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In vitro performance of one- and two-piece zirconia implant systems for anterior application

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ABSTRACT

Objectives: To investigate the long-term in vitro performance and fracture resistance of one-piece and bonded two-piece zirconia implant systems for anterior application.
Methods: Two groups of bonded two-piece zirconia (ZZB), four groups of one-piece zirconia (Z), and two groups of two-piece titanium (TTS, reference) implant systems were restored with identical monolithic zirconia crowns (n = 10/group). Eight specimens per group were mounted at an angle of 135° in the chewing simulator and subjected to thermal cycling (TC:18,000 cycles; 5°/55°) and mechanical loading (ML:3.6×10^6 cycles; 100N) simulating an anterior situation. Fracture resistance and maximum bending stress were determined for specimens that survived aging and for two references per group after 24 h water storage. SEM pictures were used for failure analysis. Data were statistically analysed (one-way-ANOVA, post-hoc Bonferroni, Kaplan-Meier-Log-Rank, $\alpha = 0.05$).
Results: A one-piece zirconia and a two-piece titanium implant system survived TCML without failures. Both bonded two-piece zirconia implant systems and a one-piece zirconia implant system totally failed (fractures of abutment or implant). Failure numbers of the other systems varied between 1× (1 group) and 5× (2 groups). Significantly different survival rates were found (Log-Rank-test: p = 0.000). Maximum fracture forces/bending stresses varied significantly (ANOVA: p = 0.000) between 188.00 ± 44.80 N/381.02 ± 80.15 N/mm^2 and 508.67 ± 107.00 N/751.45 ± 36.73 N/mm^2. Mean fracture values after 24 h water storage and TCML were not significantly different.
Conclusion: Zirconia implant systems partly showed material defects or connection insufficiencies. Bonded two-piece systems had higher failure rates and lower fracture resistance than one-piece implants.
Clinical significance: Individual zirconia implant systems may be applied in anterior regions with limitations.

1. Introduction

Implants are considered as state-of-the-art method for replacing missing teeth [1–4]. Besides the well-proven titanium implant systems, there is the possibility to use zirconia implants [5]. Both materials differ in many aspects and have their own specific advantages and disadvantages. Titanium offers its lightweight, its biocompatibility, the ability to repair itself instantaneously if damaged due to the passivating oxide layer, and the resistance to chemical attacks [2,3,6]. However, the grey colour of titanium may shine through the thin mucosa, especially if applied in the anterior region [1,5,7–10]. In addition, only newer titanium alloys are characterized by an elastic modulus that is close to human bone [6], and some studies reported on galvanic reactions that occurred after the contact with saliva and fluoride. Inflammatory response and bone resorption were also found to be induced by titanium particles [3,8,11–13].

Since in the recent years patient demands for metal-free, tooth-coloured alternatives have raised, zirconia implant systems have been developed [14]. The white colour and the possibility of staining zirconia is an advantage [15]. Zirconia shows comparable osseointegration as titanium [16,17], but less plaque accumulation, which improves the soft tissue management and reduces the risk of peri-implantitis [2,5,7,14,18]. Moreover, the high hardness and the inert character of zirconia allows to remove residual cements easily [15] and only a minimal ion release is documented [3].

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Unfortunately, experiences with titanium implant systems can be transferred to zirconia implants only with limitations. In contrast to metal, zirconia is more brittle and more assailable by bending, subcritical crack growth, and low-temperature degradation [19]. However, it offers high strength and structural reliability [1,7,15,20,21]. In addition, there are lots of differences in manufacturing processes, which may have an influence on properties and clinical performance of zirconia implant systems [5].

Due to these properties it is more difficult to realize screw connections or other gracile structures with zirconia. Screwed zirconia implant systems have been introduced to clinical application recently, but a screwed connection may not reach the same clinical reliability as proven for titanium implant-abutment connections yet [15]. Therefore, most currently used zirconia implants are one-piece or bonded two-piece systems. A bonded connection allows many benefits of a two-piece implant system. It was previously shown that the weak point is not the bonding connection, despite of the inert character of zirconia, but primarily the design of the connecting parts [1]. However, because neither one-piece nor bonded two-piece systems offer a reversible connection between abutment and implant, the entire implant has to be removed in case of severe failures [15].

Zirconia implant systems are not yet part of clinical routine treatment, also because of little scientific and in vitro information [15]. Nevertheless, there are studies which conclude that zirconia has the potential to become an alternative to titanium implants [3,17,20,22].

Before zirconia implant systems can be routinely applied in clinical practice with a clear conscience, in vitro tests may be helpful, especially regarding the challenging loading situation (bending stress) in an anterior region. In vitro mechanical loading combined with simultaneous thermal cycling may predict the influence of hydrolytic effects and the mechanical performance. Furthermore, a long-term simulation of the clinical situation might give more exact information about possible errors and reasons for fatigue failures [4,23]. Finally, a static fracture test of implant systems without appearing failures during aging might indicate the presence of initiated defects and help to compare individual systems.

The hypothesis of this investigation was that individual one-piece or bonded two-piece zirconia implant systems provide similar in vitro performance and fracture resistance like well-proven two-piece screwed titanium systems, which may justify their application for clinical anterior restorations.

2. Materials and methods

A total of six different groups of zirconia one-piece or bonded two-piece implant systems (n = 10 per group) were investigated. Two well-known two-piece screwed titanium systems were used as reference (Table 1). Depending on the availability and the specifications of the individual manufacturers, the implant diameters differed between 3.3 mm and 5.0 mm. To investigate the influence of the implant diameter within a system, a one-piece and a bonded two-piece implant-system were tested with different implant diameters (1-ZZB/2-ZZB; 3-Z/4-Z). All implants were carefully positioned in resin at bone or tissue level, as specified by the manufacturer. To get results close to the clinical situation, the structure of the natural jawbone was recreated. The cancellous bone was imitated by polyoxymethylene (POM, Young's modulus: 2.6 GPa). A 1 mm thin layer of 30% fibre-reinforced polyetheretherketone (PEEK, Young's modulus: 10.0 GPa) was added as cortical bone. The Young's moduli of the resins matched the average values of 1–4 GPa for cancellous bone and 7–20 GPa for cortical bone, as reported in literature data [19,24–27]. In order to ensure a consistent lever arm, the distance between the PEEK-bone level and the incisal edge of the crown was the same for all specimens. The bonded two-piece zirconia implant systems were completed with straight prefabricated zirconia abutments by using resin-based composite (Panavia F 2.0, Kuraray, J). For the two-piece titanium systems the prefabricated straight titanium abutments were tightened with titanium screws using a torque gauge (35 Ncm) according to the manual instructions. As routinely recommended in clinical practice, the screw preload was controlled after 15 min, and the screw was retightened if necessary. The 80 specimens were restored with full-contour crowns (tooth 21) of identical external shape. The crown length was set at 13.0 ± 0.1 mm and the crowns were made of yttria-stabilized zirconia (Cercon HT, DeguDent, Hanau, G) by using the CAD/CAM (computer aided design/computer aided manufacturing) technique (Cercon eye/art/brain/heat plus, DeguDent). In order to avoid any abutment preparations, the inner geometry of the crowns was exactly customized to the individual abutment designs, respecting a minimum layer thickness of 0.46 mm. The crowns were glazed with the corresponding glazing material (Cercon glaze, DeguDent). The inner faces of the crowns were sandblasted (50 µm, 2.0 bar) and adhesively fixed to the abutments with the same resin-based composite cement as already used for the abutment cementation (Panavia F 2.0, Kuraray, J).

Table 1
Overview of implant systems: Z: one-piece zirconia implant system; ZZS/ZZB: screwed/bonded two-piece zirconia implant system; TTS: screwed two-piece titanium implant system (HIP: Hot Isostatic Post compaction; SLM: Surface Laser Modified; ZLA: Zirconia Sand-blasted, Large grit, Acid-etched; SLA: Sand-blasted, Large grit, Acid-etched).

System	Name/Manufacturer	Material implant/ abutment	Connection	Implant diameter x length [mm]	Tissue/Bone Level (TL/BL)	Fabrication	Surface
1 – ZZB	Z5c-40/Z-Systems, CH	zirconia/zirconia	bonded	4.0 × 10.0	TL	Isostatic Pressing, HIP	SLM
2 – ZZB	Z5c-50/Z-Systems, CH	zirconia/zirconia	bonded	5.0 × 10.0	TL	Isostatic Pressing, HIP	SLM
3 – Z	Z5m-40/Z-Systems, CH	zirconia	–	4.0 × 10.0	TL	Isostatic Pressing, HIP	SLM
4 – Z	Z5m-50/Z-Systems, CH	zirconia	–	5.0 × 10.0	TL	Isostatic Pressing, HIP	SLM
5 – Z	SDS1.1_3811/SDS, CH	zirconia	–	3.8 × 11.0	TL	Isostatic Pressing, Sintering, HIP	"SLA-similar" surface, additively blasted with zirconia
6 – Z	PURE Ceramic Implant ND, Straumann G	zirconia	–	3.3 × 12.0	TL	Sintering, HIP, Machining, Proof test	ZLA
7 – TTS Reference	Bone Level, NC, Straumann G	titanium/ titanium	screwed (titanium) 35 Ncm	3.3 × 12.0	BL	Machining	SLA
8 – TTS Reference	Standard Plus, Straumann G	titanium/ titanium	screwed (titanium) 35 Ncm	4.1 × 12.0	TL	Machining	SLA