

ORIGINAL ARTICLE

Restorative angle of zirconia restorations cemented on non-original titanium bases influences the initial marginal bone loss: 5-year results of a prospective cohort study

Franz J. Strauss¹  | Marina Siegenthaler¹ | Christoph H. F. Hämmerle¹  |
Irena Sailer²  | Ronald E. Jung¹  | Daniel S. Thoma¹ 

¹Clinic of Reconstructive Dentistry, Center of Dental Medicine, University of Zurich, Zurich, Switzerland

²Division of Fixed Prosthodontics and Biomaterials, University Clinic of Dental Medicine, University of Geneva, Geneva, Switzerland

Correspondence

Daniel S. Thoma, Clinic of Reconstructive Dentistry, Center of Dental Medicine, University of Zurich Plattenstrasse 11, 8032 Zürich, Switzerland.

Email: daniel.thoma@zsm.uzh.ch

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Abstract

Aim: To assess radiographic, restorative, clinical and technical outcomes as well as patient satisfaction of directly veneered zirconia restorations cemented on non-original titanium bases over 5 years.

Material and Methods: Twenty-four patients with a single missing tooth in the aesthetic zone were recruited. All patients received a two-piece implant with a screw-retained veneered zirconia restoration cemented extraorally on a titanium base abutment. Marginal bone levels (MBL), marginal bone changes, technical complications, patient satisfaction and clinical parameters including probing depth, bleeding on probing and plaque index were assessed at crown delivery (baseline), at 1 year (FU-1) and 5 years (FU-5) of follow-up. To investigate the relationship between restorative angle and MBL as well as marginal bone changes (bone loss/bone gain), correlation tests and linear regression models were carried out.

Results: Twenty-two patients were available for re-examination at 5 years. The mean MBL amounted to 0.54 ± 0.39 mm at baseline, and to 0.24 ± 0.35 at FU-5 (=bone gain) ($p < .001$). At FU-1, a positive correlation ($r = .5$) between the mesial restorative angle and mesial MBL was found ($p = .012$). Marginal bone changes between baseline and FU-1 at mesial sites were also positively correlated with the mesial restorative angle ($r = .5$; $p = .037$). Linear and logistic regression models confirmed that mesial marginal bone loss was significantly associated with the mesial restorative angle at FU-1 ($p < .05$). At 5 years, these significant associations at mesial sites disappeared ($p > .05$). At distal sites, no correlations or associations between the restorative angle and MBL or marginal bone changes were found regardless of the time point. During the 5-year follow-up, 5 technical complications occurred, mainly within the first year and mostly chippings. All patients were entirely satisfied with their implant-supported restoration at 5 years.

Franz J. Strauss and Marina Siegenthaler and contributed equally to the manuscript and should be considered as joint first authors.

Trial registration: German Clinical Trials Register; DRKS00005458.

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Conclusion: Within the limitations of the present study, the restorative angle of implant-supported crowns on non-original titanium bases might influence the initial marginal bone loss but without affecting their favourable long-term clinical performance. A restorative angle of $<40^\circ$ may limit the initial marginal bone loss at implant-supported crowns with titanium bases.

KEYWORDS

CAD/CAM, dental implant-abutment design, dental implants, material testing, prosthodontics, titanium, zirconium

1 | INTRODUCTION

The continuous development in the field of dental materials has expanded the treatment options on the restorative level of dental implants. The major drivers in this field are aesthetics and mechanical stability shifting the field towards restorations with an aesthetic benefit (Jung, Sailer, Hammerle, Attin, & Schmidlin, 2007; Thoma et al., 2016) and accompanied by a digitalization of conventional protocols. This led to a shift from well-documented metal-ceramics (Jung, Zembic, Pjetursson, Zwahlen, & Thoma, 2012) to a myriad of all-ceramic materials such as zirconium dioxide (zirconia) ceramics (Pjetursson et al., 2021).

Zirconia has become a popular framework material not only because of its biocompatibility, favourable aesthetics and mechanical properties (Stawarczyk et al., 2013), but also because of the increasing use of CAD-CAM technologies and digital workflows in clinical practice (Muhlemann, Kraus, Hammerle, & Thoma, 2018). Hybrid abutments are CAD-CAM restorations that are cemented extra-orally to titanium bases and are supposed to combine aesthetic demands and a digital workflow together with improved mechanical stability.

Hybrid abutments were introduced by various implant manufacturers to allow the combination of different implants systems with different restorative materials (Sadowsky, 2020). In these types of implant-supported restorations, a pre-fabricated titanium abutment the so-called titanium base, acts as a connector to the implant onto which an individualized ceramic abutment (hybrid abutment) or a full-contour crown is cemented (Dhesi, Sidhu, Al-Haj Husain, & Ozcan, 2021). Despite the wide use of these restorations in clinical practice, evidence regarding the clinical and biological outcomes is still lacking. This lack of information is of particular importance as recent studies revealed that the restorative or prosthetic design may influence biological outcomes such as marginal bone loss (Inoue et al., 2020; Katafuchi, Weinstein, Leroux, Chen, & Daubert, 2018; Majzoub, Chen, Saleh, Askar, & Wang, 2021; Yi, Koo, Schwarz, Ben Amara, & Heo, 2020).

The implant/abutment connection and the abutment design play a crucial role in marginal bone level changes (bone gain or bone loss). In an effort to control the initial marginal bone loss after implant placement, the platform switching concept was introduced (Lazzara & Porter, 2006). This concept is based on the notion that by using a horizontally mismatched implant to abutment diameter the

implant-abutment interface is displaced from the bone thereby limiting the marginal bone loss (Galindo-Moreno et al., 2016). Equally as important is the maintenance of the marginal bone levels over time following the prosthetic restoration of the implant. Even though the minimum standards for what is considered an acceptable marginal bone loss over time were set many years ago (Albrektsson, Zarb, Worthington, & Eriksson, 1986), surprisingly the influence of the restorative or prosthetic design has often been neglected.

The literature reports conflicting data regarding the influence of the restorative or prosthetic design on marginal bone levels. Whilst recent studies suggest that the prosthetic design (Katafuchi et al., 2018; Majzoub et al., 2021; Yi et al., 2020), specifically the restorative angle, may influence the marginal bone loss and the risk of developing peri-implantitis (Schwarz et al., 2021), others failed to find any correlation between the restorative angle and marginal bone loss (Hentenaar, De Waal, Van Winkelhoff, Raghoobar, & Meijer, 2020). It should be noted, however, that the abovementioned studies were of cross-sectional nature and included several implant systems thereby precluding a generalization and clear interpretation of the data. These conflicting results clearly show a gap in understanding as to whether the prosthetic design influences marginal bone levels, particularly when the abovementioned titanium bases are used. Thus, it seems reasonable to further explore a possible association with a longitudinal design in order to overcome the limitations of previous studies. A further elucidation of this possible association can likely be translated with clinical benefits in the prosthetic management of dental implants.

The aim of the present prospective single cohort study was, therefore, to assess radiographic, clinical and technical outcomes as well as patient satisfaction of directly veneered zirconia restorations cemented on titanium bases over 5 years.

2 | MATERIALS AND METHODS

2.1 | Data collection

This study was designed as a single-center, prospective single cohort study. This article is reported according to the EQUATOR/STROBE guidelines for reporting observational studies (von Elm et al., 2008). Ethics approval was obtained by the local authorities (ref. number: 2013-0431, PB 2017-00165). Twenty-four healthy patients were

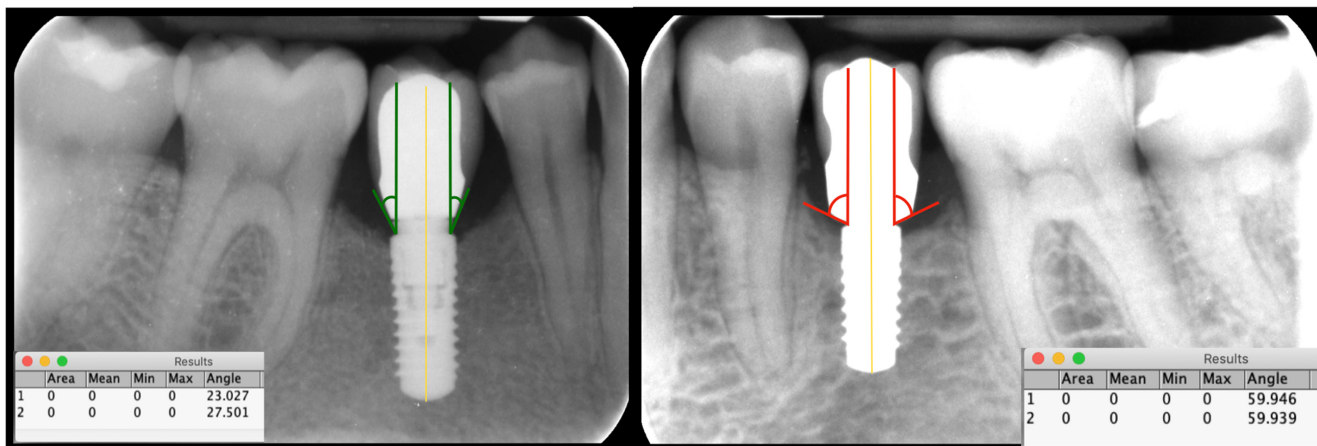


FIGURE 1 Restorative angle measurements on radiographs

enrolled in the present study and all patients signed an informed consent prior to study initiation.

2.2 | Inclusion/exclusion criteria

Detailed inclusion and exclusion criteria have been reported previously (Asgeirsson et al., 2019). In brief, inclusion criteria were as follows:

- patients aged between 18 and 80 years
- single missing tooth in the anterior maxilla or mandible (incisors, canines and premolars)
- single-tooth two-piece implant (Bone level, Institute Straumann AG, Switzerland)
- at least one natural neighbouring tooth present

Exclusion criteria were as follows:

- probing depth values >3 mm
- poor oral hygiene (plaque control record >20%)
- heavy smoker (>10 cigarettes a day)
- signs of bruxism
- pregnancy at the date of inclusion

2.3 | Clinical procedures

The detailed clinical procedure has been published in a previous publication (Asgeirsson et al., 2019). Following implant placement, a provisional phase and a final impression, all 24 participants received a directly veneered fluorescent zirconia abutment (Lava Plus High Translucency Zirconia Build up for two-piece abutment, 3 M ESPE) cemented onto a titanium base (Zirkon, Medentika GmbH) and tightened according to the manufacturer's specifications. A baseline examination was scheduled 7–10 days after crown insertion. There, a definitive composite filling (Tetric Classic, Ivoclar Vivadent AG) was

placed to close the screw access hole. Patients were enrolled in a regular maintenance program with the dental hygienist and follow-up examinations were performed at 6 months, 1 year, 3 years, and 5 years after loading.

2.4 | Fabrication of restorations

All restorations were made by a single experienced dental technician. Zirconia abutments were fabricated with a computer-assisted design/computer-assisted manufacturing (CAD/CAM) procedure. This zirconia abutment served as a framework abutment and was then directly veneered with fluorescent feldspathic veneering-ceramic (Creation ZI-CT, Creation Willi Geller International GmbH). The directly veneered zirconia abutments were cemented extraorally (Panavia 21®, Kuraray Medical Inc.) onto a titanium base. Excess cement was removed, and restorations were polished.

2.5 | Outcome measures

2.5.1 | Radiographic measurements

Two-dimensional intraoral X-rays at baseline (7–10 days after crown insertion), 1 year, 3 years and 5 years follow-up were taken using a paralleling technique with rim-holders and digital films (XCP dental film/PSP holder, Dentsply). Marginal bone levels were calculated at the different time-points by measuring the distance between the implant shoulder and the first bone-to-implant contact. The inter-thread pitch distance (0.8 mm) was used for the calibration of the apical-coronal measurements in each radiograph by using an open-source software (ImageJ 1.50i, National Institutes of Health). The marginal bone level assessments were performed by one examiner on two different occasions at least one month apart. For the 2nd occasion, radiographs of 10 patients were randomly selected using a computer-generated list (www.randomizer.org) and the intra-examiner reliability was calculated with the intra-class correlation

coefficient (ICC). The mean ICC amounted to 0.93 revealing a good intra-examiner reliability. Bone loss (MBL<0) was defined as negative changes of marginal bone levels between baseline and the follow-ups, whereas bone gain (MBL>0) was defined as positive changes of marginal bone levels between baseline and the respective follow-ups.

2.5.2 | Restorative angle

The restorative angle was calculated as previously described (Yi et al., 2020) with some modifications. The restorative angle was obtained by calculating the angle between a line parallel to the implant axis, drawn at the outer contour of the abutment and another line tangent to the height of the proximal contour of the restoration (Figure 1). Implants were then divided into two groups: those with a restorative angle $\leq 40^\circ$, and those with a restorative angle $>40^\circ$ interproximally. This cut-off was chosen to obtain a balanced sample as there were too few restorations with a restorative angle $\leq 30^\circ$. It has to be noted that the 30° cut-off applied in previous clinical studies (Katafuchi et al., 2018; Majzoub et al., 2021; Yi et al., 2020) derives from a dog study on conventional crowns and not implants (Kohal, Gerds, & Strub, 2003).

2.5.3 | Clinical parameters

Probing depth (PD), plaque control record (PCR)(O'Leary, Drake, & Naylor, 1972) and bleeding on probing (BOP) were measured at six sites for all implants and the two neighbouring teeth. All the clinical measurements were performed by an independent, blinded and trained examiner using a North Carolina periodontal probe (Hu-Friedy® UNC 15). The examiner was not involved in the surgical or prosthetic treatment. The measurements were rounded to the nearest 0.5 mm.

As a biological complication, peri-implant mucositis and periimplantitis were assessed according to the consensus report of the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions.

Peri-implant mucositis case definition (Berglundh et al., 2018):

- Presence of bleeding and/or suppuration on gentle probing with or without increased probing depth compared with previous examinations.
- Absence of bone loss beyond crestal bone level changes resulting from initial bone remodelling.

Peri-implantitis case definition (Berglundh et al., 2018)

- Presence of bleeding and/or suppuration on gentle probing
- Probing depths of ≥ 6 mm
- Bone levels ≥ 3 mm apical of the most coronal portion of the intraosseous part of the implant based on periapical X-ray.

2.5.4 | Technical parameters

Modified USPHS (United States Public Health Service) criteria were used to assess the restorations at baseline, 6 months, 1 year, 3 years and 5 years after crown insertion. Any of the following technical complications were recorded and reported: fracture or chipping of the framework and/or veneering ceramic (minor = adjustable chairside, major = needs adjustments in the dental lab), fracture or loosening of prosthetic screws, abutment loosening and/or fracture, implant fracture and loss of the screw access hole filling.

2.5.5 | Soft tissue thickness

Soft tissue thickness was assessed at baseline, 6 months, 1 year, 3 years and 5 years after crown insertion. An endodontic file (K- File, Kerr Dental, USA; diameter #15) and a rubber stopper were used to measure the soft tissue thickness 1 mm apical of the midfacial mucosal margin at the implant sites.

2.5.6 | Patient satisfaction

Patient satisfaction was assessed using a satisfaction scale (Hickel et al., 2007) with slight modifications:

- 1 = Patient is entirely satisfied.
- 2 = Patient criticizes the aesthetics.
- 3 = Patient request an improvement of the restoration.
- 4 = Patient is completely dissatisfied.

2.6 | Statistical analysis

The metric variables were described with values in mean, median, standard deviation and quartiles. To investigate the relationship between restorative angle and marginal bone level (MBL) and marginal bone changes (bone loss/bone gain) correlation tests, simple linear and binary logistic regression models were conducted. To assess the changes of MBL, PD, BOP and PI over time, the non-parametric tests Brunner-Langer and Wilcoxon signed-rank were performed as well as the parametric paired t-test. To evaluate the influence of time, angle and site (mesial/distal) on MBL, interaction tests were conducted. The data were analyzed per protocol (if not stated otherwise). The level of significance was set at 5%.

3 | RESULTS

3.1 | Study population

Twenty-four patients (11 women and 13 men) received a two-piece implant with a screw-retained directly veneered zirconia restorations cemented to non-original titanium base abutments (all single crowns,

non-matching implant-abutment junction). During the 5 years of follow-up, two implants with the respective restorations (one in the maxilla and one in the mandible) were removed at 3- and 30-months post-loading due to peri-implantitis (progressive bone loss, BOP and suppuration) resulting in a survival rate of 91.7% at 5 years.

Consequently, 22 patients (with 22 implants) were available for re-examination at 5 years (Figure S1). Twenty implants were located in the premolar region and two in the incisor region. Seventeen implants were placed in the maxilla and five in the mandible with two different diameters (17 implants had a diameter of 4.1 mm and 5 implants had a diameter of 3.3 mm) (Figure 2). The patients' age at 5 years of follow-up ranged from 29 to 75 years.

3.2 | Restorative angles

The mean restorative angle at distal sites amounted to 43.1° (median: 42.6; Q1: 30.9; Q3: 56.9) and at mesial sites to 42.6° (median: 39.2; Q1: 29.1; Q3: 55.7). Accordingly, and in order to obtain a balanced group of implants with respect to the restorative angle, implants were divided into two groups using a cut-off of 40°; those with a restorative angle $\leq 40^\circ$ and those with a restorative angle $>40^\circ$ interproximally.

3.3 | Radiographic outcomes

The mean marginal bone level (mesial/distal) significantly changed from baseline to 5 years (0.32 ± 0.36 mm; $p = .001$) indicating bone gain (Table 1). At mesial sites, this bone gain amounted to 0.32 ± 0.50 (intragroup $p = .005$) and at distal sites 0.25 ± 0.37 (intragroup

$p = .003$). An intention-to-treat analysis (including 23 patients at 5 years of follow-up) patients is presented in Table S1.

3.3.1 | Restorative angle assessment and the influence on radiographic marginal bone levels

Based on the restorative angle cut-off ($\leq 40^\circ$ or $>40^\circ$), the non-parametric model for longitudinal data (Brunner-Langer) revealed that from baseline to 5 years of follow-up, the averaged marginal bone level (mesial/distal) depended on time ($p < .001$) and angle (borderline significance; $p = .056$). This means that the trajectory of marginal bone levels differed significantly according to the time and according to the cut-off angle ($\leq 40^\circ$ or $>40^\circ$) (Figure S2). During the first year, there was a trend to gain bone under lower angles ($\leq 40^\circ$), while under higher angles ($>40^\circ$) there was a trend to lose bone (Figure S2). These opposite trends tended to disappear at later time points (Figure S2).

3.3.1 | One-year results

At mesial sites, descriptive statistics revealed that 63.6% of implants with a restorative angle $>40^\circ$ displayed marginal bone loss (Figure 3). In contrast, when the restorative angle was $<40^\circ$, only 18.2% of the implants showed marginal bone loss. A similar trend was found at the distal sites. When the restorative angle was $>40^\circ$, 53.5% of the implants displayed marginal bone loss, whereas only 27.3% of the implants showed bone loss when the restorative angle was $\leq 40^\circ$.

At one year of follow-up, correlation tests yielded a positive correlation ($r = .5$, $p = .01$) between the mesial restorative angle and the marginal bone level (Figure 4a) (Table 2). Moreover, the marginal bone changes (bone loss/bone gain) were positively correlated with the mesial restorative angle ($r = .5$, $p = .037$) (Table 2) (Figure S3). Implants that showed bone loss clustered around higher restorative angles, whereas implants that showed bone gain clustered around lower restorative angles (Figure S3).

These positive correlations were not found at the distal sites, neither between the distal restorative angle and the distal marginal bone level ($r = .1$, $p = .64$) (Figure 4b) nor between the distal restorative angle and the marginal bone changes ($r = .3$, $p = .24$) (Table 2) (Figure S4).

The linear regression model revealed that the increase in restorative angle was significantly associated with an increase in marginal bone level ($p = .012$) (Table 3). In addition, from baseline to 1-year follow-up, an increase in the angle was significantly associated with an increase in marginal bone changes ($p = .030$) (Table 3). Per additional unit in the mesial angle, the marginal bone at mesial sites changed by ≈ 0.024 mm. Conversely, this association was not found at distal sites ($p > .05$) (Table 3).

Logistic regression models revealed that restorative angles $>40^\circ$ at mesial sites were more likely (OR: 7.8, 95%: 1.11–56.1, $p = .039$) to lose bone (Table 4). At distal sites, this trend was not detected (OR: 3.2, 95%: 0.54–18.9, $p = .200$) (Table 4).

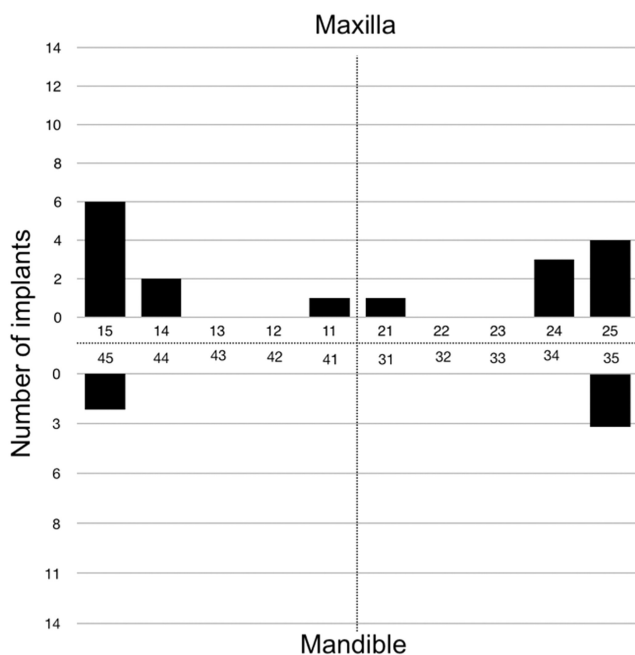


FIGURE 2 Distribution and location of the implants

TABLE 1 Radiographic data of marginal bone level at baseline and 5 years of follow-up (FU-5) with the corresponding bone changes over time

MBL		Baseline	FU-5	Bone changes (baseline to FU-5)	<i>p</i> -value
		<i>n</i> = 24	<i>n</i> = 22	<i>n</i> = 22	
Mesial (mm)	Mean ± SD	0.54 ± 0.53	0.22 ± 0.29	0.32 ± 0.50	.005*
	Median (IQR)	0.48 (0.15;0.60)	0.19 (0.00;0.31)	0.37 (0.51;0.07)	
Distal (mm)	Mean ± SD	0.52 ± 0.36	0.26 ± 0.36	0.25 ± 0.37	.003*
	Median (IQR)	0.87 (0.21;0.74)	0.19 (0.00;0.35)	0.30 (0.39;0.18)	
Mesial and distal	Mean ± SD	0.54 ± 0.39	0.24 ± 0.25	0.32 ± 0.36	.001*
	Median (IQR)	0.47 (0.30;0.67)	0.16 (0.03;0.44)	0.32 (0.50;0.13)	

Note: Changes over time were assessed using Wilcoxon signed-rank test. *p* values are given.

3.3.2 | 5-year results

At mesial sites, descriptive statistics revealed that 20% of implants with a restorative angle >40° displayed bone loss while 16.2% of the implants showed bone loss when the restorative angle was <40° (Figure 5). At distal sites when the restorative angle was >40°, 10% of the implants displayed bone loss, while 16.7% of the implants showed bone loss when the restorative angle was ≤40°. Four out of 22 mesial sites displayed bone loss, while 3 out of 22 distal sites showed bone loss.

At 5 years of follow-up correlation tests did not reveal any linear correlations (either at mesial nor distal sites) between the restorative angles and the marginal bone levels (*p* > .05) (Table 2). Likewise, simple linear regression models (Table 3) and logistic regression models (Table 4) did not show any significant association between marginal bone levels and restorative angle (*p* > .05).

3.4 | Clinical and biological outcomes

All data for probing depth (PD), plaque control record (PCR) (O'Leary et al., 1972), bleeding on probing (BOP) (yes/no), soft tissue thickness and crown height at implant sites are reported in Table 5. From baseline to 5 years of follow-up, PD increased significantly (*p* = .043) while BOP did not change significantly (*p* = .366). The mean plaque levels values and the crown height did not change significantly between both time points (Table 5).

Peri-implant mucositis was present in 11 out of the 22 patients resulting in a prevalence 50%. None of the patients presented peri-implantitis at 5 years of follow-up. Soft tissue thickness increased significantly over time, from 2.5 mm ± 1.0 mm (baseline) to 3.2 mm ± 0.9 mm (5 years) (*p* = .013).

3.4.1 | Technical parameters

Four technical complications occurred within the first year. These included two minor chippings, one major chipping and one abutment loosening. One additional technical complication (minor chipping)

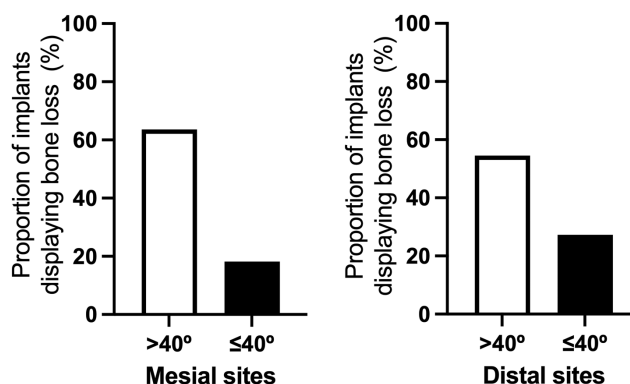


FIGURE 3 Proportion (%) of implants displaying bone loss (mesial or distal) according to the restorative angle (≤40° or restorative angle >40°) at 1 year of follow-up

occurred between the 1 year and 3 years follow-up. This resulted in an 81.8% success rate on a prosthetic level.

3.4.2 | Patient satisfaction

All 22 patients were entirely satisfied with their implant-supported restoration at 5 years of follow-up.

4 | DISCUSSION

The present study assessing the clinical, technical and biological outcomes as well as patient satisfaction of directly veneered zirconia implant-supported restorations cemented on titanium bases over 5 years predominantly revealed that: i. the restorative angle of implant-supported crowns on titanium bases influences the initial marginal bone loss in the short-term (1-year follow-up) but not in the long-term (5-year follow-up) ii. no technical complications between 3 and 5 years of follow-up, iii. a relatively high rate (50%) of peri-implant mucositis at 5 years and, iv. high levels of patients' satisfaction.

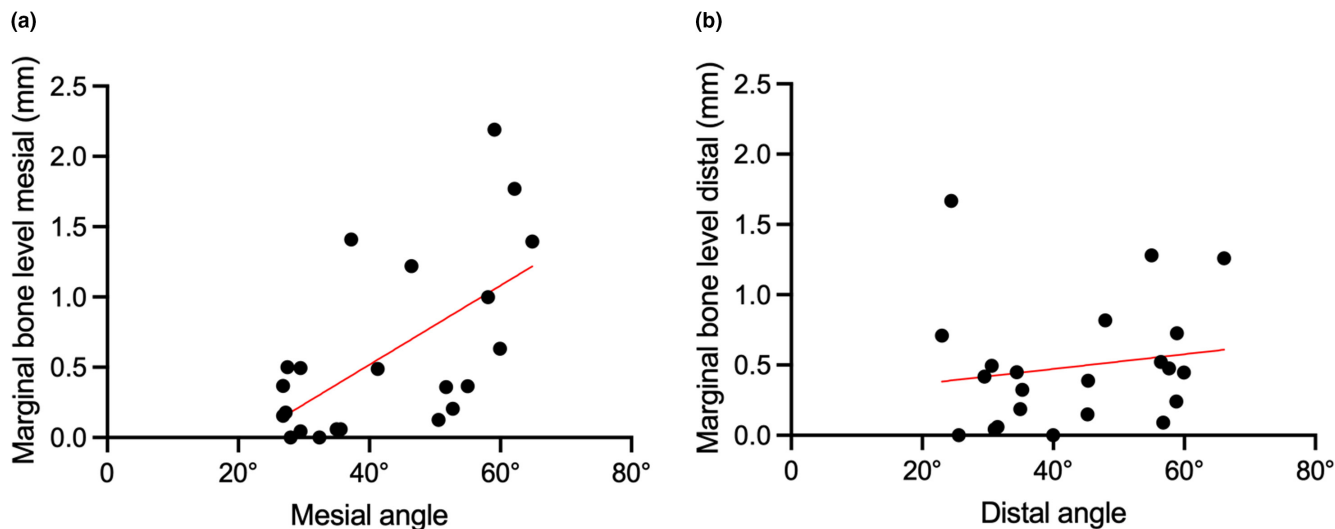


FIGURE 4 Correlation analysis between the restorative angle and the marginal bone level at 1 year of follow up. (a) Positive correlation between mesial restorative angles and mesial marginal bone level ($r = .5, p = .01$). (b) Positive correlation between distal restorative angle and distal marginal bone level ($r = .1, p = .64$)

TABLE 2 Correlation between mesial/distal restorative angles and marginal bone levels and bone changes at one and 5 years of follow-up

		Marginal bone level	Bone changes
One year	Angle	Pearson correlation	Pearson correlation
	Mesial angle	0.53 $p = .012^*$	0.50 $p = .037^*$
	Distal angle	0.10 $p = .646$	0.30 $p = .247$
Five years	Angle	Pearson correlation	Pearson correlation
	Mesial angle	-0.07 $p = .762$	-0.14 $p = .535$
	Distal angle	0.27 $p = .646$	0.33 $p = .128$

Note: Correlations were assessed using Pearson's correlation coefficient. p values are given.

Stable marginal bone levels remain an important parameter to achieve favourable therapeutic outcomes in implant dentistry. Extensive efforts have been made to identify the factors that influence marginal bone stability. Although the minimum standards for what is considered an acceptable marginal bone loss were set many years ago (Albrektsson et al., 1986), surprisingly the influence of restorative or prosthetic factors have often been neglected. The present study revealed that the restorative angle was positively correlated with bone loss at mesial sites over the short-term, meaning that higher restorative angles tended to show more bone loss during the first year, post-loading. This finding was further supported by the observation that restorative angles $>40^\circ$ were more likely to lose bone within the first year (OR: 7.8, $p = .039$). These associations, however, were not detected at distal sites. This lack of association might be attributed to the local

anatomy. Compared with distal sites, bone peaks at mesial sites tend to be larger, which may to some extent explain the higher bone loss at mesial sites. Typically, the alveolar bone crest follows the contour of the cement enamel junction (Gonzalez-Martin & Avila-Ortiz, 2021) and given that the cervical line curvatures are greater at mesial sites (Vandana & Haneet, 2014; Zhou et al., 2014), it is likely to expect larger interproximal bone peaks at mesial sites. Furthermore, bone levels at mesial and distal sites tend to be uneven after implant placement particularly when implants are placed sub-crestally. This may occur when implants are inserted according to the most appropriate prosthetic position and not according to bone availability.

Recent clinical studies have suggested that restoration angles $>30^\circ$ are significantly associated with increased marginal bone loss (Katafuchi et al., 2018; Majzoub et al., 2021; Yi et al., 2020). In a

TABLE 3 Simple linear regression for predicting the marginal bone level and marginal bone changes

	1 year follow-up			5 years follow-up		
	Coefficient	95% CI	p-value	Coefficient	95% CI	p-value
Marginal bone level (mm)						
Mesial angle	0.024	0.006–0.043	.012*	–0.001	–0.011–0.008	.762
Distal angle	0.003	–0.012–0.018	.646	0.007	–0.005–0.019	.211
Baseline to 1-year follow-up						
	Coefficient	95% CI	p-value	Coefficient	95% CI	p-value
Marginal bone changes (mm)						
Mesial angle	0.023	0.001–0.045	.036*	–0.005	–0.022–0.012	.535
Distal angle	0.007	–0.005–0.019	.247	0.009	–0.003–0.021	.128

Note: 95% confidence interval and *p*-value obtained using simple linear regression.

Abbreviation: CI, confidence interval.

TABLE 4 Multivariable logistic regression analysis for predicting bone loss (yes/no) by the restorative angle and site (mesial/distal) at one and five years of follow-up

	1 year of follow-up			5 years of follow-up		
	OR	95% CI	p-value	OR	95% CI	p-value
Mesial angle						
<40° (reference)	1			1		
≥40°	7.8	1.11–56.1	0.039*	1.25	0.14–10.9	0.840
Distal angle						
<40° (reference)	1			1		
≥40°	3.2	0.54–18.9	0.200	0.56	0.04–7.21	0.653

Note: Odds-Ratio, 95% confidence interval and *p*-value obtained using multivariable logistic regression.

Abbreviations: CI, confidence interval; OR, Odds-Ratio.

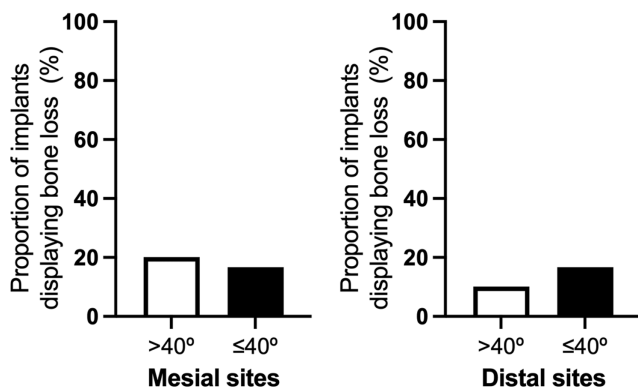


FIGURE 5 Proportion (%) of implants displaying bone loss at mesial or distal sites according to the restorative angle ($\leq 40^\circ$ or $> 40^\circ$) at five years follow-up

cross-sectional study, in which 169 patients with 349 implants were analysed, bone level implants with a restorative angle $> 30^\circ$ showed an approximate twofold increase in bone loss compared with those with a restorative angle $< 30^\circ$ (Yi et al., 2020). The same study also showed a higher prevalence of peri-implantitis when the restorative angle was $> 30^\circ$. Similarly, another recent retrospective study

investigated the influence of restorative design on the progression of peri-implant bone loss (Majzoub et al., 2021). The study, which included 65 patients and 83 bone level implants, revealed that implants with a restoration angle $> 30^\circ$ exhibited more marginal bone loss than those with an angle $\leq 30^\circ$ (Majzoub et al., 2021). The present findings appear to be consistent with the studies mentioned above, despite the fact that in the present study a different cut-off was used (40° rather than 30°). It has to be noted, however, that the applied 30° cut-off in the previous clinical studies (Katafuchi et al., 2018; Majzoub et al., 2021; Yi et al., 2020) derives from a dog study on conventional crowns and not implants (Kohal et al., 2003). Therefore, the validity of such a cut-off in a clinical setting might be questionable. The decision for the 40° cut-off over 30° was based upon the mean and median restorative angle in the present study, which amounted to $\approx 40^\circ$. There were few restorations with an angle $< 30^\circ$ thereby hindering any meaningful comparisons with that cut-off.

A positive association between the restorative angle and marginal bone loss might be attributed to various reasons. For example, it is possible that restoration angles ($> 40^\circ$) may hinder proper hygiene measures due to limited access. As shown in the present cohort, BOP levels increased from baseline to 1-year follow-up

TABLE 5 Clinical parameters at baseline (BL) and 5 years of follow-up (FU-5)

	Baseline	FU-5	p-value
PD (mm)			
Mean \pm SD	3.0 \pm 0.06	3.3 \pm 0.08	.043*
Median (IQR)	2.9 (2.6;3.5)	3.3 (2.8;3.8)	
BOP (%)			
Mean \pm SD	27.1 \pm 20.7	31.1 \pm 26.4	.366
Median (IQR)	16.7 (16.7;33.3)	25.0 (16.7;50.0)	
PCR (%)			
Mean \pm SD	11.1 \pm 21.2	13.6 \pm 17.5	.832
Median (IQR)	0.0 (0.0;8.3)	16.7 (0.0;16.7)	
Soft tissue thickness (mm)			
Mean \pm SD	2.5 \pm 1.0	3.2 \pm 0.9	.013*
Median (IQR)	2.0 (2.0;3.0)	3.0 (2.5;3.5)	
Crown height (mm)			
Mean \pm SD	8.7 \pm 1.2	8.7 \pm 1.4	.584
Median (IQR)	9.0 (8.0;10.0)	8.0 (8.0;10.0)	

Note: Changes over time were assessed using Wilcoxon signed-rank test or paired t-test according to the distribution of the data. *p* values are given. Abbreviation: BOP, bleeding on probing; PCR, plaque control record; PD, probing depth.

(Asgeirsson et al., 2019) suggesting a suboptimal hygiene. Moreover, this hypothesis seems to be further supported by a recent RCT that assessed the adjunctive effect of modifying the implant-supported prosthesis when treating peri-implant mucositis (de Tapia et al., 2019). In the mentioned 6 months follow-up study, the authors found that the modification of the restorative contour in the test group—to facilitate the oral hygiene—resulted in significant better clinical outcomes than the control group, in which the restorative contour was not modified (de Tapia et al., 2019). Consistently, outcomes from a cross-sectional study showed a tendency ($p > .05$) towards inferior BOP levels at implants with a restorative angle between 20° and 40° (Inoue et al., 2020).

Another plausible explanation for the positive correlation between the restorative angle and the observed initial marginal bone loss is the possible micromovement at the implant/abutment interface due to the use of non-original abutments in the present study. Previous data have revealed that movements between implant components can result in significant bone loss (Hermann, Schoolfield, Schenk, Buser, & Cochran, 2001) likely due to a bacterial contamination of the gap created at the interface (Broggini et al., 2003) or due to a release of material wear and debris into the local environment (Fretwurst et al., 2016). These detrimental effects could also have been reinforced directly or indirectly by the proximity of the abutment-implant interface to the bone. Several studies revealed significant more bone loss with 1-mm-height abutments than with 2.5 or 3.0mm-height abutments (Blanco et al., 2018; Galindo-Moreno et al., 2014; Novoa et al., 2017). Nevertheless, it must be mentioned that at the time of study initiation, no original titanium bases were available. Thus, the used hybrid abutments were ordered from an external source but approved by the implant manufacturer.

Interestingly, at 5 years of follow-up all positive correlations between the restorative angle and marginal bone levels and bone loss disappeared. In fact, there was an improvement in marginal bone levels over time indicating bone gain. These results seem to contradict previous clinical studies showing bone loss over time. This discrepancy might be related to two aspects; i. the two dropouts due to implant loss and ii. the subsequent absence of peri-implantitis during the remaining follow-up. In fact, by applying an intention-to-treat analysis these gains tended to dilute slightly. It should be mentioned that most studies that have focused on the restorative angle, have included many patients with peri-implantitis (Katafuchi et al., 2018; Majzoub et al., 2021; Yi et al., 2020). Conversely, in studies that have included patients without peri-implantitis no correlations between the restorative angle and marginal bone loss could be found (Hentenaar et al., 2020) being consistent with the present findings.

The initial marginal bone loss and the subsequent bone gain observed in the present study, might be explained by the major remodelling processes and marginal bone level changes around dental implants that take place during the first year (Galindo-Moreno et al., 2014). Moreover, in some cases, these bone changes may only involve demineralization of the marginal bone rather than true bone loss. Often, based on X-rays, it is difficult to distinguish a demineralization process from an initial marginal bone loss; hence, it is conceivable that the bone gain observed at 5 years might be partly attributable to a classification bias (Puisys et al., 2019). In other words, the initial marginal 'bone loss' may correspond to a process of demineralization rather than true bone loss. Nevertheless, others have also reported bone level improvements over time (bone gain), also including implants with hybrid abutments and ti-bases (Klein, Tarnow, & Lehrfield, 2020). Finally, a random or systematic error in the marginal bone levels measurement appears unlikely to account

for the initial bone loss and subsequent bone gain, as the intraclass correlation coefficients were above 0.9 indicating an excellent intra-examiner reliability.

Hybrid abutments on ti-bases are being increasingly used in clinical practice, however, long-term clinical data—with at least 5 years of follow-up—are lacking. The present study revealed no technical complications between 3 and 5 years demonstrating a good clinical performance. Most of the technical complication occurred within the first year (Asgeirsson et al., 2019). Unfortunately, a comparison between the present technical outcomes with other clinical datasets is not feasible, as there is no long-term clinical data available for all-ceramic implant-supported single crowns on titanium bases (Pjetursson et al., 2021). To the best of our knowledge, this is the longest follow-up report available using titanium bases.

Biological outcomes namely PD and BOP tended to increase over time indicating a relatively high prevalence of peri-implant mucositis. Nevertheless, these high values of peri-implant mucositis are within the range of results reported by RCTs (25%–50%) (Walter et al., 2022), cross-sectional studies (37%) (Romandini et al., 2021) and systematic reviews (19%–65%) (Derks & Tomasi, 2015). It is worth noting that there are different forms to evaluate BOP: punctiform or profuse bleeding (Renvert, Persson, Pirihi, & Camargo, 2018); bleeding after measuring the probing depth or bleeding after walking with the periodontal probe through the peri-implant sulcus. As these different methods have not been standardized in the literature (Romandini et al., 2021), an overestimation of the present rates cannot be dismissed. Despite the relatively high rates of BOP, no patient presented peri-implantitis after 3 years of follow-up.

All patients were highly satisfied with the received treatment at 5 years of follow-up, in accordance with the existing literature on implant-supported restorations (Feine et al., 2018; Lamperti et al., 2022; Wittneben, Wismeijer, Bragger, Joda, & Abou-Ayash, 2018).

The present study has some limitations that need to be acknowledged when interpreting the present findings. The sample was small and the sample size calculation was based on peri-implant soft tissue discoloration (Thoma et al., 2017) and not based on marginal bone loss, thus limiting the power. In addition, for the logistic regression, any negative change in marginal bone level was considered as marginal bone loss; therefore, a marginal bone loss due to a measurement error cannot be dismissed despite the excellent intra-examiner reliability. This limitation, however, was overcome to some extent by providing scatterplots thereby facilitating the visualization of trends, data relationships and clustering effects without applying an arbitrary cut-off.

Collectively, it is clear that prosthetic factors in implant-supported restorations merit further research attention in order to provide some prosthetic guidelines that are currently lacking. The present study revealed novel prosthetic and biological features as well as long-term clinical data on the performance of ti-base restorations that are increasingly used in daily clinical practice. Future studies will have to ascertain the credibility of the present findings.

5 | CONCLUSION

Within the limitations of the present study, the restorative angle of implant-supported crowns on non-original titanium bases influences the initial marginal bone loss but without affecting their favourable long-term clinical performance. A restorative angle of <40° may limit the initial marginal bone loss in implant-supported crowns with titanium bases.

AUTHOR CONTRIBUTIONS

Franz Josef Strauss: Data curation (equal); formal analysis (lead); investigation (lead); methodology (lead); validation (lead); visualization (lead); writing – original draft (lead); writing – review and editing (lead). **Marina Siegenthaler:** Data curation (equal); formal analysis (equal); validation (equal); visualization (equal); writing – review and editing (supporting). **Christoph H.F. Hämmerle:** Conceptualization (equal); funding acquisition (equal); project administration (equal); supervision (equal); visualization (equal); writing – review and editing (supporting). **Irena Sailer:** Conceptualization (equal); funding acquisition (equal); resources (equal). **Ronald Ernst Jung:** Conceptualization (equal); funding acquisition (equal); project administration (equal); resources (equal); supervision (equal); writing – review and editing (supporting). **Daniel S. Thoma:** Conceptualization (equal); funding acquisition (equal); investigation (equal); methodology (equal); project administration (equal); resources (equal); supervision (equal); writing – review and editing (supporting).

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CONFLICT OF INTEREST

All authors declare to have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Franz J. Strauss  <https://orcid.org/0000-0002-5832-7327>

Christoph H. F. Hämmerle  <https://orcid.org/0000-0002-8280-7347>

Irena Sailer  <https://orcid.org/0000-0002-4537-7624>

Ronald E. Jung  <https://orcid.org/0000-0003-2055-1320>

Daniel S. Thoma  <https://orcid.org/0000-0002-1764-7447>

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SUPPORTING INFORMATION

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