distal aspect of each implant to the nearest 0.1 mm. The implant length and the pitch distance between two implant threads served as reference for the calibration of each radiograph. MBL changes were calculated from BL to FU-3Y. A loss of marginal bone is described as a negative change in MBL.

2.9 | Statistical analysis

The primary aim of this RCT is to test the total prosthetic complication rate at 5 years. Accordingly, the sample size calculation was performed (Muhlemann et al., 2020). Therefore, no statistical analysis was performed with the interim 3-year results. Discrete values were described with absolute frequencies. For continuous parameters,

TABLE 1 Modified USPHS criteria.

Parameters	Rating	Criteria
Patient satisfaction	Alpha	Very satisfied. No complaints
	Bravo	Critics regarding aesthetics, chewing, or comfort. Short-term complaints after treatment
	Charlie	Unsatisfied. Constant complaints but tolerable
	Delta	Completely unsatisfied. Unbearable complaints
Ceramic fracture	Alpha	No fracture
	Bravo	Chipping (localized), but polishing/contouring possible
	Charlie	Chipping down to the framework
	Delta	New crown is needed
Abutment fracture	Alpha	No fracture
	Bravo	—
	Charlie	—
	Delta	Fracture of abutment. New crown is needed
Marginal fit	Alpha	Perfect fit. No gap that could be probed
	Bravo	Slight under- and overcontour. Probe catch but no gap
	Charlie	Clear gap. Gap that could be probed
	Delta	New crown is needed
Anatomical form	Alpha	Ideal anatomical form. Contour is continuous with the neighboring dentition
	Bravo	Slightly over- or undecontoured as compared to the neighboring dentition
	Charlie	Severely over- or undercontoured as compared to the neighboring dentition
	Delta	New crown is needed
Proximal contact (mesial/distal)	Alpha	Tight proximal contact point
	Bravo	Weak proximal contact point
	Charlie	Open proximal contact point
	Delta	—
Occlusal contact	Alpha	Occlusal contacts on the crown and the neighboring dentition equal in strength
	Bravo	Increased occlusal contacts on the crown. No occlusal contacts on neighboring dentition
	Charlie	No occlusal contact on the crown. Normal occlusal contacts on neighboring dentition
	Delta	—
Color match	Alpha	No deviation in color and translucency between crown and neighboring dentition
	Bravo	Slight deviation in color and translucency between crown and dentition. Deviation lies within natural range of dentition
	Charlie	Major deviation in color and translucency between crown and dentition. Deviation lies outside natural range of dentition
	Delta	—
Occlusal wear	Alpha	No occlusal wear
	Bravo	Slight occlusal wear, diameter of spot <2 mm
	Charlie	High occlusal wear, diameter of spot >2 mm
	Delta	—

the data were reported by means, standard deviations, ranges, medians, and interquartile ranges. Implant survival was described by the Kaplan–Meier estimator. Survival was reported as an estimated cumulative survival ± standard error and bounded by the 95% confidence interval. The variance was estimated using the method of Greenwood and Topley (1926). The confidence interval used an asymptotic likelihood solution by log transformation as recommended by Kalbfleisch and Prentice (1980).

3 | RESULTS

Recruitment of patients was done from October 2014 until October 2017. From January 2015 to February 2018 a total of 76 patients were included in this study. 39 out of these patients (mean age 57.7 years; 17 females and 22 males) were randomized to the Mono-ZrO_2 group and 37 patients (mean age 56.4 years, 17 females and 20 males) to the porcelain fused to metal (PFM)

group. 59 patients attended the follow-up examination at 3 years, of which 27 patients (mean age 55.6 years; 16 females and 16 males) and 32 patients (mean age 55.3 years; 14 females and 13 males) belonged to the Mono-ZrO_2 group and the PFM group, respectively.

In total, 14 implants (in 2 females and 12 males) were lost, which corresponds to an implant survival rate of 80% ± 5.1% (95% CI 70.8%–90.8%) after a mean observation period of 36.9 months (Figures 1 and 2). In the PFM group, 3 implants were lost without any signs of inflammation (Figure 3a); one after 8 months, one after 2 years and one after 3 years. Six crowns were lost due to implant fracture after an observation period of 13–37 months (Figure 3b). In the Mono-ZrO_2 group, 5 implants fractured after 20–36 months, and led to loss of the crowns.

3.1 | Technical outcomes

No implant crowns were lost due to prosthetic complications. During the 3-year follow-up, prosthetic complications only occurred in the PFM group. Four minor ceramic fractures were reported in the 1y-FU (Muhlemann et al., 2020). At the 3y-FU one more minor ceramic fracture was detected. However, at the 3y-FU a total of four ceramic fractures are reported because one PFM crown exhibiting a minor chipping was lost between 1 and 3 years because of implant failure. Modified USPHS criteria at the 3y-FU are presented in Table 2. Patient satisfaction was high (rating A or B) in all patients regardless of the restoration type. Proximal contacts were missing mesially at 5 and distally at 4 implant crowns. Occlusal wear (rating B) was detected more frequently at PFM crowns (18) as compared to Monolithic ZrO_2 crowns (9) (Figure 3c).

3.2 | Biological and radiographic outcomes

Clinical parameters including probing depth, BOP, and PCR are shown in Table 3. From BL to the 3y-FU the change of mesial and distal MBL was less than 0.5 mm in both groups.

4 | DISCUSSION

The present study evaluating the clinical performance of monolithic zirconia crowns on titanium–zirconium reduced-diameter implants in the molar area predominantly revealed: (i) a survival rate of 80%, (ii) minor complications limited to the control group (porcelain-fused-to-metal crown), mainly chippings, (iii) high and similar levels of patient satisfaction in both treatment groups and (iv) comparable clinical and radiographic outcomes.

At 3 years, the survival rate of reduced-diameter implants in the molar region was lower than compared to current data (de Souza et al., 2018; Schiegnitz & Al-Nawas, 2018). This is in accordance with clinical studies reporting that reduced-diameter implants showed a lower survival rate compared to regular-diameter implants (de Souza et al., 2018). Generally, reduced-diameter implants are placed in the anterior region of the jaw or in the premolar area (Schiegnitz & Al-Nawas, 2018) because of the limited alveolar ridge dimensions. In molar sites, reduced-diameter implants are often splinted to neighboring implants or are included in multiunit reconstructions, which may contribute to a higher survival rate (El-Sheikh & Shihabuddin, 2014). However, there are also data showing a high survival rate for single narrow-diameter implants in the molar region of 95% after 3 years (de Souza et al., 2018).

Some of the lost implants in the present study failed because of a sudden implant loss without any signs of inflammation (Thoma et al., 2021). This does not stand in any relation to implant loss due to periimplantitis were there are some inflammatory signs beforehand (Berglundh et al., 2018). It has been observed that asymptomatic contact loss occurs between implant and bone, which leads to interposition of connective tissue (Isidor, 1996; Szmukler-Moncler et al., 1998). As a possible reason for aseptic implant losses traumatic occlusal forces have been discussed (Bertolini et al., 2019; Isidor, 2006; Miyata et al., 2000; Monje et al., 2019; Rungsiyakull et al., 2011). A limitation of this study is that at follow-up visits (1) only occlusal contacts were checked at implant crowns while eccentric contacts were not assessed and (2) patients were not examined for exhibiting episodes of bruxism after having been included in the study (no EMG or bite-force measurements have been done). Also,

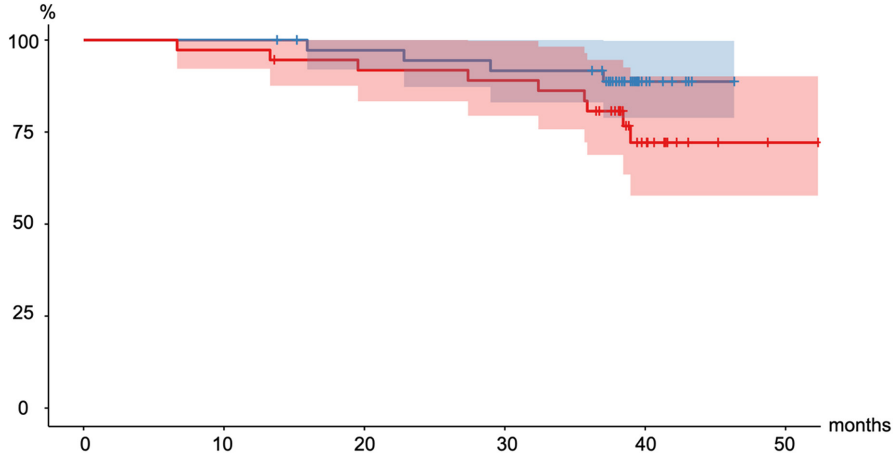

FIGURE 1 Estimated cumulative survival of reduced-diameter implants supporting porcelain fused to metal crowns (red) 72.1% ± 8.2% (95% CI 57.7%–90.1%) after 38.9 months and ZrO_2 crowns (blue) 88.7% ± 5.3% (95% CI 78.9%–99.8%) after 37.0 months.

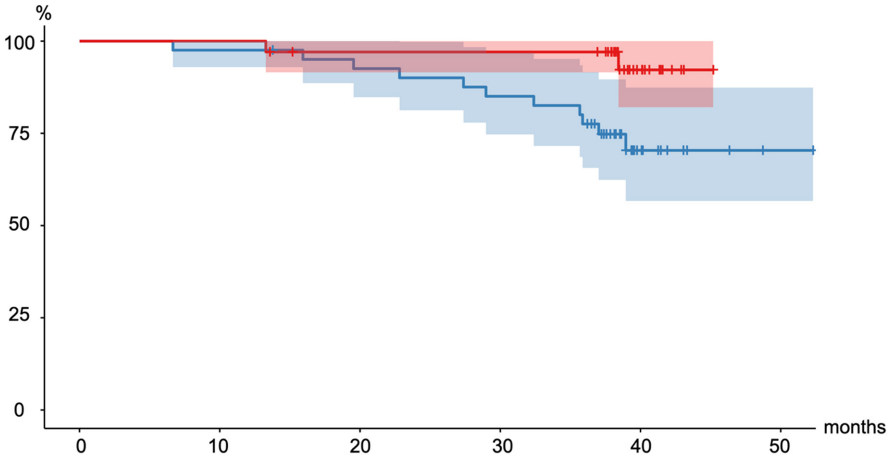

FIGURE 2 Estimated cumulative survival of reduced-diameter implants in females (red) 92.2% ± 5.5% (95% CI 82.1%–100%) after 38.4 months and in males (blue) 70.4% ± 6.6% (95% CI 65.6%–91.6%) after 38.99 months.

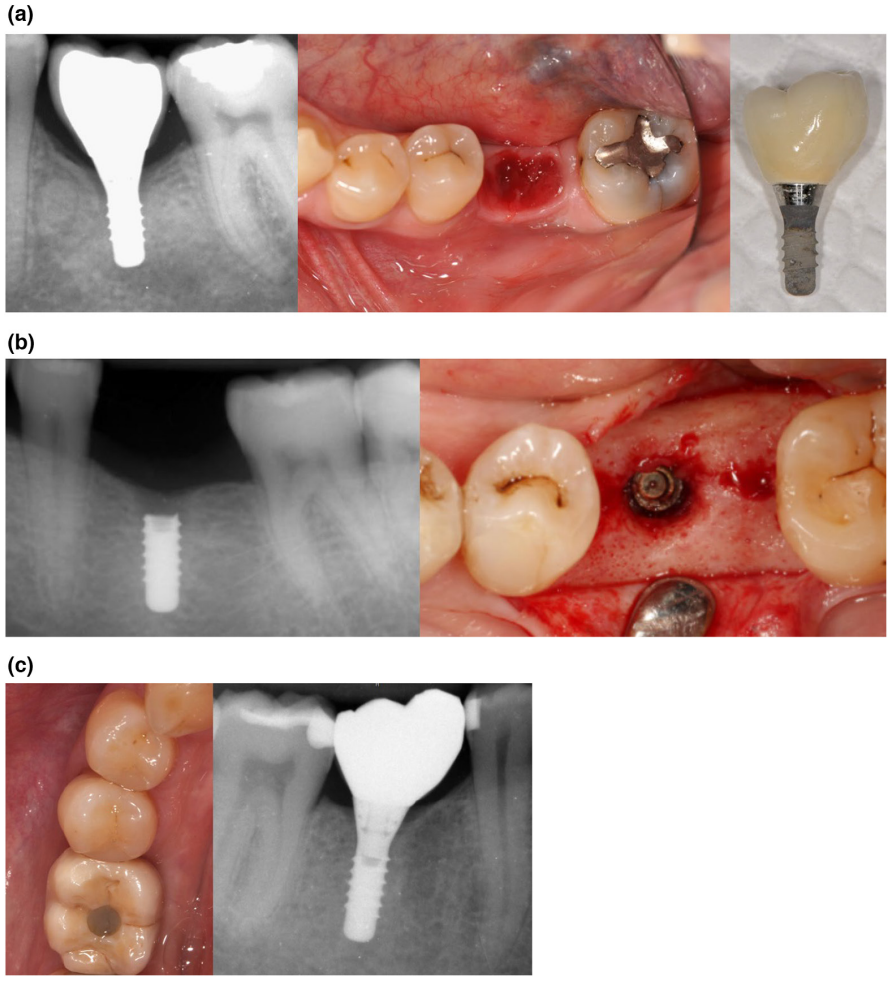

FIGURE 3 (a) Porcelain fused to metal group: Loss of implant without inflammatory signs at 16 months. (b) Mono-ZrO_2 group: Implant fracture at 12 months. (c) Mono-ZrO_2 group: Occlusal wear (rating Charlie) of cusp at 3-year follow-up.

occlusal wear assessment was limited to the study crowns, whereas the opposing unit was not checked nor characterized. Finally, the evaluation of wear was qualitative only.

Most of the lost implants in the present study failed because of implant fractures. Looking at the location of the implant fractures it can be observed that the fracture occurred in all of the cases at the same location of the implant, below the internal screw channel. Since the use of titanium–zirconium alloy for dental implants resulted in an increased mechanical strength as compared to dental implants made out of pure titanium the implant fractures observed in the present study were not expected (Kobayashi et al., 1995; Lee et al., 2016). It may be hypothesized that the shape of the implant neck of reduced-diameter implants is more prone to fracture as compared to the same type of regular-diameter implants. Implant fractures were observed more often in men ($n = 12$) than in women ($n = 2$) pointing towards a biomechanical overload since the highest

TABLE 2 Prosthetic outcome based on the modified USPHS criteria.

		3-year follow-up				3 year follow-up	
Parameter		**Mono ZrO_2 crown**	**PFM crown**	**Parameter**		**Mono ZrO_2 crown**	**PFM crown**
Patient satisfaction	n	32	27	Proximal contact mesial	n	32	27
	A	31	23		A	23	17
	B	1	4		B	6	8
	C	0	0		C	3	2
	D	0	0		D	–	–
Ceramic fracture	n	32	27	Proximal contact distal	n	22	14
	A	32	23		A	20	12
	B	0	4		B	2	2
	C	0	0		C	0	0
	D	0	0		D	–	–
Abutment fracture	n	32	27	Occlusal contact	n	32	27
	A	32	27		A	23	25
	B	–	–		B	0	0
	C	–	–		C	9	3
	D	0	0		D	–	–
Marginal fit	n	32	27	Color match	n	32	27
	A	28	27		A	5	13
	B	3	0		B	22	14
	C	0	0		C	5	0
	D	0	0		D	–	–
Anatomical form	n	32	27	Occlusal wear	n	32	27
	A	21	24		A	23	9
	B	10	3		B	9	18
	C	1	0		C	0	0
	D	0	0		D	–	–

Abbreviations: Mono-ZrO_2, monolithic zirconia implant crowns; PFM, porcelain-fused-to-metal implant crowns.

TABLE 3 Clinical parameters at Baseline and at 3-year follow-up.

		Mono-ZrO_2 crown			PFM crown		
		Mesial site	**Implant site**	**Distal site**	**Mesial site**	**Implant site**	**Distal site**
Baseline		*n* = 39	*n* = 39	*n* = 26	*n* = 37	*n* = 37	*n* = 21
PCR %	Mean ± SD	10.3 ± 15.3	3.9 ± 9.2	27.6 ± 21.0	12.2 ± 19.1	3.6 ± 8.9	21.4 ± 23.1
	Range	0–66.7	0–33.3	0–66.7	0–83.3	0–33.3	0–83.3
BOP %	Mean ± SD	7.3 ± 11.4	14.5 ± 18.1	12.2 ± 14.0	9.5 ± 12.1	10.8 ± 16.3	13.5 ± 15.5
	Range	0–33.3	0–50.0	0–50.0	0–33.3	16.7–66.7	0–50.0
PD mm	Mean ± SD	2.3 ± 0.4	3.0 ± 0.5	2.6 ± 0.5	2.4 ± 0.5	3.0 ± 0.6	2.8 ± 0.3
	Range	1.5–3.5	2.0–4.0	2.0–3.3	1.7–3.8	1.8–4.5	1.8–3.5
3-year FU		*n* = 27	*n* = 32	*n* = 22	*n* = 27	*n* = 27	*n* = 14
PCR %	Mean ± SD	0.15 ± 0.21	0.06 ± 0.17	0.35 ± 0.25	0.1 ± 0.19	0.03 ± 0.07	0.19 ± 0.27
	Range	0–0.67	0–0.83	0–0.83	0–0.83	0–0.17	0–1
BOP %	Mean ± SD	0.06 ± 0.11	0.17 ± 0.21	0.11 ± 0.18	0.7 ± 0.12	0.15 ± 0.15	0.7 ± 0.11
	Range	0–0.33	0–0.83	0–0.67	0–0.33	0–0.50	0–0.33
PD mm	Mean ± SD	2.44 ± 0.52	3.09 ± 0.60	2.56 ± 0.37	2.27 ± 0.36	2.27 ± 0.68	2.45 ± 0.24
	Range	1.83–4.17	2.17–5.17	2.0–3.5	1.83–3.17	1.33–4.50	2.0–2.83

Abbreviations: BOP, bleeding on probing; FU, follow-up; Mono-ZrO_2, monolithic zirconia; *n*, number; PCR, plaque control record; PFM, porcelain fused to metal; PD, probing depth; SD, standard deviation.

bite forces appear in the region of the first molar and are higher in male patients (Ferrario et al., 2004). At the time of ethical approval, no restriction existed by the implant manufacturer regarding the use of this implant type to support single molar crows. However, this study shows the importance to simulate the clinical scenario in an in vitro set-up identifying potential biomechanical limitations prior to a clinical study (Hjerppe et al., 2022).

The prosthetic and biologic outcomes of monolithic implant crowns are in line with data presented in a systematic review (Sailer et al., 2018) presenting survival estimates of 94.4% after 5 years. However, the loss of the implants in the present study resulted in a loss of the supporting crowns. Therefore, the survival rate of implants and crowns have to be reported separately.

5 | CONCLUSIONS

The survival rate of the reduced-diameter implants was lower as compared to the existing evidence and, therefore, cannot be recommend in molar sites. The limitation of the present study is the fact that there was only one implant type used. Consequently, no conclusions about the material or technical differences between different implant types can be drawn. At the prosthetic level, the use of monolithic zirconia crowns appears to be a viable option in the posterior region.

AUTHOR CONTRIBUTIONS

S. Mühlemann, R. E. Jung, C. H. F. Hämmerle, and G. Benic conceived the ideas. K. Zumstein, T. Waller, and S. Mühlemann collected the data. K. Zumstein and S. Mühlemann analyzed the data and performed the writing.

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CONFLICT OF INTEREST STATEMENT

S.M., R.J, C.H., G.B. provided lectures or consultations, which were reimbursed from Institute Straumann AG. S.M. provided lectures or consultations, which were reimbursed from 3M.

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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