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13-year follow-up of a randomized controlled study on zirconia and titanium abutments

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Abstract

Objectives: To assess survival rates and compare technical, biological, and esthetic outcomes of customized zirconia and titanium abutments at 13 years post loading.

Materials and Methods: Initially, 22 patients with 40 implants in posterior regions were included. The sites were randomly assigned to 20 customized zirconia abutments with cemented all ceramic crowns (ACC) and 20 customized titanium abutments with cemented metal ceramic crowns (MCC). At a mean follow-up of 13.4 years, patients were examined and implants/restorations assessed for survival and technical complications, as well as biological and esthetic outcomes (pocket probing depth [PPD], bleeding on probing [BOP], plaque control record [PCR], bone level [BL], papilla index [PAP], mucosal thickness, and recession (distance of the margo mucosae [MM]/margo gingivae MG)). Descriptive analyses were performed for all outcome measures.

Results: Fifteen patients with 21 abutments (13 zirconia, 8 titanium) were examined at 13 years. The drop-out rate was 25% (patient level). The technical survival rate of the abutments was 100%. The survival rate on the restorative level (crowns) was 100%. The assessed biological outcomes (PPD, PCR, BOP, BL) and esthetic outcomes (MG, PAP) were similar.

Conclusions: Zirconia and titanium abutments supporting single implant-borne restorations rendered a high survival rate and minimal differences in terms of technical, biological, and esthetic outcomes at 13 years of follow-up.

KEYWORDS

ceramic abutments, complications, implant abutments, implant crowns, survival, technical, titanium, zirconia

1 | INTRODUCTION

To ensure successful restoration of implants, clinicians must consider various materials and types of restorations that meet biological, aesthetic, and functional needs. The restorative material should be biocompatible, aesthetically pleasing, and capable of withstanding the strong physical forces present during function. Maximum bite forces can range from 600 N and 1200 N (Shinogaya et al., 2000) depending on age, sex, dental status and other factors (Peck, 2016). Consequently, the materials chosen for implant-borne restorations must withstand high mechanical loading.

Metal-based materials, particularly titanium and its alloy has been considered the standard of care for implant-borne restorations (Hanawa, 2020; Osman & Swain, 2015; Sailer, Philipp et al., 2009). However, concerns have arisen about the discoloration of the peri-implant mucosa caused by these materials. To address these concerns, all-ceramic restorations have been proposed to overcome the esthetic limitations of metal-based materials (Jung et al., 2008; Linkevicius & Vaitelis, 2015). Favorable clinical data on all-ceramic single and multi-unit restorations on natural teeth (Sailer et al., 2015; Sailer et al., 2015) support this approach. Among all-ceramic materials, zirconia has replaced metal-based restorations on dental implants in the esthetic zone as it offers biological and aesthetic advantages over metal-based restorations, these advantages are predominantly found in sites with a thin phenotype, where the peri-implant soft tissue appears more natural to the human eye (Cosgarea et al., 2015; Linkevicius & Vaitelis, 2015; Pitta et al., 2020).

From a biological point of view, zirconia has been found to have less bacterial adhesion compared to titanium abutments (Nascimento et al., 2014; Salihoglu et al., 2011) and the blood flow around zirconia is similar to blood flow around natural teeth (Kajiwara et al., 2015). This has led to the speculation that zirconia abutments may result in less bone resorption due to improved blood circulation better immune function (Barwacz et al., 2015; Kajiwara et al., 2015). However, in vitro studies have shown that zirconia abutments have lower fracture toughness and are more brittle than titanium abutments making them potentially less durable (Lughi & Sergo, 2010; Stimmelmayr et al., 2017).

Although studies have shown promising survival rates up to 5 years for zirconia abutments (Sailer, Philipp et al., 2009; Zembic et al., 2009; Zembic et al., 2013). There is still a scarcity of scientific data on their performance in the posterior zone. To address this knowledge gap, randomized clinical trials with an observation period of 10 years are necessary to provide the highest level of evidence to aid clinicians in material selection for individual cases.

The aim of the present study was to assess survival and complications rates of zirconia and titanium abutments 13 years post loading. The present study is a follow-up of previously published data (Sailer, Philipp et al., 2009; Zembic et al., 2009; Zembic et al., 2013).

2 | MATERIALS AND METHODS

2.1 | Study procedure and patients

The current study is a long-term follow-up of a randomized controlled clinical trial that was previously published at 1, 3 and 5 years. The trial was conduceted at the Clinic of Reconstructive Dentistry, Center of Dental Medicine, University of Zurich (Sailer, Philipp et al., 2009; Zembic et al., 2009; Zembic et al., 2013) and the manuscript was prepared according to the Consort 2010 checklist (Schulz et al., 2010). Initially the study included 22 patients (14 females, 8 males) with 40 single tooth gaps in both maxilla and mandible. In brief, regular platform titanium implants (Brånemark RP, Nobel Biocare) were inserted to replace canines, premolars and molars. Patients were randomly assigned to either the test group or the control group. The test group received a customized zirconia abutment and an all ceramic crown (ACC), while the control group received a customized titanium abutment and a metal ceramic crown (MCC). In- and exclusion criteria and further details of the original study were described previously (Sailer, Zembic et al., 2009).

The current follow-up study was approved by the local ethical committee (BASEC-Nr. 2016–01164) and patients previously participating in the RCT were invited by mail and informed on the purpose of the follow-up examination. All patients being re-examined at 13 years provided signed informed consent.

2.2 | Prosthetic procedure

Individual resin pro-abutments were fabricated by the dental technician, tailored to each patient's unique anatomical condition. These pro-abutments were then scanned using a tactile scanner and customized zirconia and titanium abutments were manufactured using CAD/CAM technology (Procera, Nobel Biocare AB, Carolinsk). A clinical try-in of the abutments was performed and any necessary adjustments were made. All abutments were then fixed onto the implants using a defined torque of 32 Ncm.

The test group received cemented ACC with frameworks made out of glass–ceramic or high-strength ceramic (alumina, zirconia). The control group received cemented MCC.

In both groups the crowns were cemented using either a resin cement (Panavia 21TC, Kuraray, Okayama, Japan or RelyX Unicem, 3 M Espe) or a glass-ionomer cement (Ketac Cem, 3 M Espe).

2.3 | Maintenance

All patients patients who participated in the study were enrolled in a routine maintenance program with the dental hygienists at the clinic of Reconstructive Dentistry, Center of Dental Medicine, University of Zurich. During these appointments, a clinician from the department performed a dental check-up and recorded any technical or biological complications.

2.4 | Clinical and radiographic examinations

To establish the survival rates of abutments and crowns, both were examined clinically for being in function. Abutments were evaluated for fractures and loss of retention (i.e. abutment screw fracture, abutment screw loosening).

The crowns were examined for major fractures (replacement needed), chipping of the veneering ceramic and loss of retention (cement seal). Furthermore, occlusion and articulation was examined using shimstock foil to evaluate whether or not there is contact in occlusion and articulation. Proximal contacts were stated as present or absent using dental floss.

The following biological parameters were evaluated at the implant site and the neighbouring teeth. Each measurement was performed at four sites (mesial, buccal, distal, oral) by one experienced clinician with the probing force 0.25 N for teeth and 0.15 N for implant sites:

- Pocket probing depths (PPD) were measured with a periodontal probe (PCB 12, Hu-Friedy) from the mucosal margin to the bottom of the probable pocket in millimeters.
- Bleeding on probing (BOP) was noted as present or absent.
- Plaque control record (PCR) was stated (O'Leary et al., 1972).

The radiographic examination of the implants was made using the long-cone parallel technique in a non-standardized way (Updegrave, 1951) (Figures 1–6). The distance from the implant shoulder (reference) to the most coronal bone-to-implant contact was measured by two independent examiners mesially and distally of the implants in 0.1 mm increments to establish the bone level (BL), using the software ImageJ (National Institutes of Health).

For purpose of calibration the predetermined distance between three implant threads (1.8 mm) was used. In case the measurements of the examiners differed more than 0.5 mm, the radiographs were reexamined and the bone levels were discussed until an agreement was found.

An esthetic examination (papillae, mucosa thickness and recession) of abutments and crowns was performed. Thereby, the contralateral tooth served as control.

The height of the papillae was measured at the mesial and distal position and evaluated using an established papilla index (Jemt, 1997).

The soft tissue thickness was examined 1 mm below the mucosal/gingival margin at implants and contralateral teeth using an endodontic file.

The distance of the margo mucosae (MM)/margo gingivae (MG) to the crown margin/cementoenamel junction was measured to evaluate a possible recession.

2.5 | Evaluation

The outcomes of biological parameters (PPD, BOP, PCR), radiographic parameters (BL) and esthetic parameters (MM/MG and papilla index) were compared between zirconia and titanium abutments at 13 years.

Secondly, biological, radiographic and esthetic changes from baseline to 13 years were analyzed between zirconia and titanium abutments.

Thirdly, all implant sites (both with zirconia and titanium abutments) were compared to the neighbouring teeth for PPD, BOP, PCR and to the contralateral tooth for mucosa thickness and MM/MG (recession) at 13 years.

3 | RESULTS

3.1 | Patients and implants

Early on in the study, 2 patients with 9 abutments (8 titanium, 1 zirconia) were withdrawn (early drop-outs) due to a change in the treatment plan. At a mean follow up of 13.4 years (12.5–14.1 years), 15 patients (7 females, 8 males) were re-examined. This encompassed patients with 21 implants (13 zirconia abutments and ACCs) and 8 implants (8 titanium abutments with MCCs).

Five patients with 7 implants were not available for the 13-year follow-up. Out of those, one patient had moved to a retirement home and was not able to come to the follow-up visit. According to her daughter, the study implant was still in place. Another patient moved abraod and was therefore not available for the follow-up. The other patients could not be reached, despite several attempts to contact them.

This resulted in a patient drop-out rate of 25%. The 7 implants that could not be evaluated, were located in the premolar and molar area in both, the mandible (5) and the maxilla (2). Four of them were in the test group (zirconia abutments with ACC) and 3 in the control group (titanium abutments with MCC).

Over the entire study period (between the 3- and 5-year follow-up), 3 implants failed due to peri-implantitis (2 in the same patient), supporting 2 zirconia abutments and 1 titanium abutment. Two of the three implants that were lost, were located in the mandible and one in the maxilla. No further implant loss was observed in the patient group attending at 13 years.

The implant survival rate was therefore 90% at a mean follow-up of 13.4 years.

3.2 | Technical outcomes

The 13-year technical survival rate of zirconia and titanium abutments was 100%. In both groups, no fractures of abutments were noted and there was no screw loosening observed.

FIGURE 1 Female patient with implant in region 14 supporting a zirconia abutment and ACC.

FIGURE 2 Male patient with implant in region 14 supporting a titanium abutment and MCC.

FIGURE 3 Male patient with implant in region 23 supporting a titanium abutment and MCC.

FIGURE 4 Female patient with implant in region 23 supporting a titanium abutment and MCC.

FIGURE 5 Male patient with implant in region 35 supporting a titanium abutment and MCC.

FIGURE 6 Female patient with implant in region 35 supporting a zirconia abutment and ACC.

The same applied for the survival rate on the restorative level (crowns) amounted to 100% in both groups (ACC and MCC). Furthermore, no chipping of the veneering ceramic occurred in the ACC group.

In the MCC group, minor chipping of the veneering ceramic took place in 3 patients up to the 5-year follow-up. The crowns were located in the lower canine and upper premolar and molar area.

3.3 | Biological outcomes

In the two groups the assessed biological outcomes (PPD, PCR, BOP and BL) were similar at 13 years (Table 1). The evaluation of mPPD for the sites with zirconia abutments was 3.84 mm (range 2.25–8 mm) and 3.18 mm (range 2.25–4.5 mm) for the sites with titanium abutments.

Values for mBOP at sites with zirconia abutments were 0.54 (range 0–1) and 0.50 (range 0–1) at sites with titanium abutments. Values for mPCR were 0.1 (range 0–1) at sites with zirconia abutments and 0.13 (range 0–1) at sites with titanium abutments.

Bone levels of more than 2 mm were found in both groups (5 implants supporting ziorconia abutments and 5 implants supporting titanium abutments) (Table 2).

3.4 | Esthetic outcomes

Similar values were found for mMG and mPAP when comparing the test group and the control group (Table 3). For sites with zirconia abutments, mMG was 1 mm (range−2.75 to 2.75 mm). For sites with titanium abutments, mMG was 0.85 mm (range−0.375 to 2.5 mm).

3.5 | Mucosal thickness

At the 21 implant sites, the mean mucosal thickness was 1.25 mm for implants and 1.07 mm for teeth at 13 years.

In six patients, implants and teeth had the same mucosa thickness. In 11 patients, dental implants demonstrated a greater mucosal thickness compared to natural teeth. In four cases, the implants exhibited a thinner mucosal thickness compared to natural teeth (three zirconia abutments, one titanium abutment).

3.6 | Occlusion and articulation

Out of the re-examined 21 implant crowns, 6 were in occlusion and 8 were in non-occlusion at 13 years. For the remaining seven sites, no data was collected. Five crowns showed contact in articulation, and nine showed no contact in articulation. For the remaining seven sites, no data was collected.

3.7 | Contact points

Eleven crowns showed a mesial and distal contact point at 13 years. Six crowns had only a distal contact point, and one had only a mesial contact point. One crown showed no mesial and distal contact point. At one specific implant sites, no neighbouring teeth were present. For one crown, no data has been collected.

3.8 | Change of biological outcomes from baseline to 13 years

Implant sites with zirconia abutments showed an increase in PPD compared to implant sites with titanium abutments between baseline and 13 years (Table 4). Moreover, zirconia abutments were associated with slightly more BOP positive values than titanium abutments. In contrast, a greater loss of marginal bone was observed at titanium compared to zirconia abutments.

3.9 | Comparison implants to teeth at 13 years

The evaluation of mPPD, mBOP and mMG showed increased values for implants at 13 years, whereas mPCR increased at natural teeth only (Table 5).

4 | DISCUSSION

The present study predominantly revealed: (i). 100% technical survival rates both for zirconia abutments and titanium abutments at 13 years with no technical complications (e.g., fractures of abutments or screw) and (ii). comparable biological and aesthetic outcomes between zirconia and titanium abutments. Collectively, these findings indicate that there is a similar clinical performance of zirconia and titanium when supporting single implant crowns.

While a previous study showed a 50% decrease in fracture toughness of zirconia after 10 years in a humid environment (Studart et al., 2007), the present study found no clinical impact on zirconia abutments at 13 years. Notwithstanding, catastrophic failures may occur at a later timepoint.

The survival rate of an abutment may be influenced not only by the material but also by the connection type (Vetromilla

TABLE 1 Biological outcomes at 13 years.

Abutment	mPPD (mm)	mBOP	mPCR	mBL (mm)
Zirconia	3.84 ± 1.70	0.54 ± 0.34	0.10 ± 0.16	2.38 ± 1.97
Titanium	3.18 ± 0.65	0.50 ± 0.38	0.13 ± 0.19	2.00 ± 1.03

Abbreviations: mBL, mean bone level; mBOP, mean bleeding on probing; mPCR, mean plaque control record; mPPD, Mean pocket probing depth.

TABLE 2 Bone level at 13 years.

Implant number	Implant region	Abutment material	BLmesial (mm)	BL distal (mm)
1.	43	Ti	0	0.6
2.	14	ZrO	1.5	1.4
3.	45	ZrO	1.6	1.9
4.	44	ZrO	7	8.7
5.	14	Ti	2.2	1.7
6.	35	ZrO	1.3	0.6
7.	24	Ti	1.7	1.8
8.	35	ZrO	1.1	1.5
9.	35	Ti	2.8	2.9
10.	36	ZrO	3.8	2.8
11.	43	Ti	2.1	2.6
12.	34	Ti	2.4	2
13.	15	Ti	1.5	0.5
14.	23	ZrO	2	1.7
15.	23	ZrO	2.4	2.3
16.	24	Ti	4.4	2.8
17.	35	ZrO	4.7	4.6
18.	14	ZrO	0.2	0.3
19.	24	ZrO	2.1	2.2
20.	35	ZrO	1.4	1.2
21.	36	ZrO	1.3	1.1

TABLE 3 Esthetic outcomes of test and control sites at 13 years.

Abutment	mMG (mm)	mPAP
Zirconia	1.0 ± 1.78	2.39 ± 0.77
Titanium	0.85 ± 1.99	2.13 ± 0.64

Note: Negative values represent recession.

Abbreviations: mMG, mean distance margo mucosae to crown margin; mPAP, mean height of the papillae.

TABLE 4 Difference of biological parameters from baseline to 13 years.

Abutment	mPPD (mm)	mBOP	mBL (mm)
Zirconia	0.88 ± 1.87	0.52 ± 0.31	0.11 ± 1.96
Titanium	0.07 ± 1.21	0.32 ± 0.35	-0.45 ± 1.02

Note: Mean pocket probing depth, mean bleeding on probing (mBOP), BL: distance from implant shoulder (reference) to most coronal bone-to-implant contact, negative values represent bone loss; positive values represent bone gain.

et al., 2019). In vitro studies have shown higher fracture strength for internally connected zirconia abutments (Sailer et al., 2018), but clinical studies do not support this assumption, as complications have been reported (Eisner et al., 2018; Heierle et al., 2019; Nothdurft, 2019).

During a 5-year follow-up study of 34 anterior implants with internally connected zirconia abutments, several complications were reported, including abutment screw loosenings and one rotational misfit. The authors attributed the cause of these failures to defects in the internal hexagon (Nothdurft, 2019).

In a RCT of 27 internally connected zirconia abutments in the anterior maxilla or mandible, 1 abutment fracture was reported after 3 years of follow-up (Heierle et al., 2019). Interestingly, the fracture occurred in the screw-retained group. Another study reported one fracture of an internally connected zirconia abutment and one abutment screw loosening after one year of function (Eisner et al., 2018). Meanwhile, in vitro studies have shown that externally connected zirconia abutments have lower fracture strength (Sailer et al., 2018). However, the present study demonstrated excellent clinical survival rates for externally connected zirconia abutments. Another long-term study also supports the excellent survival rates of 100% for externally connected zirconia abutments at 11 years in the anterior and premolar regions (Zembic et al., 2015).

The influence of the implant-abutment connection (external or internal) on the survival rate of zirconia abutments is still unclear due to the lack of clinical studies on this topic. This is an area that warrants future research.

Regarding technical complications, the present study found no chipping of veneering and no crown fractures for ACC. This finding is in contrast with the results of a systematic review comparing the survival rates of ACC and MCC on implants. The review reported a higher number of fractures for zirconia crowns, leading to more catastrophic failures of the zirconia crowns (Pjetursson, Valente et al., 2018). This may be due to the fact that zirconia is highly sensitive to the manufacturing technique and handling process (Al-Amleh et al., 2010). Therefore, it is crucial to follow the manufacturer's instructions.

It is widely recognized that bilayer materials are more prone to chipping (Zhang et al., 2013). Thus, in contemporary implant prosthodontics, monolithic materials are commonly used instead (Alsarani et al., 2018).

In terms of the biological parameters (PPD, BOP, BL & PCR), the present study found no differences between zirconia and titanium abutments after 13 years of follow-up. These results are consistent with a systematic review that found no significant differences in the same biological parameters between zirconia and titanium abutments (Sicilia et al., 2015).

Another publication demonstrated stronger inflammatory reaction and more BOP for titanium abutments than for zirconia abutments (Linkevicius & Vaitelis, 2015). Nevertheless, a recent study found that zirconia restorations were associated with increased BOP and PPD at 3 years compared to baseline when they were cemented on non-original titanium bases. The authors of that study suggested that the cement gap may be the potential cause of the increased BOP (Stucki et al., 2021).

In the present study, the increased BOP around implants compared to teeth may also be associated with the cementation as well.

TABLE 5 Biological and esthetic outcomes for implants and teeth at 13 years.

At 13 years	mPPD (mm)	mBOP	mPCR	mMG (mm)
Implants	3.57 ± 1.25	0.52 ± 0.34	0.11 ± 0.17	0.94 ± 1.81
Teeth	2.65 ± 0.65	0.33 ± 0.2	0.25 ± 0.19	−0.29 ± 0.76

Note: Negative values represent recession. Implant: with either a zirconia abutment or a titanium abutment.

Abbreviations: mBOP, mean bleeding on probing; mMG, distance mucosa/margo gingivae to implant crown margin/cementoenamel junction of tooth; mPCR, mean plaque control record; mPPD, Mean pocket probing depth.

A recent study supports this assumption with increased BOP for cemented restorations compared to screw-retained restorations on zirconia abutments at 12 months (Thoma et al., 2018). The authors highlighted that the challenging excess cementum removal may lead to gingival inflammation (Thoma et al., 2018).

The present study found increased mPPD at implant sites when compared to teeth after 13 years. One possible explanation for this finding is related to the probing technique. For teeth, the recommended probing force is 0.25 N, whereas it should not exceed 0.1–0.15 N around implants. A study comparing the probing technique around implants and teeth has shown that measurements around implants are more sensitive to changes in probing forces than measurements around teeth. This might result in higher values of PPD and BOP around implants, as observed in the present study (Mombelli et al., 1997).

A further finding that might be of interest to the clinician is the evaluation of contact points. The present study investigated the evaluation of contact points, occlusion, and articulation over time, although in a non-standardized way. Out of 21 implant crowns examined, only 11 had both contact points, and only 6 crowns showed contact in occlusion at the 13-year follow-up.

According to a systematic review, every second implant experiences implant infraposition and proximal contact point loss during the first 5–15 years (Papageorgiou et al., 2018). The review also suggests a higher risk for loss of the mesial contact point due to the mesial drift of teeth, which is consistent with the present findings. A missing proximal contact point may lead to food impaction and periodontal problems, representing a biological risk for the implant (Manicone et al., 2022). Consequently, contact points should be controlled in regular follow-ups by either the clinician or the dental hygienist.

The drop-out rate in the present study was relatively low at 25%, despite the long observation period of 13 years. This rate falls within the expected range of 4% annual drop-out rate, as reported in previous studies (Pjetursson, Zarauz et al., 2018). To support the present findings, more RCTs with larger sample sizes and longer observation periods (of 10 years or more) are needed It would also be valuable to investigate whether surface roughness and crown material could influence the biological parameters in future studies.

The present study had some limitations, including the lack of a power analysis and the involvement of several clinicians in the study procedures. The use of different cements for crown fixation and the absence of examiner calibration were additional factors that could have influenced the results.

5 | CONCLUSION

Zirconia and titanium abutments supporting single implant crowns showed no difference in the clinical performance at 13 years post-loading. Based on the present results, clinicians may choose either a zirconia or titanium abutment in both anterior and posterior regions. Both abutment materials appear to meet technical, biological and esthetic requirements when in function for 13 years.

AUTHOR CONTRIBUTIONS

Viviane Laura Humm: Writing – original draft; Writing – review & editing. Irena Sailer: Conceptualization; Project administration. Daniel S. Thoma: Supervision; Writing – review & editing. Christoph H. F. Hämmerle: Supervision. Ronald E. Jung: Supervision. Anja Zembic: Writing – review & editing; Investigation.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest with the contents of this article.

DATA AVAILABILITY STATEMENT

The data that supports 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.

ETHICS STATEMENT

The study was evaluated and approved by the local ethical committee (Kantonale Ethikkomission Zürich, BASEC-Nr. 2016–01164).

CONSENT STATEMENT

After the approval, letters were sent out to the participants, informing them about the follow-up study and its purpose. Signed informed consent was obtained by all patients.

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