Analysis of the influence of the macro- and microstructure of dental zirconium implants on osseointegration: a minipig study

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Objectives. It was the aim of this study to analyze the influence of implant design and surface topography on the osseointegration of dental zirconium implants.

Study Design. Six different implant designs were tested in the study. Nine or 10 test implants were inserted in the frontal skull in each of 10 miniature pigs. Biopsies were harvested after 2 and 4 months and subjected to microradiography.

Results. No significant differences between titanium and zirconium were found regarding the microradiographically detected bone-implant contact (BIC). Cylindric zirconium implants showed a higher BIC at the 2-month follow-up than conic zirconium implants. Among zirconium implants, those with an intermediate Ra value showed a significantly higher BIC compared with low and high Ra implants 4 months after surgery.

Conclusions. Regarding osseointegration, titanium and zirconium showed equal properties. Cylindric implant design and intermediate surface roughness seemed to enhance osseointegration. (Oral Surg Oral Med Oral Pathol Oral Radiol 2013;116:e1-e8)

Titanium is seen as the current "gold standard" material in dental implantology. However, metals such as titanium undergo electrochemical corrosion due to contact with body fluids such as saliva.[1] As a consequence, ion release from the implant surface and enrichment of the particles in the periimplant tissues,[2] the regional lymph nodes,[3,4] and distant organs, especially the lung, has been described.[5,6] High local fluoride concentrations, like those seen after application of fluoride toothpastes, were found to propagate ion release further.[7,8] On top of that, Lalor et al.[9] described sensibilization due to accumulation of titanium ions in the tissue. Stejskal and Stejskal underscored the possibility of triggering or exacerbating autoimmune disease, such as rheumatoid arthritis, multiple sclerosis, or amyotrophic lateral sclerosis, by continuous release of metal ions in low doses.[10] Consequently, a preexisting autoimmune disease might be seen as a contraindication for dental implant treatment. Additionally, in patients with a thin periodontal biotype, the shine of the gray titanium color through the gingival tissue represents an esthetic comprise.[11] In contrast to titanium, zirconium is characterized by a lack of unwanted electrochemical characteristics as well as a tooth-like color.

Successful osseointegration is a prerequisite for the long-term success of dental titanium as well as zirconium implants.[12] Implant insertion causes surgical trauma to the bone. Blood released by the surrounding vessels fills the periimplant gap and forms a coagulum.[13] Thrombocytes attach to the implant surface and become activated, resulting in the release of various growth factors, such as platelet-derived growth factor, transforming growth factor β, serotonin, and histamine. A growth factor gradient is established in the periimplant gap. Osteogenic progenitor cells migrate along the gradient through the fibrin matrix to the implant surface and differentiate into osteoblasts, which synthesize bone matrix in an implantofugal way, resulting in contact osteogenesis.[12]

Statement of Clinical Relevance

Owing to electrochemical corrosion and potential sensibilization by titanium, zirconium has been tested as an alternative. However, no studies investigating the influence of surface topography of zircon implants on their osseointegration are available at present.

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Osseointegration of dental zirconium implants is reported in contradictory ways in the literature.[14] Bone apposition was found on zirconium as well as titanium surfaces.[15] Several investigations of the bone-implant interface proved proper osseointegration of zirconium implants and absence of connective tissue in the peri-implant space.[16] In a comparative animal study, Koh et al. al. were able to demonstrate that titanium and zirconium implants showed equal osseointegration properties.[17] Furthermore, the healing of the surrounding soft tissue showed no differences between the materials.[17] According to the results reported by Dubruille et al., bioceramics achieve a higher bone-implant contact than titanium. However, those authors fixed their implants in oversized bur holes with bone cement, resulting in reduced comparability with the standard implantology literature.[18] In another study, Lee et al. integrated zirconium particles in the surface of hydroxyapatite-coated implants and compared the osseointegration of those implants with the bone tissue response to uncoated control implants. Direct apposition of new bone was found only for implants without zirconium. In contrast to other studies, addition of zirconium disturbed osseointegration.[19] Hayashi et al. compared steel with zirconium and showed no significant differences regarding bone affinity of the materials. According to those authors' conclusion, zirconium shows equal properties as steel of achieving an implant-bone unit.[20]

Although much data exist regarding the comparison between zirconium and titanium, few studies investigating the influence of macro- and microstructure of zirconium implants on osseointegration have been performed. Taking this into account, it was the aim of the present study to investigate the influence of design and thread geometry as well as surface topography of dental zirconium implants on osseointegration using the minipig model.

MATERIALS AND METHODS

Experimental implants

Experimental implants were provided by the Institute for Bioprocessing and Analytical Measurement Techniques, Heilbad Heiligenstadt, Germany, after topographic and mechanical evaluation as well as standard in vitro testing.[21] According to differences in the material, shape and thread design, and micro- and nanostructure, implants were subdivided into 6 different designs:

1. commercially pure (c.p.) titanium; cylindric; thread design 1 (n = 16); Ra = 1.7 μm; specific surface 45.22%
2. Y-TZP; cylindric; thread design 1; Ra = 1.7 μm; specific surface 23.25% (n = 16)
3. Y-TZP; cylindric; thread design 2; Ra = 1.7 μm; specific surface 23.25% (n = 16)
4. Y-TZP; conic; thread design 2; Ra = 1.7 μm; specific surface 23.25% (n = 17)
5. Y-TZP; cylindric; thread design 1; Ra = 0.3 μm; specific surface 13.69% (n = 16)
6. Y-TZP; cylindric; thread design 1; Ra = 3.0 μm; specific surface 31.46% (n = 16)

Regarding shape, cylindric (length 12.0 mm, diameter 4.3 mm) and conic (length 11.5 mm, diameter 4.05 mm) implants were compared. Furthermore, 2 different thread designs were tested. Thread design 1 is a standard design of titanium dental implants produced by Impulse Biomedical Cooperation. In contrast, thread design 2 was optimized for a more homogeneous strain distribution in the surrounding bone tissue and lower maximal bending stress in the root of the implant. Therefore, slight chances of some geometric thread parameters (inner diameter, thread width, pitch, root radius, distal and proximal half angle) have been implemented (Figure 1).[22]

The titanium surface was treated by sandblasting and acid etching,[23] resulting in a mean roughness index (Ra) of 1.7 μm and a specific surface of 45.22%. Zirconium implants with an Ra of 1.7 μm were constructed by sandblasting of the surface with zirconium powder, resulting in a specific surface of 23.25%. Zirconium implants with an Ra of 3.0 μm were constructed also by sandblasting and showed a specific surface of 31.46%. Sandblasting of zirconium implants was performed with zirconium powder and different process parameters according to DE 102007957917B3.[24] In contrast, zirconium implants with an Ra of 0.3 μm were constructed by milling of the threads, which resulted in a specific surface of 13.69%.

All dental implants were supplied in a sterile packaging after steam sterilization (122°C, 3 bar, 20 min).

Animal model and surgical protocol

Animal investigations were performed on 10 female minipigs 9-14 months old with an average body weight from 18.3 to 22.6 kg (Ellegaard Göttingen Minipigs, Dalmose, Denmark) after approval of the study protocol by the local authorities (approval no. 02-032/09; Thuringian State Office for Food Safety and Consumer Care, Bad Langensalza, Germany).

After overnight fasting with free access to water, the pigs were premedicated with ketamine (15 mg/kg body weight Ketavet; Pharmacia and Upjohn, Erlangen, Germany) and midazolam (0.2 mg/kg body weight Dormicum; Ratiopharm, Ulm, Germany) to allow placement of an intravenous line in the ear vein. General anesthesia was induced with propofol (0.2-0.3 mg/kg body weight, Fresenius Kabi, Bad Homburg, Germany).