Early bacterial colonization and soft tissue health around zirconia and titanium abutments: an in vivo study in man

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Abstract

Aim: To compare the early bacterial colonization and soft tissue health of mucosa adjacent to zirconia (ZrO2) and titanium (Ti) abutment surfaces in vivo.

Materials and methods: Twenty edentulous subjects received two endosseous mandibular implants. The implants were fitted with either a ZrO2 or a Ti abutment (non-submerged implant placement, within-subject comparison, left-right randomization). Sulcular bacterial sampling and the assessment of probing pocket depth, recession and bleeding on probing were performed at 2 weeks and 3 months post-surgery. Wilcoxon matched-pairs, sign-rank tests were applied to test differences in the counts of seven marker bacteria and the clinical parameters that were associated with the ZrO2 and Ti abutments, at the two observation time points.

Results: ZrO2 and Ti abutments harboured similar counts of Aggregatibacter actinomycetemcomitans, Porphyromonas gingivalis, Prevotella intermedia, Tannerella forsythia, Peptostreptococcus micros, Fusobacterium nucleatum and Treponema denticola at 2 weeks and 3 months. Healthy clinical conditions were seen around both ZrO2 and Ti abutments at all times, without significant differences in most clinical parameters of peri-implant soft tissue health. Mean probing depths around Ti abutments were slightly deeper than around ZrO2 abutments after 3 months (2.2 SD 0.8 mm vs. 1.7 SD 0.7 mm, P = 0.03).

Conclusions: No difference in health of the soft tissues adjacent to ZrO2 and Ti abutment surfaces or in early bacterial colonization could be demonstrated, although somewhat shallower probing depths were observed around ZrO2 abutments after 3 month.

Introduction

Titanium (Ti) has been the “gold standard” material for implant abutments, but the use of high-strength ceramics, both as permucosal abutments and as coping for ceramic crowns, is increasing. Zirconia (ZrO2) is especially promising because of its high fracture toughness and favourable light dynamics. To date, there is only limited information available with respect to the clinical and biological performance of ZrO2-based restorations [Jung et al. 2008; Sailer et al. 2009b; Zembic et al. 2009a]. Attention in the literature has predominantly been focused on the bone–implant response to Ti and ZrO2, and on the biomechanical properties of these materials [Wenz et al. 2008]. Much less information is available regarding the soft tissue response to ZrO2 and comparative in vivo studies in humans are quite scarce [Myshin & Wiens 2005; Teughels et al. 2006b; Linkevicius & Apse 2008a].

The establishment and maintenance of healthy soft tissues around implant abutments are considered to be important for the long-term service of the implant [Berglundh et al. 1991; Lindquist et al. 1996]. The intimate contact between the marginal mucosa and implant abutment protects the implant body from the microbial communities of the mouth. As on teeth, periodontal pathogens on implants induce soft tissue infection [Zitzmann et al. 2002]. It is presumed that this may jeopardize the osseointegration process [Norowski & Bumgardner 2009a].

The adhesion, proliferation and colonization of cells and micro-organisms are dependent upon the surface properties, among which are its bio-compatibility (i.e. chemistry), surface topography (i.e. roughness) and surface-free energy [Quirynen et al. 1993, 1994; Bollen et al. 1996a; Rimondini et al. 1997; Abrahamsson et al. 1998, 2002; Rasperini et al. 1998; Grossner-Scheier et al. 2001a; Hamdan et al. 2006; Rompen et al. 2006; Teughels et al. 2006b; Linkevicius & Apse 2008b]. Bacterial colonization of the abutment starts directly after exposure to the oral environment and within weeks, the
subgingival microbiota is similar to that found around teeth in the same mouth (van Winkelhoff et al. 2000; Quirynen et al. 2005, 2006b; DeAngelio et al. 2007; Furst et al. 2007a; Salvi et al. 2008). Strategies aimed at reducing bacterial adhesion and biofilm formation on implant abutment surfaces are of pertinent clinical interest and can be used for the maintenance of soft tissue health or possibly in the treatment of peri-implantitis. Recent studies have shown that antimicrobial (e.g. vancomycin or chitosan) derivatization of a Ti alloy surface renders it less susceptible for bacterial colonization in vitro (Parvizi et al. 2004; Antoci et al. 2008; Shi et al. 2008). Implant coatings that deliver antibiotics have been described as well, predominantly in the field of orthopaedics (Norowski & Bumgardner 2009b). It was shown that the physical properties of the Ti surface can be adapted, for example by applying a coating of Ti-nitride through vapour deposition. This reduces plaque adhesion compared with uncoated Ti surfaces both in vitro and in vivo (Grossner-Schreiber et al. 2001b, Scarano et al. 2003) and still facilitates cellular adhesion of human fibroblasts in vitro (Grossner-Schreiber et al. 2006). In addition, it has been observed that silver and zinc oxide-modified surfaces possess antibacterial properties as well (Norowski & Bumgardner 2009c).

Wennerberg and colleagues compared the inflammatory response in human peri-implant mucosa around standard Ti abutments and abutments that were roughened by grid blasting. They found no correlation between the number of inflammatory cells and the degree of roughness after 4 weeks (Wennerberg et al. 2003). However, creating much smoother surfaces than those generally encountered on currently used Ti abutments (Ra-value approximately 35 nm) reduces bacterial adhesion in vitro (Pier-Francesco et al. 2006). Other authors compared Ti abutments with different roughnesses and a smooth ceramic abutment [of undisclosed chemical composition, Rz-value 60 nm]. Because fibroblasts require a certain roughness to be able to adhere to a Ti substrate, the authors suggest an optimal surface roughness Rz-value of 200 nm. Such roughness constitutes a good balance. It reduces plaque adhesion as compared with a rougher surface, yet is still rough enough for fibroblast adhesion and the establishment of a durable epithelial soft tissue seal (Bollen et al. 1996b; Quirynen et al. 1996). Interestingly, no difference in early biofilm formation on subgingival abutment surfaces with varying roughnesses could be demonstrated by others (Elter et al. 2008b).

The potential advantages of ZrO2 compared with Ti, with respect to biofilm formation in the oral cavity, has been demonstrated in various studies. ZrO2 discs that were glued on a device and worn intra-orally for a day elicited less plaque accumulation than Ti discs in vivo (Scarano et al. 2004). This finding was attributed to the superficial structure of the ZrO2, more specifically, to its electric conductivity. Others reported similar favourable findings in vitro and in vivo in a comparable experiment (Rimondini et al. 2002a). These observations were not verified on functional, permcusosal abutments. Degidi and colleagues performed a study in five patients comparing ZrO2 and Ti in permucosal applications. Less pronounced inflammation-related processes were noticed around ZrO2 vs. Ti healing abutments after 6 months (Degidi et al. 2006). The peri-implant microbiota was not investigated in the latter study.

The present investigation focuses on the peri-implant mucosa condition adjacent to ZrO2 and Ti abutment surfaces and on early submucosal bacterial colonization. These issues are compared under the null hypotheses that permucosal sites adjacent to ZrO2 and Ti abutment surfaces exhibit similar clinical characteristics of peri-implant soft tissue health and microbiological features during the first 3 months.

Materials and methods

The study was designed as a prospective, human, within-subject comparison with left–right randomization. Twenty edentulous patients, nine males and 11 females, aged between 39 and 76 years (mean 56.4 years) who were scheduled for two mandibular implants and overdenture treatment, were enrolled in the study. Inclusion criteria were:

- reasonable-to-good general health, as expressed by a score I or II on the physical status classification system by the American Association of Anesthesiologists (ASA-score);
- bone height in the mandibular anterior region allowing the placement of 11, 13 or 15 mm screw implants. Bone width had to be such that implants of 3.5 or 4 mm in diameter could be placed;
- no history of previous implant loss, no pathology or irradiation of the (anterior) mandible.

The study protocol was approved by the medical ethics committee of the University Medical Center Utrecht and written informed consent was obtained.

Implant installation

Two Ti screw implants (OsseoSpeed™ Implants, Astra Tech AB, Mölndal, Sweden) were placed in local anaesthesia in the region of the former mandibular cuspsids. Subjects received antibiotics (Vibramycin, from 1 day pre-operatively 200 mg until 7 days post-operatively, once daily 100 mg) and rinsed with a 0.2% chlorhexidine solution from 2 days pre-operatively until 2 weeks post-operatively.

Implant diameter and length within each subject were similar. The implants were placed and randomized to immediately be provided with either one (experimental) ZrO2 or one Ti abutment, functioning as a permucosal healing abutment.

Two weeks after surgery, brushing was allowed. Subjects were enrolled in a strict follow-up protocol that focused on oral hygiene, but during the experimental period, the abutments were never professionally cleaned.

Abutments (ZrO2 and Ti)

The experimental abutments were especially designed, fabricated and CE-marked for the study and are not commercially available. Bulk material for the Ti abutments was Ti, grade 4, according to ASTM F-67 and Y-TZP according to ISO 13356 for the ZrO2 specimen (Astra Tech AB). Abutment materials and production methods were basically similar to those used in the production of commercially available, regular Ti and ZrO2 abutments by the same manufacturer (i.e. the ZirDesign™ and TiDesign™ abutments, Astra Tech AB). Surface finish requirements for both abutment types were also similar to ordinary production.

The surface roughness of the experimental ZrO2 and Ti abutments was measured at three locations on one specimen of each material by means of contact profilometry. Mean Ra-values were 236 nm [range: 217–255 nm] for the ZrO2 abutment and 210 nm [range: 173–272] for the Ti abutment. The corresponding Rz-values were 292 nm [range: 260–330 nm] and 259 nm [range: 220–332 nm] for the ZrO2 and Ti abutments. Hence, the surface roughness of the materials used was considered to be in the same order of magnitude, and the main difference between the two experimental abutments is their chemical composition.

The location for the ZrO2 and Ti abutment (left/right) was allotted at random in such a way that the distribution over the 20 patients resulted in a balanced design.

Microbiological sampling and follow-up

Microbiological sampling and measurement of clinical parameters were performed at 2 weeks and 3 months post-operatively. Sulcular plaque samples were obtained by performing a circumferential motion (360°) in the peri-implant sulci.
with a sterilized single-use plastic scaler (Implacare®, Hu-Friedy, Rockwell St, Chicago, IL, USA).

Microbiological analysis
Detection and counting of the numbers of Aggregatibacter actinomycetemcomitans (Aa), Porphyromonas gingivalis (Pg), Prevotella intermedia (Pi), Tannerella forsythia (Tf), Parvimonas micra (Pm), Fusobacterium nucleatum (Fn) and Treponema denticola (Td) were performed using real-time PCR as described by others (Kuboniwa et al. 2004a; Boutaga et al. 2005b). In brief, amplification of species-specific 16S rDNA sequences was performed in a 20 μl reaction mixture containing 10 μl of 2× LightCycler® 480 Probes Master (Roche, Indianapolis, IN, USA), 300 nM of species-specific primers, 100 nM of a species-specific probe (both from TIB MolBiol GmbH, Berlin, Germany, modified by a FAM reporter and a BHQ-2 quencher) and 5 μl of DNA purified from the plaque samples. The sequences of species-specific primers and probes have been described by Boutaga et al. (2003, 2003a) and those for T. denticola by Kuboniwa et al. (2004b). Five microlitres of the DNA extracted from the following well-defined reference strains was used to prepare a standard curve as positive controls: P. gingivalis strain HG66 (W83), T. forsythia ATCC 43037, A. actinomycetemcomitans NCTC 9710, P. intermedia ATCC 25611, F. nucleatum ATCC 25586, P. micra HG 1179 (ATCC 33270) and T. denticola (ATCC 33520); 5 μl of sterile H2O was used as a non-template control.

The samples were subjected to an initial single incubation at 95°C for 10 min, followed by 45 cycles at 95°C for 10 s and 60°C for 20 s. DNA amplification was monitored by quantitatively analysing the fluorescence emission (LightCycler® 480, software version 1.5, Roche) during each annealing-extension step.

Statistical analysis
The mean values for the clinical parameters and levels of the seven marker bacteria associated with the ZrO2 and Ti abutments were described and statistically compared at 2 weeks and after 3 months post-surgery. Non-parametric statistical procedures were used for all comparisons (Wilcoxon matched-pairs, sign-rank test). All statistical computations were performed in a standard statistical program (SPSS version 16, SPSS Inc., Chicago, IL, USA). Statistical significance of the comparison between the ZrO2 and Ti abutments and the two observation periods was set at $P < 0.05$.

Results
Data at 3 months in one subject could not be recorded because of a breach of protocol. The experimental abutments had already been removed before microbiological sampling and clinical measurement taking.

Mean values for the clinical parameters of the peri-implant mucosa surrounding the ZrO2 and Ti abutments at 2 weeks and at 3 months are presented in Table 1 (meanPPD, meanREC and BOP). Mean probing depths at 3 months were shallower around ZrO2 compared with Ti abutments. No further statistically significant clinical differences between ZrO2 and Ti abutments were observed for meanPPD, meanREC or BOP at 2 weeks or 3 months. The meanPPD decreased significantly for both the ZrO2 and the Ti abutments between 2 weeks and 3 months. In contrast, meanREC increased in time for both abutment types. Slightly less BOP was observed around the Ti abutments at 3 months compared with the observations 2 weeks post-operatively (Table 1).

The numbers of peri-implant sites with detectable levels of seven periodontal bacteria at 2 weeks and at 3 months are presented in Table 2. The cumulative bacterial load is described per subject in Table 3. No statistically significant difference could be observed in counts of the 7 marker bacteria or in cumulative bacterial load between the ZrO2 and Ti abutments, both at 2 weeks and at 3 months. Generally, slightly larger numbers of bacteria were found at the ZrO2 abutment surfaces compared with the Ti surfaces, although this never reached a statistically significant level (Table 2).

Clinical parameters
Probing pocket depth (PPD), recession (REC) and bleeding on probing (BOP) were assessed at two sites per implant (mid-buccal and mesial). A plastic periodontal probe with 0.25 N of calibrated probing force was used (Click-probe®, KerrHawe, Bioggio, Switzerland). PPD was measured in millimeters from the mucosal margin to the clinical pocket. REC was measured in millimeters from the edge of the abutment to the mucosal margin [Fig. 1]. BOP was recorded as absent (score = 0) or present (score = 1). Mean values per implant were calculated for the continuous parameters (meanPPD, meanREC). BOP is presented as the percentage of implants that demonstrated either mid-buccal or mesial BOP.

Table 1. Evaluation of mean pocket probing depth (MeanPPD), mean recession (MeanREC) and bleeding on probing (BOP, either buccal or mesial)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>2 weeks</th>
<th>3 months</th>
<th>P-level</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MeanPPD</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ZrO2</td>
<td>3 (1.1)</td>
<td>1.7 (0.7)</td>
<td>$Z_{0.14}, P = 0.89$</td>
</tr>
<tr>
<td>Ti</td>
<td>2.9 (0.8)</td>
<td>2.2 (0.8)</td>
<td>$Z_{1.2}, P = 0.03$</td>
</tr>
<tr>
<td><strong>MeanREC</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ZrO2</td>
<td>2.1 (1.2)</td>
<td>2.7 (0.6)</td>
<td>$Z_{0.97}, P = 0.14$</td>
</tr>
<tr>
<td>Ti</td>
<td>1.9 (1.2)</td>
<td>2.6 (1)</td>
<td>$Z_{0.97}, P = 0.03$</td>
</tr>
<tr>
<td><strong>BOP</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ZrO2</td>
<td>50%</td>
<td>52.6%</td>
<td>$Z_{0.03}, P = 0.8$</td>
</tr>
<tr>
<td>Ti</td>
<td>75%</td>
<td>47.4%</td>
<td>$Z_{0.01}, P = 0.05$</td>
</tr>
</tbody>
</table>

Pairwise comparison of data after 2 weeks and 3 months for zirconia (ZrO2) and for titanium (Ti) abutments (Wilcoxon matched-pairs test, sign-rank test). Standard deviations between brackets ($n = 20$ subjects for the 2 weeks and 19 subjects for the 3-month interval).

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Table 2. The number of peri-implant sites with detectable levels of seven periodontal bacterial species using RT PCR, 2 weeks and 3 months after installation of the zirconia (ZrO₂) and titanium (Ti) abutments (n = 20 subjects for the 2 weeks and n = 19 subjects for the 3 month interval)

<table>
<thead>
<tr>
<th>Subject</th>
<th>ZrO₂</th>
<th>Ti</th>
<th>ZrO₂</th>
<th>Ti</th>
<th>ZrO₂</th>
<th>Ti</th>
<th>ZrO₂</th>
<th>Ti</th>
<th>ZrO₂</th>
<th>Ti</th>
<th>ZrO₂</th>
<th>Ti</th>
<th>ZrO₂</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aa</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>7</td>
<td>6</td>
<td>17</td>
<td>15</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ZrO₂/Ti-</td>
<td>13</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>17</td>
<td>17</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ZrO₂/Ti+</td>
<td>27</td>
<td>17</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>4620</td>
<td>220</td>
<td>440</td>
<td>91</td>
<td>22,000,000</td>
<td>4100</td>
<td>1900,041</td>
<td>400</td>
<td>1540</td>
<td>1070</td>
<td>49,504</td>
<td>280</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>0</td>
<td>190</td>
<td>0</td>
<td>6802</td>
<td>0</td>
<td>0</td>
<td>94,798</td>
<td>33,530</td>
<td>434,701</td>
<td>8,410,665</td>
<td>69,999</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median</td>
<td>4620</td>
<td>220</td>
<td>440</td>
<td>91</td>
<td>22,000,000</td>
<td>4100</td>
<td>1900,041</td>
<td>400</td>
<td>1540</td>
<td>1070</td>
<td>49,504</td>
<td>280</td>
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</tr>
</tbody>
</table>

3 months (n = 19)

| N detected | 0    | 1  | 1    | 0  | 11   | 17 | 17   | 2  | 0    |    | 2    | 1  | 17   | 17 |
| ZrO₂/Ti-   | 0    | 0  | 0    | 0  | 0    | 0  | 0    | 0  | 0    |    | 0    | 0  |      |    |
| ZrO₂/Ti+   | 0    | 0  | 0    | 0  | 0    | 1  | 2    | 0  | 0    |    | 0    | 0  |      |    |
| Mean       | 0    | 1,000,000 | 64,000 | 600,088 | 3,600,089* | 3700 | 0    | 221,651 | 170,351* | 1.728,753 | 702,662 | 280 | 0    |    |
| SD         | 0    | 0  | 36,770 | 952,117 | 804,935  | 0  | 338,980 | 509,342 | 4,555,954 | 1,548,894 | 170 | 0    |    |
| Median     | 0    | 1,000,000 | 64,000 | 200,090 | 2000    | 0  | 3800  | 2000 | 120,000 | 37,000 | 280 | 0    |    |

Mean absolute counts (mean) for those observations exceeding the detection threshold and their standard deviation (SD) as well as the median values are presented.

*Statistically significant difference between 2 weeks and 3 months, P<0.05.

Table 3. Cumulative bacterial load of seven periodontal bacterial species using RT PCR on zirconia and titanium abutment surfaces at 2 weeks and 3 months post surgery (n = 20 subjects for the 2 weeks and 19 subjects for the 3 month interval)

<table>
<thead>
<tr>
<th>Subject</th>
<th>ZrO₂</th>
<th>Ti</th>
<th>ZrO₂</th>
<th>Ti</th>
<th>ZrO₂</th>
<th>Ti</th>
<th>ZrO₂</th>
<th>Ti</th>
<th>ZrO₂</th>
<th>Ti</th>
<th>ZrO₂</th>
<th>Ti</th>
<th>ZrO₂</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aa</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
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<td>6</td>
<td>17</td>
<td>15</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ZrO₂/Ti-</td>
<td>13</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>0</td>
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</tr>
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<td>ZrO₂/Ti+</td>
<td>27</td>
<td>17</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>4</td>
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<td>49,504</td>
<td>280</td>
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</tr>
</tbody>
</table>

Mean absolute counts (mean) for those observations exceeding the detection threshold and their standard deviation (SD) as well as the median values are presented.

Data are presented per subject, in absolute counts per sample and pairwise compared (Wilcoxon matched-pairs, sign-rank test). Sites where the detection threshold was not exceeded are awarded the value "0".

Discussion

ZrO₂ is becoming a favoured material in restorative dentistry for implant abutments and as copings for crowns and bridges, mainly because of its presumed favourable light dynamics. In a way, this is somewhat worrying considering the fact that long-term clinical data documenting the performance of ZrO₂ abutments and restorations are scarce. The same can be said with respect to the soft tissue response to ZrO₂ itself, because well-controlled in vivo human studies are lacking as was also postulated in a consensus statement on soft tissue integration [Klinge & Meykle 2006]. The present study deals with the peri-implant soft tissue response to ZrO₂ and Ti implant abutments and the early bacterial colonization.

The choice for a within-subject comparison in edentulous subjects was made because it offered the best possibility for eliminating confounding factors. For example, the bacterial challenge by the oral microflora is the same in one individual. As a result, implant dimensions and many other variables within the same subject were similar in all cases and microbiological sampling and clinical procedures could be standardized as much as possible. Because the surface roughness of the experimental abutments made from ZrO₂ and Ti was also more or less similar, potential differences in soft tissue response and in bacterial colonization are presumably the result of differences in the chemical composition and consequently of differences in surface-free energy (electrical conductivity). The surface roughness

At 2 weeks, the most frequently detected periodontal species were P. micra and F. nucleatum. In contrast, periodontal pathogens such as A. actinomycetemcomitans, P. gingivalis and T. denticola were not detectable in the majority of patients (Table 2). A. actinomycetemcomitans was detected in three subjects at 2 weeks post-surgery, but was no longer detectable at 3 months in any of test sites. Two subjects hosted P. gingivalis at 3 months, but not at 2 weeks. The bacterial colonization of ZrO₂ surfaces did not undergo major changes between 2 weeks and 3 months, although a slight increase of F. nucleatum cells was observed (Z = 1.07, P = 0.05). At Ti abutment surfaces, the counts of P. intermedia [Z = 3.03, P < 0.05] and P. micra [Z = 3.10, P < 0.05] increased statistically significantly in time (Table 2).
of the abutments that were used \((R_s\text{-values 210-236 nm})\) approached the optimal roughness that was suggested in the literature for perimucosal implant abutments \(\text{(Bollen et al. 1996c; Quirynen et al. 2006a)}\).

Only a few reports describe longitudinal changes of the subgingival microflora after changing substrata or during implantation \(\text{(Lee et al. 1999; Furst et al. 2007b)}\). In the present study, a detection method was chosen comprising high specificity and sensitivity towards pathogenic bacterial species that are related to peri-implant infection. Therefore, we have not performed an investigation method that gives an overview of “all species”, like anaerobic culture or – a money-wise expensive – molecular technique as next-generation sequencing, although the latter may be an interesting option \(\text{(Zaura et al. 2009)}\). Another advantage of the chosen method was that it enabled us to really quantify the numbers of bacterial cells per species during the examination period. Other techniques as DNA-DNA checkerboard hybridization are semi-quantitative only. A real-time PCR is more precise in detecting bacteria \(\text{at implant sites in patients}\). It has been suggested that the use of 0.25 N of calibrated probing force \(\text{performed more} \text{convincingly rejected for most parameters with the exception of the pocket probing depth. Some-what shallower probing depths were observed around ZrO}_2 \text{abutments after 3 months}\).

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