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Original article

Ultimate force and stiffness of 2-piece zirconium dioxide implants with screw-retained monolithic lithium-disilicate reconstructions

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ABSTRACT

Purpose: The aims were to analyze stiffness, ultimate force, and failure modes of a 2-piece zirconium dioxide (ZrO_2) implant system.
Methods: Eleven 2-piece ZrO_2 implants, each mounted with ZrO_2 abutments plus bonded monolithic lithium disilicate (LS_2) restorations, were grouped for 3.3 mm (A) and 4.1 mm (B) diameter samples. Quasi-static load was monotonically applied under a standardized test set-up (loading configuration according to DIN ISO 14801). The ultimate force was defined as the maximum force that implants are able to carry out until fracture; stiffness was measured as the maximum slope during loading. An unpaired t-test was performed between group A and B for ultimate force and stiffness ($p < 0.05$).
Results: Force-displacement curves revealed statistically homogenous inner-group results for all samples. Failure modes showed characteristic fractures at the neck configuration of the implants independent of the diameter. Mean stiffness was 1099 N/mm ($\pm$ 192) for group A, and significantly lower compared to group B with 1630 N/mm ($\pm$ 274) ($p < 0.01$); whereas mean ultimate force was 348 N ($\pm$ 53) for group A, and significantly increased for group B with 684 N ($\pm$ 29) ($p < 0.0001$).
Conclusions: The examined 2-piece ZrO_2 implant system mounted to LS_2-restorations seems to be a stable unit under in-vitro conditions with mechanical properties compared to loading capacity of physiological force. The metal-free implant reconstructions demonstrated high stiffness and ultimate force under quasi-static load for single tooth replacement under consideration of the dental indication of narrow and standard diameter implants.

1. Introduction

Poly-crystalline zirconium dioxide (ZrO_2) is widely used in fixed prosthodontics. Clinical indications are ranging from single- to multi-unit dental reconstructions, such as copings, frameworks or monolithic full-contoured restorations as well as implant prosthodontic components [1]. The advantages of ZrO_2 as restorative material are strong mechanical properties combined with a tooth-a-like white appearance. An additional benefit of ZrO_2 is a high level of biocompatibility without potential of corrosion, and a low biofilm affinity [2]. Consequently, it ensures an inflammation-free incorporation and stabilization of the oral mucosa [3].

Recently, ZrO_2 implants were introduced into dental implantology as an alternative to the well-established titanium implants. Titanium (alloy) is typically characterized by its dark grayish color; and therefore, it is associated with a higher risk of esthetic compromises, especially in cases with thin mucosal biotypes [4]. A possible immunologic reaction due to a successive release of ions favored an increasing demand of metal-free treatment protocols in implant dental medicine [5].

Early generations of dental ceramics have been tested sensitive to shear and tensile loading. Laboratory and clinical investigations reported a high risk for fractures and surface flaws. Therefore, high-strength ZrO_2 ceramics with improved fracture resilience and

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flexural strength have been developed and became attractive as new materials in implant dentistry [6].

Since the introduction of all-ceramic implants in dental medicine, the initial challenge was to create a surface topography, which could demonstrate a similar osseointegrative potential to titanium implants [7]. Animal studies mainly focused on bone-implant contact (BIC) values with improved results over time. Today, ZrO_2 implants show a comparable potential of osseointegration as titanium implants with modified rough surfaces [8]. Due to the mechanical properties of ceramics in general, the first commercially available all-ceramic implant systems showed a 1-piece design.

From a biological point of view, 1-piece 'seamless' implants copy the natural tooth model concept, and therefore, they do not have a (micro-) gap in-between the implant body and abutment component. However, surgical and prosthodontic limitations exist for 1-piece implant systems. The expected 3D soft tissue architecture has to be surgically estimated prior to prosthodontic rehabilitation, and the post-operative implant healing takes place trans-mucosally, which may cause complications in case of simultaneous bone or soft tissue augmentation procedures [9]. From a prosthetic oriented view, the 1-piece implant design already integrates the abutment direction in the prolonged axis of the implant itself. Therefore, only minor reconstructive corrections are feasible of the implant angulation, and subsequently, of the final implant restoration. Here, the clinician has to grind the abutment intra-orally with the risk of heat-development and possible damage of osteoblasts, which may lead to early implant loss [10]. Aging of the modified ceramic surface has to be taken in account as an additional risk factor [11]. Moreover, the connection type of the restoration is already pre-defined with need for cement-retention. Without the option to create an individualized abutment following an iso- or slightly sub-mucosal margin, the risk is increased for an iatrogenic induced peri-cementitis [12].

The need for a 2-piece all-ceramic implant system arises, combining the advantages of the metal-free material properties and the autonomy using different implant prosthodontic components [13]. Therefore, the 2nd challenge in the era of all-ceramic implants was the development of a 2-piece metal-free system. Nevertheless, the specific material properties of dental ceramics and a suitable engineering technique realizing predictably high quality standards with reproducible fit of the implant components have made it difficult to develop a 2-piece all-ceramic implant system [14].

The Zeramex implant system follows a 2-piece concept with a 6-edge indexing implant platform (Zeramex P6, Dentalpoint AG, Zurich, Switzerland). The geometry and outer-design of the Zeramex implant is analogous to the Straumann Tissue Level Implant (Straumann TL RN, Institut Straumann AG, Basel Switzerland). For the Zeramex system, the implant body as well as the implant abutment is made of highly dense alumina-toughened zirconia (ZrO_2-ATZ), which is processed by the method of hot iso-static post-compaction (HIP) to improve the mechanical properties. This is achieved by the reduction of the pore and defect content while increasing the density and purity leading to a higher long-term life expectancy and to a reduced tendency to subcritical crack growth. The hydrophilic, micro-structured implant surface is created by sandblasting and etching (Zeramex P6 Zerafi, Dentalpoint AG, Zurich, Switzerland). Finally, A complete metal-free implant-abutment-connection is guaranteed using a carbon fiber-reinforced screw (CFR) (Fig. 1).

In general, novel technologies and treatment approaches have to maintain or even outdo the characteristics of the gold standard providing a predictable and long-lasting potential with high success rates. So far, the current evidence for long-term success of ZrO_2 dental implant systems is scarce. Only a limited number of

Fig. 1. Schematic cross-section of the all-ceramic 2-piece zirconia implant | abutment system with carbon-fiber reinforced polymer screw (Zeramex P6 Implant, Zerafix Abutment + Screw, Dentalpoint AG, Zurich, Switzerland).

publications on low level of evidence are available presenting case reports [15,16]. For the Zeramex all-ceramic implant system, the data of warranty replacements of 15255 Zeramex implants were evaluated retrospectively over a period of 4 years. The results of this study implied that two-piece zirconia implants showed competitive success rates, ranging from 96.7 % to 98.5 % [14]. Besides the biological ability of osseointegration and biocompatibility, it is of pertinent importance to verify the mechanical properties for these new 2-piece ZrO_2 implant systems [17].

Therefore, the aims of this in-vitro investigation were to quantify and compare stiffness, ultimate force, and failure modes of a completely metal-free 2-piece ZrO_2 implant system with two different diameters and bonded monolithic reconstructions out of lithium disilicate (LS_2).