Ligature-Induced Peri-implant Bone Loss Around Loaded Zirconia and Titanium Implants

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Purpose: To radiographically investigate ligature-induced peri-implant bone loss around loaded titanium (Ti-SLA) and zirconia (ZrO$_2$-ZLA) implants using a canine model. **Materials and Methods:** Forty sandblasted and acid-etched titanium and zirconia implants were alternately placed in the mandibles of five canines (20 Ti-SLA, 20 ZrO$_2$-ZLA). Implants were restored after 6 weeks of unloaded healing. After 4 weeks of functional loading, oral hygiene procedures were stopped and experimental peri-implant bone loss was initiated by placing cotton ligatures. After 8 weeks of active progression, ligatures were removed and plaque was allowed to accumulate for another 16 weeks of spontaneous progression (without ligatures). Standardized radiographs were taken at implant placement, at functional loading, and every 2 weeks during active and spontaneous progression of bone loss. **Results:** Before ligature placement, all implants were successfully osseointegrated and no clinical or radiographic signs of peri-implant infections were detectable. Two weeks after ligature removal, one titanium implant was lost; however, no zirconia implant failures were observed during the study. Radiographically, zirconia implants revealed statistically significantly less crestal peri-implant bone loss compared with titanium implants at the end of the active progression period (Ti-SLA: 3.92 mm; ZrO$_2$-ZLA: 2.65 mm; P < .01); however, no significant differences occurred after the spontaneous progression period (P = .6). Combining the active and spontaneous progression periods together, zirconia implants demonstrated significantly reduced peri-implant bone loss compared with titanium implants (Ti-SLA: 3.76 mm; ZrO$_2$-ZLA: 2.42 mm; P < .01). **Conclusion:** These results demonstrate a significantly reduced ligature-induced inflammation and bone loss for ZrO$_2$-ZLA implants compared with Ti-SLA implants in the canine model. INT J ORAL MAXILLOFAC IMPLANTS 2019;34:357–365. doi: 10.11607/jomi.7015

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Currently, titanium implants are considered to be the "gold standard" in implant dentistry. Many experimental and clinical studies have confirmed the excellent osseointegrative capacity and clinical reliability of titanium implants with a microrough surface topography.[1] Survival and success rates of 95% and more up to and after 10 years of functional loading have been reported.[2–5] However, pathologic tissue transformations around dental implants, such as peri-implant infections, are among the main reasons for early and late titanium implant failure[6] and, consequently, endanger clinical short- and long-term results. In this context, a reversible inflammatory reaction of the peri-implant soft tissues, termed peri-implant mucositis, has to be distinguished from inflammatory reactions that are associated with peri-implant pocket formation and peri-implant bone loss, named peri-implantitis.[7–9] A recently published meta-analysis has reported a prevalence of 43% and 22% for peri-implant mucositis and peri-implantitis, respectively, around titanium implants of various types and placed with a number of different treatment protocols.[10]
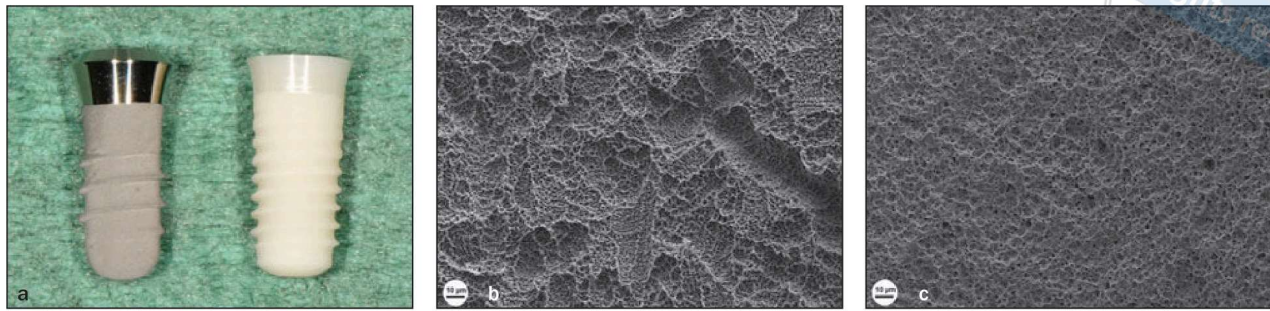
Fig 1 *(a)* Titanium (control, left) and zirconia (test, right) implants. Diameter 4.1 mm, length 8 mm. *(b, c)* SEM image of microrough intraosseous implant surfaces. Titanium-SLA (*[b]* Sa = 1.15 µm) and zirconia-ZLA (*[c]* Sa = 0.70 µm) surfaces. Scale bar indicates 10 µm (original magnification was 500×). Calculations were performed with the use of a Gaussian filter with a cut-off wavelength of 30 µm (information provided by the Straumann Group).

With regard to the etiology of peri-implant infections, microbial colonization, subsequent biofilm formation, and plaque accumulation are considered essential.[11–13] On teeth and implant surfaces in an oral environment, bacteria live in structured communities termed biofilm. Over time, these biofilms can lead to plaque accumulation.[14] Experimental and clinical studies have shown that plaque on titanium implant and abutment surfaces—if not removed—can induce peri-implant mucositis and, subsequently, peri-implantitis.[15–20] Interestingly, it has been reported that biofilm and plaque formation on implant surfaces are not only dependent on surface characteristics such as surface roughness and surface free energy, but also on the type of biomaterial used.[21,22]

Zirconium dioxide (zirconia, ZrO_2) has become an alternative to titanium for the fabrication of dental implants. In comparison to other oxide ceramics, zirconia shows superior biomechanical properties[23] that give zirconia dental implants the ability to withstand oral occlusal forces.[24,25] Results from animal experiments have reported that microroughened zirconia implants show at least a comparable osseointegrative capacity to moderately rough titanium implants.[26–30] In clinical studies, survival rates of more than 95% for investigation periods up to 5 years have been described for microroughened zirconia implants of the newest generation.[31–34] With regard to biofilm formation, less bacterial adhesion on zirconia compared with titanium surfaces[35–37] and fewer inflammatory cells in the peri-implant soft tissue of zirconia compared with titanium or other metals[38,39] have been reported. However, it remains unclear if material characteristics per se—zirconia compared with titanium—or reduced bacterial adhesions are associated with a minor occurrence of peri-implant inflammation or reduced inflammatory peri-implant bone loss. Moreover, regarding in vivo pathogenesis of peri-implant infections around zirconia compared with titanium implants, no scientific data are available so far. Thus, the aim of the present study was to analyze ligature-induced peri-implant bone loss around loaded zirconia and titanium implants using an experimental canine model and periapical radiographs.

MATERIALS AND METHODS

Animals

Five large mixed-breed, male American foxhounds of approximately 2 years of age and with a body weight of approximately 30 to 35 kg were used in this study. The animals were kept in a purpose-designed room for experimental animals and fed with a standard laboratory diet. Prior to the experiment, the animals underwent a quarantine period to help ensure health and acclimatization. The University of Texas Health Science Center at San Antonio's Institutional Use and Care of Animals Committee approved the experimental protocol.

Implant Design and Surface Characterization

In the present study, two different types of implants with an intraosseous diameter of 4.1 mm and a length of 8 mm were used. Both types of implants had a tissue-level platform design with a machined 1.8-mm-high transmucosal neck, a 4.8-mm shoulder diameter, and a microroughened endosseous part with a screw design (Fig 1).

Control implants were made from grade 4 commercially pure titanium with a microrough surface topography produced by sandblasting with large grit followed by an acid etching (SLA) procedure in a mixture of HCl and H_2SO_4. The control implants had a cylindrical intraosseous screw design with a thread pitch of 1.25 mm.

The test full-ceramic implants were made from yttria-stabilized zirconium dioxide (zirconia, ZrO_2) with a microrough surface topography that was manufactured by a sandblasting procedure followed by an etching procedure (zirconia large-grit sandblasted and acid-etched, ZLA). The test implants had a coronal tapered intraosseous screw design with a thread pitch of 0.8 mm.
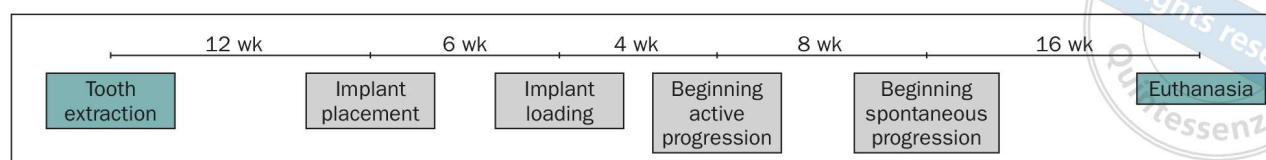
12 wk	6 wk	4 wk	8 wk	16 wk	
Tooth extraction	Implant placement	Implant loading	Beginning active progression	Beginning spontaneous progression	Euthanasia

Fig 2 Study design showing the different experimental phases. Oral hygiene procedures were only performed between implant placement and beginning of active progression period (wk = weeks).

Test and control implants were manufactured and provided by the Straumann Group.

Study Design

The study was performed in six experimental steps. Initially, premolars 1 to 4 and molar 1 (P1 to M1) were surgically extracted from both sides of the mandible (step 1). After a healing period of 12 weeks, two titanium and two zirconia implants were placed in each hemi-mandible in an alternating manner using a randomized scheme (step 2). After an unloaded healing period of 6 weeks, abutments and prefabricated crowns were placed and all implants were functionally loaded (step 3). During unloaded healing and functional loading periods, oral hygiene procedures were performed twice a week. After a functional loading period of 4 weeks (step 4), experimental peri-implantitis was induced by placing subgingival cotton ligatures around the implant shoulders to allow plaque accumulation. At the same time, oral hygiene procedures were stopped (step 5, active progression period). After 8 weeks of plaque accumulation and active progression of the peri-implant infections, the cotton ligatures were removed and another 16 weeks of plaque accumulation without oral hygiene procedure followed (step 6, spontaneous progression). After the spontaneous progression period, the animals were euthanized (Fig 2). Standardized periapical radiographs were taken at implant placement and at crown cementation. Additionally, standardized periapical radiographs were taken once every 2 weeks within the active and spontaneous progression period to monitor peri-implant bone loss. The primary outcome of the study was to radiographically evaluate the peri-implant bone loss during the active and the spontaneous progression period.

Surgical Procedures: Tooth Extraction

Mandibular tooth extractions were performed under general anesthesia and sterile conditions in an operating room using intravenous (IV) Thiopenthal-Na solution 4%, 0.4 mL/kg body weight as a premedication. The dogs were placed on a heating pad, intubated, and inhalated with isoflurane 1.5% to 2% and monitored with an electrocardiogram (EKG) during surgery. The surgical site was first disinfected with 10% povidone–iodine solution/1% titratable iodine. After that, 2% lidocaine HCl with epinephrine 1:100,000 was given as local anesthetic by injection. Following crevicular incisions, buccal and lingual flaps were reflected and all four premolars (P1 through P4) and the first molar (M1) of both sides of the mandible were extracted. Prior to extraction, the bifurcated teeth (P2 to M1) were sectioned to help prevent tooth fracture during extraction. Sharp bone edges were smoothed with an acrylic bur. The mucoperiosteal flaps were repositioned and sutured with nonresorbable interrupted sutures.

The day of surgery, the animals received 20 mg of the analgesic nalbuphine subcutaneously twice a day (10 mg/mL). Additionally, 3 mL of the antibiotic benzathine penicillin (150,000 IU) combined with procaine penicillin G (150,000 IU) was administered subcutaneously once a day every 48 hours for 7 to 10 days. For suture removal, after a period of 7 to 10 days, the animals were briefly anesthetized with a combination (1.1 mL/15 kg body weight) of xylazine (7.1 mg/mL), acepromazine (2.1 mg/mL), atropine (0.1 mg/mL), and ketamine (50 mg/mL) intravenously.

Surgical Procedures: Implant Placement

Twelve weeks after tooth extraction, a total of 40 tissue-level implants (20 titanium, 20 zirconia) were placed. Each hemi-mandible received two titanium and two zirconia implants. Both types of implants were placed in an alternating manner using a randomized scheme (four implants per hemi-mandible, eight implants per dog). Implant placement was performed under the same conditions as the tooth extractions (sterility, operating room, anesthesia). The recipient sites in the created edentulous areas of the mandible were exposed by a crestal incision and the elevation of buccal and lingual mucoperiosteal flaps. Prior to implant placement, the edentulous alveolar ridge was flattened. Osteotomy preparation was performed according to the surgical protocol recommended by the manufacturer using spiral drills with increasing diameter at 500 rpm and copious irrigation with sterile physiologic saline. Subsequently, the thread was cut into the osteotomy site with a tap. According to the randomized scheme, test and control implants were inserted on each side of the mandible and were left to heal in a transmucosal mode using 3-mm-high healing caps. The dogs received the same medication as given after the tooth extractions. Additionally, to reduce swelling, the dogs received

2 mL of the anti-inflammatory dexamethasone intramuscularly once a day on days 1 and 4 (2 mg/mL) according to the in-house protocol. The sutures were removed after 7 to 10 days. Following suture removal, oral hygiene procedures were performed twice a week using manual brushing with 0.2% chlorhexidine rinse.

Prosthetic Reconstruction and Functional Loading

After 6 weeks of unloaded healing, the animals were briefly anesthetized and both types of implants were functionally loaded with prefabricated single zirconia crowns. For the titanium implants, titanium solid abutments were connected and torqued to 35 Ncm using a torque driver. After that, zirconia crowns were cemented using glass ionomer cement (Ketac Cem, 3M). With regard to the ceramic implants, zirconia abutments as well as zirconia crowns were cemented with the same glass ionomer cement as previously used. After crown placement, oral hygiene procedures were performed as previously described.

Experimental Peri-implant Infections

After 4 weeks of functional loading, oral hygiene procedures were stopped and cotton ligatures (Ultrapak #1, Ultradent) were placed according to a previously described technique in a submarginal position around both types of implant necks.[20,40] The animals were briefly anesthetized, and ligatures were tightened around the implants and gently positioned apically of the gingival margin (active progression). The ligatures were exchanged once every 2 weeks and finally removed when a bone loss of approximately 40% to 50% had taken place. This occurred in all cases after 8 weeks of active progression period and was followed by another 16 weeks of plaque accumulation without cotton ligatures and without any oral hygiene procedure (spontaneous progression).

Euthanasia

Thirty-four weeks after implant placement, the animals were euthanized with an overdose of pentobarbital sodium intravenously (100 mg/kg body weight). Block-resection of the mandibles was performed using an oscillating autopsy saw, and the recovered segments with the implants were immersed in a solution of 4% formaldehyde combined with 1% $CaCl_2$ for histologic preparation and analysis.[41]

Radiographic Evaluation

For each animal, customized radiographic stents allowing standardized x-ray projections during the experimental period were prepared. For this purpose, a conventional film holding bite-block with paralleling beam-guiding device (XCP, Rinn) was customized with

acrylic resin to avoid changes in the x-ray beam projection at the different time points.

The digital radiographs were randomized, and a number was assigned to each image to guarantee a blinded evaluation with regard to the investigational time point. The radiographic evaluations were performed two times by two different examiners (S.R., D.C.). Using digital medical imaging software (Osirix Lite Version 7.0.4, PIXMEO SARL), a computer-assisted calibration—using the titanium implant diameter as reference—was carried out. With this calibration, the linear measurements were transformed into millimeters. Following that, linear measurements were performed on the mesial and distal side of each implant to evaluate the distance from the implant shoulder to the first visible bone-to-implant contact (DIB).[42,43] The DIB value of each implant was calculated as the average of the mesial and distal value. The amount of peri-implant bone loss/bone remodeling was calculated by subtracting the current DIB from the previous DIB, respectively. Finally, the bone loss between the different experimental phases was calculated by subtracting the DIB values from the corresponding time points:

- $DIB_{implant\ placement} - DIB_{prosthetic\ reconstruction}$
- $DIB_{prosthetic\ reconstruction} - DIB_{beginning\ active\ progression}$
- $DIB_{beginning\ active\ progression} - DIB_{end\ active\ progression}$
- $DIB_{end\ active\ progression} - DIB_{end\ spontaneous\ progression}$
- $DIB_{beginning\ active\ progression} - DIB_{end\ spontaneous\ progression}$

Statistical Analysis

The mean time-specific bone loss was calculated as the mean of mesial and distal measures of examiners 1 and 2. Additionally, standard errors of the time-specific mean bone loss were reported. To examine differences in bone loss over time by material, the difference in differences was calculated by subtracting the material-specific difference in bone loss at a given point in time by the corresponding difference at a previous time. P values were reported for the difference in differences. Differences in measurement between examiners were evaluated applying paired t tests. Stata statistical software (Version 13.1; StataCorp) was used for data analysis.

RESULTS

Clinical and Radiographic Observations

The titanium as well as the zirconia implants were placed with good primary stability. After implant placement, postoperative healing was uneventful in all dogs. Clinically, after 6 weeks of unloaded healing, all 40 implants showed clinical ankylosis and healthy peri-implant soft tissue. Before placing the cotton ligatures,

Fig 3 Clinical situation *(a)* at the beginning of the active progression period, *(b)* at the end of the active progression period, *(c)* at 2 weeks after ligature removal, and *(d)* at 16 weeks after ligature removal. # = titanium implant; * = zirconia implant.
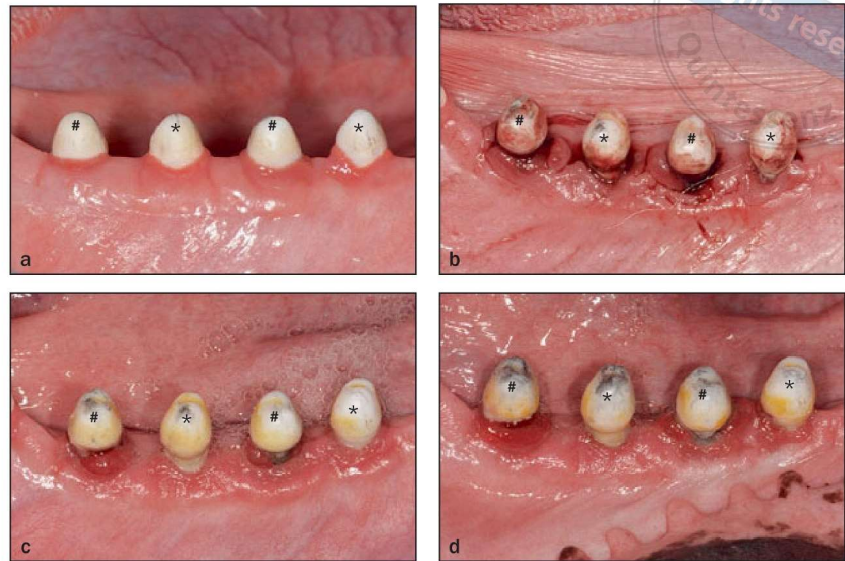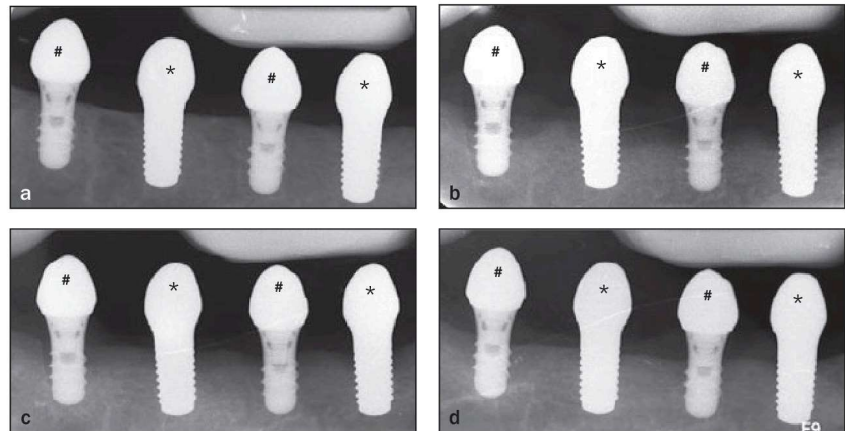

Fig 4 Radiographic situation *(a)* at the beginning of the active progression period, *(b)* at the end of the active progression period, *(c)* at 2 weeks after ligature removal, and *(d)* at 16 weeks after ligature removal. # = titanium implant; * = zirconia implant.

no clinical signs of inflammation were visible and no continuous peri-implant radiolucencies were apparent on the radiographs. At the end of the active progression period, both types of implants harbored large amounts of plaque and the peri-implant mucosa showed obvious clinical signs of massive inflammation (Fig 3). Additionally, extensive peri-implant bone loss was observed on the radiographs (Fig 4). Clinically, 2 weeks after ligature removal, the degree of inflammation around both types of implants decreased compared with the end of the active progression. However, 16 weeks after ligature removal, major inflammation of the peri-implant mucosa was still evident around both types of implants (Fig 3). At the beginning of the spontaneous progression period (2 weeks after ligature removal), one titanium implant showed clinical mobility and was removed.

Radiographic Evaluation: DIB

Each examiner performed 592 measurements. For examiner 1, the mean difference between the two measurements was 0.008 mm (CI: −0.04 to 0.06 mm). Thus, the difference between both measurements was not

statistically significant (P = .73). For examiner 2, the mean difference between both series of measurements was 0.053 mm (CI: −0.01 to 0.11 mm). Again, the difference between both measurements was not statistically significant (P = .09).

At implant placement, the mean distance from the implant shoulder to the first bone-to-implant contact was 1.44 mm for titanium and 1.45 mm for zirconia, indicating a slightly subcrestal position of the micro-rough surface at implant placement for both types of implants (Fig 5). Between implant placement and functional loading, the mean DIB increased for both materials (titanium: mean DIB 1.67 mm, zirconia: mean DIB 1.97 mm); the increase for zirconia was statistically significant (titanium: P = .058; zirconia: P < .01). At the beginning of the active progression period, the mean DIB was 1.44 mm and 1.96 mm for titanium and zirconia, respectively. Within the active progression period, the mean DIB values showed a statistically significant increase for both types of implants (P ≤ .01), indicating excessive peri-implant bone loss, with the highest increase occurring within the first 4 weeks after ligature
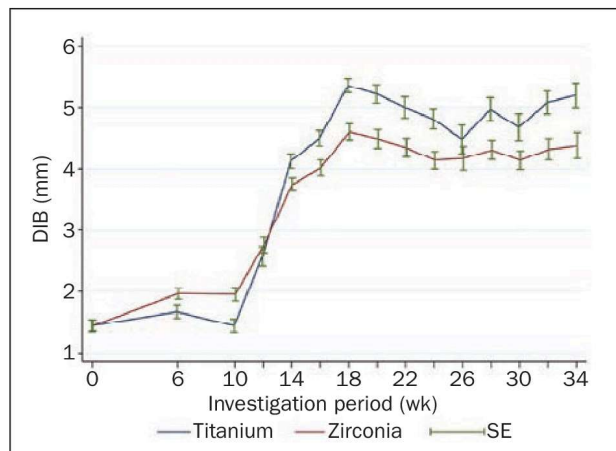
Fig 5 Mean DIB values for titanium and zirconia implants subdivided by implant material.

Table 1 Mean Differences in DIB Values Between Different Investigation Intervals

Investigation intervals	DIB differences (mm)		P value
	Titanium	Zirconia	
Implant placement – Prosthetic reconstruction	−0.23	−0.52	.04
Prosthetic reconstruction – Beginning active progression	0.23	0.01	.065
Beginning active progression – End active progression	−3.915	−2.646	< .01
End active progression – End spontaneous progression	0.159	0.223	.598
Beginning active progression – End spontaneous progression	−3.756	−2.423	< .01

P values < .05 indicate statistically significant differences. Negative values indicate bone loss.

placement. Between the second and fourth week after ligature placement, the titanium implants started to show a higher DIB compared with zirconia implants. At the end of the active progression period, titanium revealed significantly higher mean DIB values compared with zirconia (titanium: mean DIB 5.36 mm; zirconia: mean DIB 4.60 mm; $P <$ .01).

Within the first 6 to 8 weeks of spontaneous progression, titanium as well as zirconia implants showed decreasing DIB values, indicating bone regeneration. Subsequently, DIB values started to increase again and resulted in a statistically significantly higher mean value of 5.2 mm for titanium implants compared with 4.38 mm for zirconia implants ($P <$ .01; Fig 5).

Radiographic Evaluation: DIB Differences

Between implant placement and crown cementation, titanium implants showed significantly less bone loss compared with zirconia (titanium: ΔDIB −0.23 mm; zirconia: ΔDIB −0.52 mm; $P =$ .04). In contrast, after 4 weeks of functional loading, both materials demonstrated some extent of bone gain (titanium: ΔDIB 0.23 mm; zirconia: ΔDIB 0.01 mm). Within the active progression period, titanium implants showed a significant increase in peri-implant bone loss compared with zirconia implants (titanium: ΔDIB −3.92 mm; zirconia: ΔDIB −2.65 mm; $P <$ .01), whereas the greatest bone loss for both types of implants occurred within the first 4 weeks after ligature placement. Within the spontaneous progression period, bone regeneration and bone loss also occurred for both materials. Interestingly, for titanium, a greater variability in bone loss and in bone regeneration could be observed compared with zirconia (titanium: ΔDIB range −0.49 to 0.33 mm; zirconia: ΔDIB range −0.18 to 0.20 mm). However, at the end of the spontaneous progression period, zirconia and

titanium implants showed comparable bone regeneration (titanium: ΔDIB 0.16 mm; zirconia: ΔDIB 0.22 mm; $P =$ .6). Considering active and spontaneous progression periods together, zirconia implants revealed a statistically significant reduction in peri-implant bone loss compared with titanium implants (titanium: ΔDIB −3.76 mm; zirconia: ΔDIB −2.42 mm; $P =$ .01; Table 1).

DISCUSSION

In the present study, ligature-induced peri-implant infections around loaded implants have been investigated in an established experimental canine model. The titanium implants showed significantly higher mean peri-implant bone loss during the ligature period than the zirconia implants.

It has been reported that the canine model is most frequently used to investigate experimental peri-implantitis,[44] and many studies using the same protocol have demonstrated that placing cotton ligatures in a submucosal position around titanium implant shoulders leads to plaque accumulation on the implant and abutment surfaces and subsequently induces peri-implant mucositis and peri-implantitis.[15–17,20] In addition, it has been shown that configurations and sizes of ligature-induced peri-implantitis bone defects in dogs seemed to resemble naturally occurring peri-implantitis lesions in humans.[45] To the best of the authors' knowledge, the present study directly compared peri-implant infections around titanium and zirconia implants for the first time and provided radiographic evidence for typically shaped peri-implantitis lesions around both implant types in this experimental model.

Previously, it was reported that the titanium and zirconia implant surfaces used in this study showed

a similar osseointegrative capacity.[26–30] The present study confirmed these findings, showing no early implant failures and successful osseointegration of both implant types after 6 weeks of unloaded healing. At implant placement, titanium as well as zirconia implant shoulders (border between rough/smooth surface) were positioned in a slightly subcrestal position. After 6 weeks of unloaded healing, both types of implants showed crestal bone loss. However, between implant placement and crown cementation, zirconia implants revealed significantly more bone loss compared with titanium (titanium −0.23 mm; zirconia −0.52 mm; $P = .04$), in agreement with the findings of a previous study comparing titanium with zirconia implants in the canine.[30] Crestal bone loss between implant placement and loading has previously been reported in canine studies investigating the same type of titanium implants (range: 0.34 to 0.52 mm).[42,43] The authors of one of the latter studies concluded that this crestal bone loss "was probably caused by the surgical trauma" during implant placement.[42] In addition to that, experimental studies in canines have shown that the position of the rough/smooth border influences crestal bone remodeling around unloaded titanium implants and that a subcrestal implant shoulder position leads to crestal bone loss.[46–48]

Thus, the different crestal bone loss of titanium and zirconia between implant placement and loading observed in the present study might be explained by the implant shoulder position or by the different implant designs and the varying surgical protocols; due to the cylindrical endosseous shape, after osteotomy preparation and tapping, Ti-SLA implants were directly placed. In contrast to that, due to the conical endosseous design of the zirconia implant, besides osteotomy preparation and tapping, the surgical protocol of this implant type also required additional profile drilling prior to zirconia implant placement.

At the end of the active progression period, the mucosa around both types of implants showed evident signs of inflammation and tissue loss. From a clinical point of view, the inflammation appeared to be more severe around titanium compared with zirconia. The implant loss among the titanium group may substantiate this clinical observation, whereas no zirconia implant failures could be observed within the course of this study. Previously, results from experimental and clinical studies have shown reduced clinical signs of inflammation, or rather, fewer inflammatory cells in the peri-implant abutment and healing cap soft tissue of zirconia in comparison to titanium or other metals.[38,39] In addition, experimental and clinical studies have reported a statistically significant lower bacterial adhesion on zirconia compared with titanium surfaces.[35–37] In detail, significantly reduced human biofilm

formation has been reported for ZrO_2-ZLA surfaces compared with Ti-SLA surfaces after 72 hours of incubation in an anaerobic flow chamber.[35] The authors of the latter study suggested a lower potential for peri-implant infections on zirconia implant surfaces compared with titanium implant surfaces and concluded that "not only surface roughness or surface hydrophilicity might be important factors for biofilm formation, but also material composition, ie, metals compared with ceramics".[35]

With regard to the course of experimentally induced peri-implantitis, only preclinical studies investigating titanium implants have been performed so far.[16,17,49–51] The latter studies have reported that peri-implant bone loss occurs during an active (ligature-induced) and a following spontaneous (no ligatures, no oral hygiene procedures) progression period. Additionally, when investigating implants with different surface topographies, it has been shown that microrough surfaces demonstrate statistically significantly higher bone loss during the spontaneous, but not during the active, progression periods compared with smooth implant surfaces.[16,49–51] Thus, it has been concluded that titanium implant surface characteristics only influence peri-implant bone loss during the spontaneous progression period and that the amount of tissue destruction during an active breakdown period might depend more on the presence and position of the ligature rather than on the surface topography of the implant.[16,49–51] However, two studies suggest that experimentally induced peri-implant bone loss during active and spontaneous progression periods must not be considered independently.[52,53]

In the present study, microroughened zirconia implants revealed significantly less crestal bone loss compared with microroughened titanium implants after the active, ligature-induced progression period (32.4% less bone loss around zirconia compared with titanium) and similar bone remodeling during the spontaneous progression. These results are in contrast to previously reported findings on titanium implants[16,49–51] and suggest that the type of biomaterial used for manufacturing the implants (zirconia compared with titanium) seems to be more important than the implant surface topography with regard to peri-implant bone loss during an active ligature-induced progression period. In contrast, during the spontaneous progression, the present study has shown no significant differences between both materials. These findings could be explained by the fact that the presently used zirconia and titanium implants had comparable microrough surface topographies that show similar osseointegrative capacities.[26–30] Thus, previously reported findings on titanium implants have been confirmed: during a spontaneous
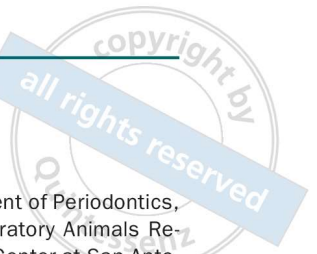
progression period, implant surface characteristics seem to be more important with regard to crestal bone loss than the implant material itself. However, taking active and spontaneous progression periods together, zirconia implants showed a significantly reduced peri-implant bone loss compared with titanium implants (35.64% less bone loss around zirconia compared with titanium).

The macroscopic implant design may be considered as a major limitation of this study. In spite of identical transmucosal portions and soft tissue level design, titanium and zirconia implants had different endosseous thread designs. Previously, it has been reported that implant and thread geometry of different titanium implants had no effect on peri-implant crestal bone loss during an active ligature-induced progression period up to 26 weeks.[54] However, it cannot be completely excluded that the experimentally induced peri-implant bone loss was also influenced by the different thread designs used in the present study.

The present study focused on clinical and radiographic findings that occurred over time during an active and a spontaneous infection period. Consequently, dynamic peri-implant marginal bone level changes were investigated using standardized radiographs. In addition to the radiographic evaluation, the peri-implant soft and hard tissues were also histomorphometrically analyzed at the time point of euthanasia. The histologic and histomorphometric results will be presented in a separate article.

CONCLUSIONS

One Ti-SLA implant was lost during the spontaneous progression period, whereas no zirconia implant loss could be observed until study termination. Taking active and spontaneous progression periods together, functionally loaded zirconia implants revealed significantly reduced peri-implant crestal bone loss compared with titanium implants. Thus, the reported radiographic findings indicate a significantly reduced crestal bone loss progression of experimentally induced peri-implant infections around ZrO_2-ZLA implants compared with Ti-SLA implants. Moreover, it might be supposed that within an active, ligature-induced progression period, implant material and probably biocompatibility appear to be more important regarding peri-implant bone loss than surface topography. However, the clinical relevance of experimental peri-implantitis models is not clearly demonstrated and should be addressed in future clinical research.

ACKNOWLEDGMENTS

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