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Stability and aging resistance of a zirconia oral implant using a carbon fiber-reinforced screw for implant-abutment connection

Benedikt C. Spies[a,b,*], *Alexander Fross*[a], *Erik Adolfsson*[c], *Aimen Bagegni*[a], *Sam Doerken*[d], *Ralf-Joachim Kohal*[a]

[a] *Medical Center – University of Freiburg, Center for Dental Medicine, Department of Prosthetic Dentistry, Faculty of Medicine, University of Freiburg, Hugstetter Str. 55, 79106 Freiburg, Germany*

[b] *Charité – Universitätsmedizin Berlin, Corporate Member of Freie Universität Berlin, Humboldt-Universität zu Berlin, and Berlin Institute of Health, Department of Prosthodontics, Geriatric Dentistry and Craniomandibular Disorders, Aßmannshauser Str. 4-6, Berlin, Germany*

[c] *Swerea IVF AB, Argongatan 30, 431 53 Mölndal, Sweden*

[d] *Medical Center – University of Freiburg, Institute of Medical Biometry and Statistics, Faculty of Medicine, University of Freiburg, Stefan-Meier-Str. 26, 79104 Freiburg, Germany*

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ABSTRACT

Objective. To investigate the long-term stability of a metal-free zirconia two-piece implant assembled with a carbon fiber-reinforced (CRF) screw by means of transformation propagation, potential changes in surface roughness, the gap size of the implant-abutment connection, and fracture load values.

Methods. In a combined procedure, two-piece implants made from alumina-toughened zirconia were dynamically loaded (10^7 cycles) and hydrothermally aged (85°, 60 days). Implants made from titanium (Ti) and a titanium–zirconium (TiZr) alloy with a titanium abutment screw served as control. Transformation propagation (ATZ) and gap size of the IAC were monitored at cross-sections by scanning electron microscopy (SEM). Furthermore, changes in surface roughness of ATZ implants were measured. Finally, implants were statically loaded to fracture. Linear regression models and pairwise comparisons were used for statistical analyses.

Results. Independent of the implant bulk material, dynamic loading/hydrothermal aging did not decrease fracture resistance ($p = 0.704$). All test and control implants fractured at mean loads >1100 N. Gap size of the IAC remained stable (<5 μm) or decreased. None of the CFR screws fractured during static or dynamic loading. Monoclinic layer thickness of ATZ implants increased by 2–3 μm at surfaces exposed to water, including internal surfaces of the IAC. No changes in surface roughness were observed.

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* *Corresponding author at*: Charité – Universitätsmedizin Berlin, Department of Prosthodontics, Aßmannshauser Straße 4-6, 14197 Berlin, Germany.

E-mail address: benedikt.spies@charite.de (B.C. Spies).

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Significance. Combined hydrothermal aging and dynamic loading did not affect the above-mentioned parameters of the evaluated two-piece ATZ implant. Mean fracture loads >1100 N suggest a reliable clinical application.

1. Introduction

Since their first application more than 50 years ago [1], titanium implants constantly developed over time. Improvements affected the implant surface (turned, micro-roughened, active), the implant-abutment connection (from external to internal connections and from matched to switched platforms), and the alloys used for fabrication (from gold to titanium for abutment-screws and from pure titanium to titanium–zirconium alloys for the bulk material) [2], significantly reducing the incidence of technical and biological complications over time [3]. Furthermore, the indication range increased towards implants with a reduced length and diameter as well as early and immediate loading protocols. In contrast, ceramic implants developed significantly slower although introduced to the market at the same time [4,5]. Early products made from mono- or polycrystalline alumina had several drawbacks by means of a reduced fracture resistance. With the use of yttria-stabilized zirconia as implant material, stability of ceramic implants increased due to the allotropic character of this ceramic material allowing for a phase transformation toughening mechanism [6]. To date, fractures are only scarcely observed and mostly limited to reduced diameter implants (<4 mm) and zirconia implants supporting removable prostheses [7–9]. However, clinical evidence for zirconia implants is still limited to single-tooth restorations and three-unit fixed dental prostheses. Even though promising, clinical long-term data exceeding three years of observation are still rare and restricted to one-piece implants [10]. A one-piece design offers sufficient fracture resistance and exposes a minimum surface area susceptible for hydrothermal aging (also known as low-temperature degradation; LTD). However, the final and provisional restoration need to be cemented to the abutment — a procedure that is known to be associated with increased incidence of biological complications [11]. Due to a rising demand for screw-retained solutions, several two-piece ceramic systems are available on the market by now. The majority, however, is still using titanium abutment screws questioning the metal-free approach of this concept. One concept to replace titanium as abutment screw material represents the use of a carbon fiber-reinforced (CRF) screw [12,13]. To date, only little is known on the long-term stability of such two-piece implants when subjected to cyclic loads and the moist environment of the oral cavity. It was shown, that LTD initiation is liable to start from all surfaces exposed to water [14]. Compared to one-piece implants, two-piece systems comprise a more complex design and water access to internal surface areas of the implant-abutment connection. Assuming the same sensitivity of the material itself to aging, the reduced thickness of the components and the increased surface area exposed to water might result in identical environmental conditions having an increased impact on the mechanical performance of a two-piece implant system compared to a one-piece system. In order to decelerate transformation propagation, some manufacturers prefer the use of zirconia composite materials like alumina-toughened zirconia (ATZ) characterized by increased stability and decreased degradation kinetics [15,16]. Since available ISO standards do not account for the specific material properties of micro-roughened dental implants, the patient cannot rely on the safety of market-available products [17,18]. Therefore, the primary aim of the present investigation was to measure the amount of phase transformation induced by applied mechanical stress during a hydrothermal treatment and evaluate its impact on the fracture strength of a CRF screw-retained ATZ implant. Furthermore, gap sizes were monitored to evaluated the integrity of the IAC and surface roughness was determined prior to and after the treatments.

2. Materials and methods

2.1. Sequence of experimental procedures

Three different two-piece implant systems (alumina-toughened zirconia/Zr: test group, titanium/Ti and titanium–zirconium/TiZr: control groups, n = 16 samples per group) of a comparable design were used for the experiment (Fig. 1). Of the 16 samples per group, eight were subjected to a simultaneous aging/loading procedure (L) in a chewing simulation device as described earlier [14] and the remaining eight served as reference without any treatment (N). This resulted in six subgroups (ZrL, ZrN, TiL, TiN, TiZrL, TiZrN). Subsequently, a cross-section of one sample per subgroup (n = 6) was evaluated by scanning electron microscopy to monitor transformation propagation (ZrL and ZrN) and gap sizes of the IAC (all samples). Surface roughness was evaluated on one samples per subgroup. Except for the implants used for cross-sections, all implants (n = 42) were finally loaded to fracture in a static loading test and statistically analyzed.

2.2. Investigational implants

The Zr implants (Zeramex P6, REF: P16512; Dentalpoint AG, Zürich, Switzerland) were wet-grinded out of fully sintered ATZ BIO-HIP blanks (Metoxit AG, Thayngen, Switzerland) and consisted of a parallel-walled screw-shaped endosseous part (micro-roughened by sandblasting and acid etching) merging into a divergent polished emergence profile. The implant was 14.55 mm in length and destined for installation on tissue-level. The total length consisted of 12 mm for the endosseous part (4.1 mm in diameter), 1.8 mm for the emergence profile and 0.75 mm for the implant shoulder (4.8 mm in diameter).

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