Prospective long-term investigation of clinical parameters, patient satisfaction, and microbiological contamination of zirconia implants after more than 7 years

Running title:
7-year zirconia implant follow up

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Keywords: zirconia dental implants, patient satisfaction, zirconia, microbial contamination

Abstract

Objectives
Aim of this study was to analyze zirconia dental implants regarding their clinical performance compared to natural teeth (control teeth, CT) after a mean period of integration of 7.8 years.
Materials and Methods
Eighty-three zirconia implants in 28 adults were analyzed in a prospective clinical study after 7.8 years of integration. The Approximal Plaque Index (API), Sulcus Bleeding Index (SBI) probing pocket depth (PPD), probing attachment level (PAL), and creeping or recession (CR/REC) of the gingiva were detected. Furthermore, pink esthetic score (PES), Periotest values (PTV), microbial colonization of the sulcus fluid, and patient satisfaction were assessed.
Results
The survival rate of zirconia implants was 100%. In the study group significantly less plaque accumulation (API) and recession (CR/REC) could be observed, while analysis of PPD revealed significant higher values compared to CT. Microbial analysis revealed statistically significant higher amounts of single bacteria species, especially of the red complex in the zirconia implant group.
Conclusions
Zirconia implants presented favorable clinical results over a long period of loading, comparable to natural teeth (SBI and PAL), and, regarding adhesion of plaque (PI) and creeping attachment (CR/REC), even superior. The first time-performed microbiological investigation after a long period of loading revealed a shift in peri-implant colonization around zirconia implants over years without clinical effect on peri-implantitis. The present study reports in a unique way the long-term interaction between plaque accumulation and peri-implant bacteria, especially those of the red complex, and the clinical signs of peri-implantitis in zirconia implants.

1. Introduction

Today, requirements for dental implants are more than just the replacement of missing teeth or the stabilization of dentures. Especially in the anterior region, the esthetic demands of patients and practitioners are increasing and lead to modifications of treatment protocols and dental and implant materials. Because of its favorable mechanical properties and tooth-like color, ceramics of different compositions are widely used for tooth- and implant-retained restorations (Kohal et al. 2008). In past years, ceramics also experienced a renaissance as a base material for dental implants. Especially densely sintered Yttria-stabilized tetragonal zirconia ceramics could prove to fulfill the mechanical and technical demands of bending strength and fracture toughness (Andreiotelli et al. 2009). Furthermore, it is known that zirconia, besides its tooth-like color, possesses favorable biological properties such as low thermal conductivity, low affinity to plaque, and high biocompatibility (Picconi & Maccauro 1999, Scarano et al. 2004, Depprich et al. 2014).

In the past decades, conventional dental implants made from titanium have been widely investigated in different clinical settings, indications, and regions. To date, dental implants from titanium can be regarded as a reliable and long-term, stable treatment option to replace missing teeth and attach dentures in case of tooth loss [Jung et al. 2012; Pjetursson et al. 2012]. However, titanium implants with all their approved technical and biological advantages still exhibit some major disadvantages, such as the metallic color. Especially in the esthetically challenging anterior region and in cases of gingiva of a thin biotype, the metallic color can impair the final esthetic result. Dental implants made from zirconia are a promising approach to circumvent this problem.

Individual animal and clinical studies reported zirconia implants as a comparable alternative to titanium implants regarding biocompatibility and osseointegration (Scarano et al. 2004, Kohal et al. 2004, Depprich et al. 2008, Wenz et al. 2008). However, in different systematic reviews, zirconia implants could not be confirmed as a reliable alternative to conventional dental implants made from titanium due to a lack of necessary long-term clinical data and the heterogeneity of the performed studies and their variable investigation parameters [Andreiotelli et al. 2009, Wenz et al. 2008].

In a previously published study by our workgroup, the clinical and microbiological performance of one-piece zirconia implants compared to natural teeth was investigated. One hundred six zirconia implants in 38 adults were analyzed in a clinical study after 1 year of loading. The plaque index (PI), bleeding on probing (BOP), probing pocket depth (PPD), probing attachment level (PAL), and creeping or recession (CR/REC) of the gingiva were detected and compared with natural control teeth (CT). Furthermore, the papilla index (PAP), Periotest® values (PTV), microbial colonization of the implant/dental sulcus fluid, and patient satisfaction were assessed. The survival rate of the zirconia implants was 100%. No statistical significance was observed between implants and teeth regarding BOP, PPD, and PAL. The low plaque affinity and the favorable soft-tissue compatibility could be proven by statistical significant less plaque accumulation (PI) and recession (CR/REC) in the study group. Mean PAP was 1.76 ± 0.55, whereas the mean PTV was –1.31 ± 2.24 (range from –5 to +6). The microbiological analysis revealed a non-statistically significant higher colonization of periodontitis/peri-implantitis bacteria in the implant group. The questionnaire showed that the majority of the patients were satisfied with the overall treatment, indicating a high level of acceptance of zirconia implants (Holländer et al. 2016).

The aim of the present study was to investigate the clinical and microbiological long-term performance of dental implants made of zirconia. Implant survival, peri-implant parameters such as plaque index, bleeding on probing, probing pocket depth, probing attachment level, and creeping or recession as well as microbiological colonization of the implants was investigated after a mean period after implantation of 7.8 years. To the best of our knowledge, long-term data for zirconia implants after more than 7 years of loading are rare, and comparison of the results after one year and 7.8 years might contribute to a more detailed and accurate view on the long-term performance of dental implants made of zirconia.

2. Materials and Methods

2.1. Patient collective and study design

In the present prospective study, 28 healthy adult, partially edentulous patients (15 female, 13 male) with a mean age of 63.5 years (range 39–80 years) were included. The present study was performed at the department of oral-, maxillofacial and plastic facial surgery of the goethe university Frankfurt (Germany) in collaboration with the private practice of the authors (N.G., W.H.). The study was initiated nine years ago and approved by the Ethics Committee of the University Hospital in Frankfurt, Germany (No. 118/08). The clinical and microbiological results of the one-year follow-up investigation were previously published by Holländer et al. (2016). At the beginning of the study, 38 patients with altogether 106 zirconia implants were included. The number of included patients decreased to 28 patients with 83 zirconia implants due to decease and relocation. All included patients were informed about the study and gave written consent to the participation. The study was conducted according to the fifth revision of the World Medical Association Declaration of 2000 in Helsinki, the Consolidated Standards of Reporting Trials (CONSORT) guidelines of 2010 and the STROBE (STrengthening the Reporting of Observational studies in Epidemiology) guidelines of 2007.

Enrolled patients received at least one zirconia implant between March and September 2008 and were previously followed up one year after placement of the zirconia implants. The study aims and protocol were discussed with the patients previous to the study enrollment, and all patients gave informed consent prior to enrollment in the study. All patients who fulfilled the inclusion criteria (see table 1) participated in this study.

In total, 83 zirconia implants (IMP) (38 in the upper jaw and 45 in the lower jaw; see table 2) and 570 natural control teeth (CT) of 28 patients were examined clinically after a mean period after implant placement of 7.8 years. The number of CT was set higher than investigated IMP to prevent bias from the type of investigated tooth. All implants were restored with all-ceramic superstructures (Cerec®, Sirona, Bensheim, Germany) 4 months (lower jaw) and 6 months (upper jaw) after the surgical intervention.

2.2. Implants

In the present study, the Z-Look 3® implant system (Z-Systems, Oensingen, Switzerland), a one-piece implant system made of yttrium-strengthened zirconia (Y-TZP-A-Bio-HIP®), was examined. The implant is certified according to ISO 13356 and available in diameters from 3.25 mm to 5 mm and lengths from 8 mm to 14 mm. The implant has a sandblasted intra-osseous section and a polished transgingival/abutment portion. The surgical procedure was conducted according to the recommendations of the manufacturer. Implants are inserted through an external hexagon surface that is needed to place the implant and becomes abraded after insertion. Because of the one-piece design, the healing modus is transgingival. To prevent the implant from loading during the osseointegration period, the implants are protected with a splint or an adhesive-attached provisional appliance until definitive prosthetic restoration.

2.3. Clinical examinations

The clinical study parameters were investigated by one practitioner with experience in the field of implant and restorative dentistry (N.G.). Prior to the study, the investigator calibrated the probing force with an electronic Florida-Probe and a probing force of 0.5 N and an insertion angle of 30°.

According to the one-year follow-up investigation by Holländer et al., the following parameters were evaluated: Approximal Plaque Index (API), Sulcus Bleeding Index (SBI), probing pocket depth (PPD), probing attachment level (PAL), creeping or recession of the gingiva (CR/REC), and the pink esthetic score (PES). Peri-implant parameters were investigated to analyze the peri-implant soft-tissue condition around the zirconia implants. PI, PPD, and BOP were evaluated to determine whether the implant material induces an inflammatory response compared to natural teeth. PI and BOP describe the presence or absence of plaque, respectively; bleeding was documented at 4 sites per implant/tooth and calculated in percentage. PPD and PAL were determined also at 4 sites per implant/ tooth by using a blunt periodontal probe and the changeover from the implant shoulder to the crown as a reference point. Based on PPD and PAL, CR/REC of the gingiva were calculated. Furthermore, the pink esthetic score (PES) according to Fürhauser (Fürhauser et al. 2005) was evaluated to describe the aesthetic appearance of the zirconia implants and the corresponding restoration. An independent, experienced investigator (J.L.) familiar with the PES scoring method reviewed images recorded of only zirconia implants in the esthetic region (regio 14–24 and regio 34–44), restored with single crowns. The score was calculated by adding the point score (from a minimum of 0 to a maximum of 2) for the seven items (mesial papilla, distal papilla, soft-tissue level, soft-tissue contour, alveolar process deficiency, soft-tissue color, and texture) for a maximum score of 14 (see table 3). Besides soft-tissue parameters, the implant stability was also determined. Therefore, the Periotest® method (Medizintechnik Gulden, Modautal, Germany) was applied (Schulte & Lukas 1992). Furthermore, a validated questionnaire (see table 4) was applied to evaluate patients´ satisfaction concerning the surgical intervention, the management (handling, comfort, articulation, mastication, and phonetic qualities), and esthetics of the protective device as well as the overall patient satisfaction with the treatment method. A 10-grade scale, ranking from positive (grade 1: “very good”) to negative (grade 10: “unsatisfactory”), was used for most of the questions; the remaining questions were to be answered by “Yes” or “No”.

2.4. Microbial analysis

According to previously published methods (Holländer et al. 2016), the microbial contamination of the investigated zirconia implants and the control teeth were analyzed with the Paro Check 20® (Greiner Bio-One, Frickenhausen, Germany; Institute for Mikro-ecology, Herborn-Hörbach, Germany) according to the manufacturer instructions.
The applied Paro Check 20® is a DNA sampling test for semi-quantitative detection of up to 20 periodontitis- and peri-implantitis-associated bacteria. The results of the Paro Check 20® test system are given as SNR (signal-to-ratio) values, which are relative values rather than absolute values or number of bacteria.
One implant per patient was randomly allocated, and probes from the peri-implant sulcus were taken with paper points on four sites per implant (mesio-buccal, disto-buccal, mesio-oral, and disto-oral). Subsequently, the probes from the implant were pooled for microbial analysis. Samples from the control teeth were taken on one tooth per quadrant on randomly allocated molar or premolar teeth in the first and third quadrants and incisor or canine in the second and fourth quadrants, according to previously published methods (Holländer et al. 2016). Probes from the control teeth were also pooled for microbial analysis.

2.5. Statistical evaluation

SPSS for Windows 17.0 statistical software package was used for data analysis. The Gaussian distribution was analyzed using the Kolmogorov–Smirnov test. The majority of the data and its differences were non-normally distributed. Therefore, non-parametric tests were applied. The level of statistical significance was set at 0.05. The Wilcoxon signed-ranks test was employed for comparison of the Approximal Plaque Index, Sulcus Bleeding Index, Probing Pocket Depth, Probing Attachment Level, creeping or recession of the gingiva, and the microbial investigation at teeth and implants.

3. Results

3.1. Clinical results

After a mean follow-up period after implant placement of 7.8 years (ranging from 6.1 to 9.7 years), none of the 83 investigated zirconia implants was lost, leading to a survival rate of 100%. No implant failure could be detected, and all implants were in loading and restored with sufficient prosthetics. No important harm or unintended effects could be recorded. No major complications such as implant or screw fractures occurred, and no signs of an acute or advanced per-implant infection were obvious.

Investigation of the plaque accumulation revealed a significantly lower (**P <0.01; see table 5) mean Approximal Plaque Index (API) at the zirconia implants compared to the control group of natural teeth (API_{IMP} 25.0 ± 26.4% vs. API_{CT} 40.7 ± 14.9%). In correlation, the mean Sulcus Bleeding Index (SBI) showed a contrary result, because the mean SBI was higher in the zirconia implants group compared to the control group (SBI_{IMP} 22.2 ± 33.2% vs. SBI_{CT} 11.4 ± 8.1%). However, these results did not reach a statistical significance (P = 0.278; see table 5).

Analysis of probing depths and attachment level on zirconia implants and natural teeth revealed statistically significant higher values for probing depths in zirconia implants (PPD_{IMP} 2.57 ± 1.10 mm vs. PPD_{CT} 2.40 ± 0.95 mm, **P <0.01), whereas the differences in attachment level did not show statistical significance (PAL_{IMP} 2.98 ± 1.05 mm vs. PAL_{CT} 3.03 ± 1.25 mm, p = 0.418; see table 5). Regarding the course of the marginal (peri-implant) gingiva, a creeping attachment could be observed in 7% of the implants. The mean value for recession was significantly lower at zirconia implants compared to natural teeth (CR/REC_{IMP} 0.43 ± 0.80 mm vs. CR/REC_{CT} 0.62 ± 0.97 mm, *P <0.05; see table 5).

The esthetic appearance evaluated with the pink esthetic score revealed a mean value of 9 ± 2.7 in 19 zirconia implants. Eight implants located in the esthetic region of the upper jaw revealed a PES of 10.1 ± 1.3, whereas 11 implants located in the esthetic region of the lower jaw revealed a PES of 8.2 ± 3.2 (see Table 5).

Periotest® values, evaluated to determine the stability of the investigated zirconia implants, ranged in all implants between –8 and +4. The mean Periotest® value (PTV) was –2.3 ± 3.1 with slightly lower values in the upper jaw (–1.9 ± 3.6) than in the lower jaw (–2.7 ± 2.7).

Analyzing the questionnaire designed for the present study, all questions (patient´s satisfaction concerning the surgical intervention, the management, esthetics, and the overall patient satisfaction with the treatment method) revealed a point score between 1 and 2 with a mean point score of 1.3 (grade 1: "very good" to grade 10: "unsatisfactory"). None of the patients mentioned a foreign-body feeling, all patients mentioned high confidence in the zirconia material and would choose zirconia implants again as the treatment of choice (see table 4).

3.2. Microbiological results

The mean SNR value of probes extracted from zirconia dental implants was 151, and the mean SNR value of probes of control teeth was 119. This difference was not statistically significant. Regarding the SNR values of the 20 detected bacteria, the highest values on implants and teeth was observed for Fusobacterium nucleatum and Veillonella parvula. Significantly higher SNR-values for the zirconia implant group were observed for *Aggregatibacter actinomycetemcomitans* (A.a.,* P <0.05), *Tannerella forsythia* (T.f.,* P <0.05), *Tannerella denticola* (T.d.,* P <0.05), *Porphyromonas gingivalis* (P.g.,** P <0.01), and the *Streptococcus constellatus* group (S.c.,* P <0.05) (see figure 1).

Assigning the 20 detected bacteria according to the bacteria-complexes published by Socransky et al. (1998), the bacteria from the red complex showed a significantly higher presence in probes of zirconia implants (*P <0.05) when compared to the control group (see figure 2). Figures 3 and 4 give a graphical comparison of the percentage of distribution of the Socransky complexes of the zirconia implants and the natural teeth.

Figure 5 a-c show clinical and X-ray images of a prosthetically restored zirconia implant in the upper front (figure 5a) and the lower molar regions (figure 5b and c). The peri-implant bone level and soft-tissue levels appear stable and free from infection.

4. Discussion

The present study reports the long-term clinical and microbiological results of dental implants made from zirconia. Eighty-three zirconia implants placed in 28 patients were investigated for a mean integration period of 7.8 years. Clinical parameters such as Approximal Plaque Index (API), Sulcus Bleeding Index (SBI), Probing Pocket Depth (PPD), probing attachment level (PAL), creeping or recession of the gingiva (CR/REC), and the pink esthetic score (PES) were investigated. Peri-implant parameters (PI, PPD, and BOP) and microbiological contamination of the peri-implant tissue were analyzed to determine the peri-implant soft-tissue condition around the zirconia implants and compared to 570 control teeth (CT). Patients included in the present observation have already been followed up for a mean period of integration of one year. Thus, the present follow-up investigation enables a statement about the long-term performance of the zirconia implants, the stability of the peri-implant hard and soft tissue, and the microbial setting around the implants.
The clinical follow-up investigation revealed a survival rate of 100% 7.8 years after placement. No major complications such as implant fracture or severe inflammation could be detected. No statistically significant difference between zirconia implants and control teeth could be observed in the SBI. According to the evidentially proven low plaque affinity, also in this study, the zirconia implants presented a statistically significant lower plaque accumulation (**P <0.01), whereas peri-implant PPD were significantly higher around the implants (**P <0.01). However, it has to be mentioned that the difference between both groups in PPD was 0.17 mm. It has to be considered that this "significant difference“ has hardly any clinical relevance. Furthermore, the implant group showed significantly fewer recessions, so that the soft-tissue conditions around the zirconia implants were generally found to be clearly superior compared to the CT. This data underlines the tissue-friendly properties of zirconia ceramics. Compared to other studies, the result of a mean PES of 9 ± 2.7 exhibits an average result. However, this evaluation has to be interpreted carefully, because the PES is a cumulative score of several single parameters. It has to be considered that out of the different PES criteria, the color of the gingiva performed best, pointing out an advantage of the zirconia oxide implant material.

In addition to the performed clinical evaluation, microbiological analysis was perfomed in the present study. These data revealed no statistically significant difference in the total number of bacteria within the peri-implant sulcus when compared to corresponding regions of the control teeth. Interestingly, several bacteria species, and especially bacteria from the red complex, were detected in statistically significant higher numbers around zirconia implants when compared to the control group. Bacteria of the red complex are considered to play a vital role in the development of periodontitis (Cortelli et al. 2013). Matching the results from the clinical and microbiological analyses of the present study revealed that within the implant group smaller amounts of plaque contained a higher amount of bacteria of the red complex, leading to an increase of PPT. This might lead to the assumption that mechanical plaque control cannot elimiate the bacteria load (especially of particular species) completely.
Comparing the results of the clinical follow-up investgation after 7.8 years with the results of the one-year follow-up, it becomes obvious that the peri-implant hard and soft tissue seems to be stable, because PPD and the bleeding index (API) showed comparable results. At both follow-up time points, the plaque accumulation (API) and recession of the peri-implant soft tissue was significantly lower in the implant group, underlining the low plaque affinity of zirconia ceramics.

When comparing the microbiological contamination of the implants one year and 7.8 years after placement, it becomes obvious that a potential shift in the microbiological population occured. First, the mean SNR values around zirconia implants increased over the observation period from 102.47 to 151. In the one-year observation period, *T. forsythensis*, *P. intermedia*, *A. odontolyticus*, *P. nigrescens*, and *V. parvula* were identified in significantly higher numbers around zirconia implants compared to those in natural teeth, but 7.8 years after placement, significantly higher SNR-values in the zirconia implant group were observed for *T. forsythia*, *T. denticola*, *P. gingivalis*, and the *S. constellatus* group. Regarding the arrangement of bacteria according to the Socransky complexes after one year of loading, the violet complex was detected in a statistically significant highr ratio, whereas 7.8 years after placement, the bacteria from the red complex showed a significantly higher presence in probes of zirconia implants. Comparison of the one-year and 7.8-year data show that a change in the microbiological contamination can be assumed, because the amount of total measured bacteria increased, and the affiliation of the bacteria shifted to the more aggressive red complex. However, this seems not to be of clinical relevance because no further signs of peri-implantitis could be observed.

In the context of the present study, it has to be clearly mentioned that the investigated zirconia implants are single-unit implants without connection between implant and abutment. However, technical and material advancement in the past years has led to a further development of two-stage implants made from zirconia.

In a recently published meta-analysis, the clinical outcome, the survival rate of and marginal bone loss from zirconia implants was analyzed. The screening procedure detected relatively little scientific data of a high evidence grade (two randomized, controlled clinical trials and seven prospective clinical trials). Thus, meta-analysis of (in total) 326 patients who received 398 implants was conducted. The follow-up range, up to 60 months of the patient collective, revealed an implant survival of 95.6% and a mean marginal bone loss of 0.79 mm after 12 months. In this particular review, only one of the 9 included studies evaluated a two-piece implant system, whereas the other 8 studies investigated a one-piece implant system, as in the present study. No statistically significant difference regarding marginal bone loss could be observed between the implant types (Pieralli et al. 2017). In a further systematic review, 14 articles were selected and analyzed with a mean focus on survival rate. The overall survival rate of zirconia one- and two-piece implants was calculated at 92% after one year of function. The authors concluded that zirconia implants provide a potential alternative to titanium ones. However, clinicians should be aware of the lack of knowledge regarding long-term outcomes and specific reasons for failure (Hashim et al. 2016).

The scientific debate about zirconia implants has increased again, especially as, due to progress in material science, two-stage ceramic implant systems are available. In an interesting study, the expression of host-derived markers in peri-implant/gingival crevicular fluid and clinical conditions at ceramic implants and contralateral natural teeth have been analyzed (Cionca et al. 2016). Similar to the present investigation, plaque index, gingival index, probing depth, and bleeding on probing were assessed, and a significantly lower plaque accumulation could be observed, although probing depths were significantly higher compared to natural teeth. In addition, a wide range of pro-inflammatory markers have been determined. Laboratory analyses have revealed significantly higher levels of IL-1ß and TNF-α at zirconia implants than at control teeth. The authors explained their results with the existence of a patient-specific inflammatory response pattern and an overall higher concentration of cytokines that was also found around titanium implants compared to natural teeth (Cionca et al. 2016, Recker et al. 2015, Nowzari et al. 2012).

A further study on zirconia implants investigated a relatively new two-stage implant system for single tooth replacement after at least one year of loading. The cumulative implant survival rate one year after loading was 87%. All failures were reported by the authors to be the result of aseptic loosening during the osseointegration period (Cionca et al. 2015). In the present one-year and 7.8-year investigation, the osseointegration process progressed without complications. However, the results from the aforementioned study highlight the importance of an accurate handling of this specific implant type with respect to biomechanical and biological conditions.

The present study was able to demonstrate that implants made of zirconia oxide show very good long-term results and are equivalent to standard titanium implants in terms of published results. However, it must be clearly mentioned that the investigated implant system is a single-unit implant, without design-related weaknesses such as a micro-gap. For further analyses, it is important to verify the present results with two-stage zirconia implant systems. Nevertheless, the present results highlight and scientifically validate the favorable capacity of zirconia as an effective material for dental implants. Further clinical studies showing high evidence levels and long-term follow-up periods are necessary to substantiate that zirconia implants are a true alternative to dental implants made from titanium. According to the present data, a special focus must be placed at the interaction between the plaque accumulation and peri-implant bacteria, especially those of the red complex, and the clinical signs of peri-implantitis. This research might end with a new perspective on peri-implantitis parameters, which presently are known only for titanium-based implants.

5. Conclusion

The present findings from the 7.8-year follow-up investigation of one-piece zirconia implants present a unique, long-term analysis of zirconia implants, especially regarding the microbiological analysis. By using clinical and microbiological methodology, the superiority of zirconia implants' regrading plaque affinity and soft-tissue compatibility could be proven. However, bleeding index, probing pocket depths, and microbiological colonization showed significantly higher values in the zirconia implant group. Subdivision of the detected bacteria species revealed a significantly higher population of bacteria of the red complex, which are known to play a major role in the development of periodontitis and peri-implantitis. Compared to the one-year follow-up investigation of the same population, the different clinical parameters presented no major difference, whereas the microbiological analysis revealed a shift from the violet to the red complex, but obviously without apparent clinical consequence. Because scientifically valuable, long-term data of zirconia implants is still rare, the findings of the present prospective study could prove the ability of zirconia implants to replace missing teeth with maintenance of peri-implant hard- and soft-tissue health.

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Figure legends:

Table 1:
Inclusion criteria for patient inclusion in the present study

Table 2:
Distribution of all 83 investigated zirconia implants in the different regions of the upper and the lower jaw

Table 3:
Description of the particular index values for the Pink esthetic Score (PES) according to Fürhauser et al. 2005

Table 4:
Survey of the different answers to the questionnaire; questions 1 to 8 were rated with a 10-grade scale from 1 (“very good”) to 10 (“unsatisfactory”)

Table 5:
Overview of the investigated clinical parameters in implants and teeth; statistical significance of comparisons between implants and teeth was set at (*P<0.05)
(API: Appriximal Plaque Index, SBI: Sulcus Bleeding Index, PPD: Probing Pocket Depth, PAL: Probing Attachment Level, CR/REC: Creeping or Recession of the Gingiva, PAP: Papilla Index, PTV: Periotest Values)

Figure 1:
SNR-values of the 20 different investigated bacteria on zirconia implants and control teeth. Significantly higher SNR-values could be observed in T.f., T.d., S.c.g. (* P<0.05) and P.g. (** P<0.01). (A.a.: Aggregatibacter actinomycetemcomitans; A.v.: Aggregatibacter viscosus; T.f.: Tannerella forsythensis; C.r./s.: Campylobacter rectus/showae; T.d.: Treponema denticola; E.c.: Eikenella corrodens; P.i.: Prevotella intermedia; P.b.: Peptostreptococcus micros; P.g.: Pophyromonas gingivalis; F.n.: Fusobacterium nucleatum; A.o.: Actinomyces odontolyticus; C.sp.: Capnocytophaga sp.; C.c.: Campylobacter concisus; E.n.: Eubacterium nodatum; S.c.g.: Streptococcus constellatus; C.g.: Campylobacter gracilis; S.m.g.: Streptococcus mitis; P.n.: Prevotella nigrescens; S.g.g.: Streptococcus gordonii; V.p.: Veillonella parvula)

Figure 2:
SNR-values of the different bacteria complexes according to Socransky et al. (1998) on zirconia implants and control teeth.
Significantly higher SNR-values could be observed in the red complex (*P<0.05)

Figure 3 and 4:
Overview about the allocation of the different bacteria-complexes (according to Socransky et al. 1998) of the total amount of bacteria on implants (figure 3) and teeth (figure 4).

Figure 5 a-c:
Clincial and radiological image of Zirconia implants at the follow-up investigation
a:
clinical image of a prosthetically restored zirconia implant in regio 11 recorded for the PES-analysis. The marginal gingiva is free of infections without signs of a peri-implant infection.
b:
X-ray of a zirconia implant in Regio 36. The peri-implant bone level is stable and reaches the most coronal windings. No signs of an acute or chronical infection are obvious.
c:

Clincial image of the corresponding zirconia implant in regio 36. The marginal gingiva is free of infections without signs of a peri-implant infection.