

CERAMIC IMPLANTS- AN ALTERNATIVE TO TITANIUM IMPLANTS?

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Abstract

Titanium is regarded as the 'gold standard' for contemporary dental implant materials. Numerous studies have affirmed the high success and survival rates of titanium implants in many different applications. However, the use of implants to replace missing teeth in the aesthetic zone is challenging. A focus of interest in implant dentistry is the application of ceramic materials for the fabrication of dental implants. The ceramic materials of choice are currently alumina and zirconia. They are considered to be inert in the body and exhibit minimal ion release compared to metallic implants. Zirconium oxide partially stabilized with yttrium appears to offer advantages over aluminium oxide for dental implants due to its higher fracture resilience and higher flexure strength. Because of its excellent biomechanical characteristics; biocompatibility, and bright tooth-like color, zirconia has the potential to become a substitute for titanium as dental implant material. The present review discusses the available literature on the use of these ceramic materials in implant dentistry.

Key Words: - Alumina, Dental Implant, Titanium, Zirconia.

Introduction

The use and development of dental implants for restoring single or multiple losses of teeth has been through several phases to reach the optimal goal of having a permanent, artificial anchoring of fixed bridges or crowns in the upper and lower jaw. This period, mainly based on trial-and-error approaches, has led to the development of different implant materials, designs and treatment techniques that have not always led to the results expected or desired. The success of implants has been attributed to their firm bone anchorage, referred to as osseointegration, or functional ankylosis.¹ A variety of forms, materials, and surface treatments evolved, some more and some less for the benefit of the patients. Today, the endosseous- cylinder / screw surface textured type of implant, made from commercially pure titanium, is considered the gold standard for the fabrication of oral implants.² Numerous studies have affirmed the high success and survival rates of titanium implants in many different applications. The high biocompatibility of titanium is due to the spontaneous formation of a dense oxide film on its surface. Indeed, titanium has been related to certain disadvantages such as grayish color, which results in poor aesthetics, especially in anterior sites in the mouth and the possible accumulation of titanium ions surrounding dental implants and in local lymph nodes.³

According to Albrektsson *et al.*, the quality of the implant surface is one major factor that influences wound healing at the implantation site and subsequently affects osseointegration.⁴ In recent years, much effort has been made to improve implant anchorage in bone tissue by modifying the surface characteristics of titanium implants. Various studies have demonstrated that the success of integration of implants into bone tissue correlates positively with a special roughness of the implant surface.⁵ However, in recent years ceramic implants made of Zirconia, have been introduced, and these are now dominant among dental implants. This change is mainly caused by the favorable long-term experimental results obtained with this type of implants and is not based to the same extent on systematic biomechanical research and knowledge of the optimal

biomechanical connection between the implants and the bony structures.

In fact, ceramic materials such as Zirconia are radiopaque, extremely hard, wear resistant and its ivory color is similar to the color of natural teeth compared to the gray color of titanium, which render it an important material for use in the esthetic zone. Generally, Zirconia ceramics present a high degree of biocompatibility and exhibit minimal ion release. In addition, higher fracture resilience and higher flexure strength were detected in Zirconia dental implants.

Zirconium also exhibits a relatively low Young's modulus (200 GPa) in comparison to aluminium oxide, indicating a higher elastic deformation capability. Various experimental studies reveal the capability of zirconia implants to withstand long-term loading.⁶

In orthopedics, zirconia has been extensively utilized as a material for femoral ball-heads in total hip replacements since its introduction in 1980's. In dentistry, Zirconia has been used for cores and frameworks in all-ceramic restorations, as well as for ceramic abutments in dental implant prostheses. Although ceramic abutments associated with all-ceramic crowns have been shown to be an excellent treatment in critical esthetic situations, the presence of an abutment fixture junction has raised concerns. Thus, the utilization of a one piece zirconia implant might be an option to fulfill the esthetic and functional requirements in dental implant therapy, particularly when thin biotype tissue is present. The present review discusses the available literature on the use of ceramic implant in the field of dentistry.

Ceramic Implants-A Reality

Ceramic implants in dentistry are not new. Ceramic materials for oral implants were already investigated and clinically used some 30–40 years ago. At that time, the ceramic material utilized was aluminum oxide. Sandhaus was one of the first to report on aluminum oxide ceramic implants (Sandhaus 1968, 1971)⁷. However, the Crystalline Bone Screw showed a success rate of only 25% after an

average observation period of 5 years. Many years later he introduced the Cerasand ceramic oral implant (Sandhaus 1987).

In 1976, Schulte & Heimke introduced the aluminum oxide Tübingen implant for immediate implant placement in the anterior area. This oral implant system was also fabricated from alumina and was investigated both pre-clinically as well as clinically. Further ceramic implant developments in the late seventies and early/mid-eighties were the ceramic anchor implant. Besides polycrystalline aluminum oxide as implant material, single-crystal alumina (sapphire) has also been used as an implant material. In contrast to the polycrystalline alumina, this material had a glassy appearance. Alumina's physical properties include: a density of the alumina grains of approximately 4 g/cm³, a Vickers hardness of 2300, a compressive strength of 4400MPa, a bending strength of 500MPa, a modulus of elasticity of 420GPa and a fracture toughness (KIC) of 4MPam^{1/2}. The high hardness and modulus of elasticity make the material brittle. Combined with the relatively low bending strength and fracture toughness the material is prone to fracture when loaded unfavorably. This might be the reason for there currently being no alumina implant system on the market. Interestingly however, fracture was seldom mentioned in the literature as a reason for implant loss. It can be assumed, though, that the anxieties raised by dentists that ceramic implants are prone to fracture might have played a role. There was therefore a search for tougher ceramic materials for use as an oral implant substrate instead of alumina.

Currently the material of choice for ceramic oral implants is Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP, short: zirconia). Compared with alumina, Y-TZP has a higher bending strength, a lower modulus of elasticity and higher fracture toughness. Preclinical investigations on the stability of Y-TZP oral implants have shown that this material may be able to withstand oral forces over an extended period of time.

Zirconia Implants

Zirconia was applied relatively early as a coating material for oral implants in animal investigations. Akagawa *et al*⁸ were the first to report the use of oral implants made of zirconia in beagle dogs. The authors reported that no implant was mobile and no fracture occurred during the experiment. In 1975, Cranin *et al*⁹ used zirconia flame-spray deposition-coated Vitallium implants in beagle dogs. They showed that five of nine zirconia-coated implants were surrounded by connective tissue and that the results were not satisfactory.

Albrektsson *et al*¹⁰ observed a fibrous, tissue-free zone with a 20- to 40-nm thick proteoglycan layer at the titanium implants. Scarano *et al*¹¹ investigated the bone response to 20 YTZP implants, which were inserted in the tibiae of five rabbits. According to the authors, all implants were osseointegrated without signs of inflammation or mobility. In another study, Sennerby *et al*¹² evaluated the bone tissue

response to zirconia implants with two different surface modifications in comparison to machined, non-modified zirconia implants and to oxidized titanium implants. The modified zirconia implants showed a resistance to removal torque forces similar to those of oxidized titanium implants and a four- to fivefold increase compared with machined zirconia implants. In a recent study, Hoffmann *et al*¹³ compared the degree of early bone apposition around four zirconia dental implants and four surface-modified titanium implants at 2 and 4 weeks after insertion in the femurs of four rabbits. A comparably high degree of bone apposition could be observed on all implants during early healing. Depprich *et al*¹⁴ inserted 24 acid-etched zirconia implants and 24 acid-etched titanium implants into the tibia of 12 minipigs. BIC was evaluated after 1, 4 and 12 weeks. Histological results did not show statistically significant differences between the two groups at any time point.

However, regarding the clinical use of zirconia oral implants, scientific information is lacking. To the authors knowledge there are only three retrospective observational cohort investigations were identified in the international literature. Mellinghoff (2005) published the clinical results of 189 zirconia implants inserted in 71 patients. The 1-year survival rate of the implants was 93%. The author reported that six implants were lost due to increased implant mobility, one implant fractured 1 week after prosthetic reconstruction. In another retrospective study, Oliva *et al*¹⁵ (2007) evaluated the success rate of 100 one-piece zirconia dental implants inserted in 36 patients after 1 year of follow-up. Five implant designs with two different surfaces were examined. The overall implant success rate after 1 year was 98% in both the bioactive ceramic-coated and non-coated groups. In a further retrospective investigation by Lambrich & Iglhaut (2008), the survival rates of rough titanium implants and one-piece zirconia implants were compared. The survival rate of the titanium implants was 98.4% in the maxilla and 97.2% in the mandible, while zirconia implants had a survival rate of 84.4% in the maxilla and 98.4% in the mandible.

Zirconia oral implants and osseointegration

Implant placement in bone is presently associated with defined expectations of success based on defined clinical and radiographic endpoints. This successful outcome has been correlated to the histologically represented bone-implant interface and is commonly referred to as "osseointegration". Currently, an implant is considered as osseointegrated when there is no progressive relative movement between the implant and the bone with which it has direct contact. Essentially, the process of osseointegration reflects an anchorage mechanism whereby non-vital components can be reliably incorporated into living bone and which persist under all normal conditions of loading. Several studies have been investigated the osseointegration of zirconia implants using different experimental models. The percentage of BIC as a measure of osseointegration ranged from a low of 2% after 2 weeks in the tibia of rabbits (Chang *et al*).

1996) to a high of 86.8% after 96 weeks in the tibia of dogs (Hayashi *et al.* 1992) with a mean value above 60%.

Only a few animal investigations used titanium implants as a control group (Dubruille *et al*¹⁶ 1999; Kohal *et al.* 2004). As with alumina implants, the above studies could show that bone reacts similarly or even better to zirconia as it does toward titanium and therefore zirconia could be used – from an osseointegration standpoint – as a material for the fabrication of oral implants. However, with the exception of the study by Kohal *et al.* (2004), there were no other studies comparing loaded titanium implants with loaded zirconia implants in the same animal model. A parameter that can possibly influence the process of early bone formation is the implant surface. Aldini *et al.* (2004) coated Y-TZP implants with a bioactive glass and found faster bone healing and a better osseointegration rate in osteopenic bone. Gahlert *et al.* compared the osseointegration of submerged acid etched zirconia implants with sandblasted, acid-etched titanium implants in the anterior maxilla of minipigs. After 4 weeks, the BIC of zirconia (27%) and titanium (24%) showed no significant differences. Depprich *et al.* compared the BIC of submerged, acid-etched zirconia with acid-etched titanium implants in minipig tibiae. After 1 and 4 weeks of healing, BIC was higher for titanium (48% and 59%, respectively) compared with zirconia (35% and 45%, respectively). These differences were not statistically significant.

In clinical practice, implant loading can influence osseointegration. Akagawa *et al*¹⁷ compared submerged and non-submerged zirconia implants and observed collagen fibers in the apical regions of submerged implants after 3 months in dogs. The mastication of food was considered responsible for this effect. For loaded implants, a loss of crestal bone was described after 3 months. Kohal *et al*² compared loaded sandblasted zirconia and sandblasted, acid-etched titanium implants in the anterior bone of monkeys. The soft and hard tissue dimensions were evaluated after 9 months of healing and 5 months of loading. The bone–implant contact reached 67% for zirconia implants and 73% for titanium implants and showed no statistical difference.

Following a systematic review, Andreiotelli *et al*¹⁸ concluded that zirconia may have the potential to be a successful implant material, but noted that clinical application needs to be supported by clinical studies.

Future

Currently, the scientific clinical data for ceramic implants in general and for zirconia implants in particular are not sufficient to recommend ceramic implants for routine clinical use. The biocompatibility of the material is of great importance and a predictor of osseointegration, as it is essential stable fixation with direct bone-implant contact and no fibrous tissue at the interface.¹⁹ Zirconia, however, may have the potential to be a successful implant material but no clinical investigation can support this assumption yet. The issues related to phase transformation of zirconia

are still not clear and more investigations are needed. In vivo studies have showed very positive bone tissue and soft tissue response to the zirconia surface. More in vitro and in vivo research is needed to increase clinicians' confidence in using zirconia implants.

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