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REVIEW ARTICLE

ZIRCONIA IMPLANTS IN ORAL IMPLANTOLOGY – A REVIEW ARTICLE

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ABSTRACT

So far dental implants have taken over the field of dentistry as the most approachable method for replacement of missing teeth wherever possible. However as newer advances are being made to combat the existing hurdles of aesthetics and durability, a newer material for dental implants has been in revision. Zirconia has emerged as a new material for dental implants. This review article aims to review Zirconia based on its aesthetics, mechanical properties, surface roughness standards, biocompatibility, integration, bacterial colonization, soft tissue responses and compare it to the existing widely used titanium implants. Based on the reviews we conclude that zirconia has earned a valuable place in the field of dental implantology and further research and awareness of the same needs to be done to enhance the treatment standards provided to patients.

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INTRODUCTION

Rehabilitation of edentulous spaces in patients using osseointegrated dental implants has been a scientifically accepted and well-documented treatment modality. In 1908, Branemark was the first to discover the concept of osseointegration as a serendipity when blocks of titanium, placed into the femur of rabbit got ankylosed with the surrounding bone. Ever since then, several investigations and clinical studies have established the use of titanium as a reliable biomaterial for oral rehabilitation and reconstruction in dental implantology. Titanium and titanium alloys have been widely used in the manufacturing of dental implants due to their excellence in biocompatibility, mechanical properties and long term follow-up in clinical success. Eventually it became the gold standard for tooth replacement in dental implantology. However despite its advantages, titanium offers a notable amount of disadvantages. The principal disadvantage of titanium is its dark grayish color. This is often is visible through the peri-implant mucosa, thus impairing esthetics. Various modifications in the structure, composition, and design of titanium implants have been made since then to enhance its physical, mechanical and optical properties. However, the development of undesirable allergic reactions, cellular sensitization, galvanic current formation and anesthetics gray hues have risen demands for more aesthetic and biocompatible implant material. This lead to the discovery of zirconia ceramics as a new material for dental implants. However, it is important to understand the similarities and differences between zirconia and titanium implant system so as to enable the clinician to provide the best treatment outcomes for their patients. This review aims to analyze the credibility of Zirconia as an alternative to replace Titanium based implant system .

Zirconia background: Zirconia implant is made from a lustrous, grey-white, strong transition metal named Zirconium. Zirconia is the oxide form of zirconium. Jons Jakob Berzelius in 1824 was the first to isolate zirconium in an impure form. Initially, it was used in various orthopedic surgical procedures like in hip replacement surgeries. Later it was introduced in dentistry for fabrication of endodontic posts, crown/bridge, restorations, esthetic orthodontic brackets and implant abutments for rehabilitation of partial and complete edentulous arches (Mc Lean, 2001). In 1968, that the first ceramic implant known as the Sigma implant (Sanhause, Incermed, Lausanne, Switzerland) was developed by Sandhaus. Zirconia appears to be an appropriate dental implant material. This is because of its strong mechanical properties and tooth like color. The material offers fracture toughness and high strength. Bone resorption and inflammatory response induced by ceramic particles are less compared to those induced by particles of titanium, thus recommending the bio-compatibility of ceramics (Yilmaz *et al.,* 2007).

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Mechanical properties of zirconia: Yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) materials illustrate superior corrosion, wear resistance and high flexural strength (800–1000 MPa) compared to other dental ceramics (Denry *et al.,* 2008). ZrO_2 is a polymorphic material. It occurs in three forms: Monoclinic, tetragonal, and cubic. The monoclinic phase is stable at room temperatures up to 1170°C. The tetragonal form is stable at temperatures between 1170–2370°C and the cubic form is stable at tepmeratures over 2370°C (Chevalier *et al.,* 2009). Alloying pure zirconia with stabilizing oxides like CaO, MgO, Y_2O_3, or CeO_2 causes retention of the metastable tetragonal structure at room temperature. Dental procedures involving grinding/ sandblasting, can trigger a conversion from tetragonal to monoclinic in the surface region (Piconi *et al.,* 1999). Transformation from tetragonal phase to monoclinic phase leads to volume expansion. This results in compression of cracks, thereby retarding its growth and improving fracture toughness. This martensitic-like mechanism is known as transformation toughening (Garvie *et al.,* 1975). Due to drastic environmental conditions involving moisture and stress, the resulting zirconia may transform more aggressively into the monoclinic phase with catastrophic results. This type of high metastability is not recommended for dental implants. This mechanical property of zirconia is known as "aging" of the material (Suresh *et al.,* 2003). This transformation is particularly enhanced in water or in vapor, while the most critical enhancing effects occur in the range of temperature between 200–300°C (Sato *et al.,* 1985). The transformation from tetragonal to monoclinic form, starts from surface and progresses towards the core. When the monoclinic phase dominates, it shows reduction in strength, toughness, and density, which in turn leads to micro cracking on the surface. This phenomena leads to penetration of water and causes corrosion (Sato and Shimada, 1985). Low temperature degradation of the material involves increased wear, roughening and formation of micro cracks, generation of particle debris, and premature failure (Chevalier *et al.,* 2006). This aging process depends on various factors like, residual stresses, porosity, grain size, and the content of stabilizer (Deville *et al.,* 2000). It was found that decrease in grain size and increase in stabilizing oxide content can considerably reduce the transformation rate (Sato *et al.,* 1985). Aging can be avoided by more accurate processing (Sato *et al.,* 1985). Some in vitrostudies have found that the aging reduces the mechanical properties of zirconia, even though within clinical acceptable limits, in simulated dental treatment conditions (Watanabe *et al.,* 1984).

Surface roughness of zirconia implants: Direct bone apposition can occur on different types of surfaces, it has been demonstrated that a certain degree of surface roughness can accelerating bone apposition onto implant surface (Zechner *et al.,* 2003). It was found that roughening the zirconia implants enhances bone apposition and has a beneficial effect on the interfacial shear strength (Gahlert *et al.,* 2007) which was later contradicted by Hoffmann *et al.* (2012) High hardness of zirconia implants makes the process of surface roughening difficult. Hence, recently, lasers have been used to engrave a pattern on the zirconia surface. A scanning electron microscopic (SEM) study done to find the influence of erbium-doped yttrium aluminium garnet (Er: YAG), carbon dioxide (CO2), and diode laser irradiation on the surface properties of polished zirconia implants demonstrated that diode and Er: YAG lasers did not cause any visible surface alterations. However, the CO2 laser produced distinct surface alterations to zirconia (Stübinger *et al.,* 2008).

Biocompatibility of zirconia implants: Several in vitro tests were conducted with zirconia on osteoblasts, fibroblasts, lymphocytes, monocytes, and macrophages to check its biocompatibility. The results illustrated that zirconia had no cytotoxic effect on osteoblasts and enhanced elaboration of the extracellular matrix by synthesizing various essential and structural proteins (Josset *et al.,* 1999). Zirconia does not enhance pseudo-teratogenic effect, thus making it biocompatible (Torricelli *et al.,* 2001). Laser-modified zirconia showed better adhesion to osteoblasts due to better wettability characteristics (Kohal *et al.,* 2002). Zirconia does not provoke any inflammation pathway, as reported by Liagre *et al.* (2002). Wear products of zirconia could be as cytotoxic as titanium and other ceramics, when tested with fibroblasts (Ito *et al.,* 1993). Biocompatibility tests were also conducted in vivo for zirconia, and it was found that when implanted in soft tissue, it became encapsulated by a thin layer of fibrous tissue which is similar to that seen in the case of alumina (Christel *et al.,* 1989). No cytotoxicity was noted in the soft tissue in relation to wear products of zirconia. Zirconia was found to be biocompatible with hard tissue when tested in vivo according to a study in which pellets of stabilized zirconia with 6% Y_2O_3 were inserted into the femur of monkeys (Styles *et al.,* 1976). When compared with alumina, zirconia showed no difference in bone reaction (Wagner *et al.,* 1986; Christel *et al.,* 1989).

Osseointi Egration of zirconia implants: One of the most important criteria for the success of implant treatment lies in its osseointegration. Bone apposition takes place on different types of implant surfaces and depends on surface roughness of the implant (Zechner *et al.,* 2003). Studies show that zirconia coating on the surface of titanium implants favours bone apposition as opposed to no coated titanium implants (Franchi *et al.,* 2004). When BIC of zirconia implants was compared with that of titanium and alumina and it was found that there was no statistical difference between the BIC of all three types (Dubruille *et al.,* 1999). Relatively, the bone healing around zirconia implants was found to be better than that around titanium implants (Schultze-Mosgau *et al.,* 2000). Some studies indicated that the zirconia implants might withstand higher occlusal loads over a longer period of time (Kohal *et al.,* 2002). A similar rate of bone apposition on zirconia implants and surface-modified titanium implant surfaces during early healing was found when a histological examination of early bone apposition around zirconia dental implants at 2 and 4 weeks respectively was carried out after insertion was compared to that of surface-modified titanium implants (Hoffmann *et al.,* 2012). No difference in osseointegration was evident between acid-etched zirconia implants and acid-etched titanium implants (Depprich *et al.,* 2008).

Measurement of osseointigration: Torque removal forces have been used as a biomechanical measure of osseointegration. Greater forces required to remove implants may be directly related to the strength of osseointegration (Klokkevold *et al.,* 1997). In the study conducted by Sennerby *et al.,* it was found that coated titanium and zirconia implants showed a higher removal torque value than machined zirconia implants (Sennerby *et al.,* 2005). Another study wherein the removal torque values of,

sandblasted zirconia implants, machined zirconia implants and acid-etched titanium implant were examined, the machined zirconia had the least removal torque value whereas acid-etched titanium implants had the highest removal torque value, followed by sandblasted zirconia implants. The findings suggested that sandblasted zirconia implants can achieve a higher stability in bone than machined zirconia implants (Gahlert *et al.,* 2007). Even when zirconia was coated on titanium implants, the removal torque value increased (Alzubaydi *et al.,* 2009). But in one of the studies that compared the biomechanical properties of six types of implant surfaces, it was found that removal torque value of zirconia implants was the least (Ferguson *et al.,* 2008). It is hence concluded that the removal of torque value of zirconia implants was improved after surface modification, however it is not more than that of titanium implants.

Soft tissue response to zirconia implants: Many studies have been performed around the implications of a zirconia implants on the surrounding soft tissue. Tete *et al.* found that the collagen fiber orientation around zirconia implants was parallel to the implant surface just like that of titanium (Tetè *et al.,* 2009). Brakel et al. reported that zirconia had similar probing depth as in titanium (Van Brakel *et al.,* 2011). Wellander *et al.* reported that titanium implants had better soft tissue healing as compared to zirconia implants. The distance from the peri-implant mucosa to the apical end of the barrier epithelium was found to be lesser for zirconia implants as compared to that of titanium implants. The very same study found that zirconia showed less mucosal color change as compared to titanium (Welander *et al.,* 2008). This was contradicted by Zembic *et al.* (2009) however, no significant difference in the soft tissue around zirconia abutments and titanium abutments was found by Brakel *et al.* (2011).

Bacterial colonization around zirconia implants: Inflammation in the form of mucositis and peri-implantitis are not unusual sightings around titanium implants. Meta-analyses of the prevalence of peri-implant diseases revealed mean values of 43% and 23% for mucositis and peri-implantitis, respectively (Derks and Tomasi, 2015). Bacterial infection is the main aspect of these pathological conditions (Mombelli and Décaillet, 2011). It has been concluded that bacterial biofilm accumulates less easily on zirconia than on titanium and so it can be hypothesized that peri implant soft tissues around zirconia implants might be at lower risk for inflammation and infection than around titanium implants. All implant materials have a specific surface freeenergy. Zirconia abutments have been known to have a low surface free energy and surface wettability, resulting in reduced adhesion of bacteria (Al-Radha *et al.,* 2012). An in vivo study conducted by Sarano *et al.* concluded that zirconia showed significantly lesser adhesion of bacteria than titanium, (Rimondini *et al.,* 2002; Scarano *et al.,* 2004) which was contradicted by Brakel *et al.* and Egawa *et al.* who reported that the bacterial adhesion of zirconia was in fact similar to that of titanium (Van Brakel *et al.,* 2011; Egawa *et al.,* 2013). Another study was conducted by (Salihoglu *et al.,* 2010) in which 2 implants were placed in 12 patients each. After 12 weeks, each implant was loaded with either a zirconia abutment or a titanium abutment. The results did not show any statistically significant differences between the DNA counts of *Aggregatibacter actinomycetemcomitans* and P. *gingivalis* in either of the abutments. However, these results were refuted by to two other studies (DoNascimento *et al.,* 2016; Nascimento *et al.,* 2014).

Inflammatory reactions : Zirconia has always exhibited excellent biocompatibility. In a study conducted by Degidi *et al.* in 2006, gingival biopsies of 5 patients were harvested around zirconia and titanium healing abutments which were placed on titanium implants. The inflammatory infiltrate around the titanium samples was far more prominent. There were signs of mucosal ulceration seen in one case. The micro-vessel density, nitric oxide synthase and expression of vascular endothelial growth factor were all higher in the mucosa around titanium healing abutments as compared with that around zirconia healing abutments. So far due to limited clinical experience with zirconia implants there appears to be a conclusion that peri-implantitis seems to be less of a problem with these type of implants as compared to those with titanium implants.

Clinical studies

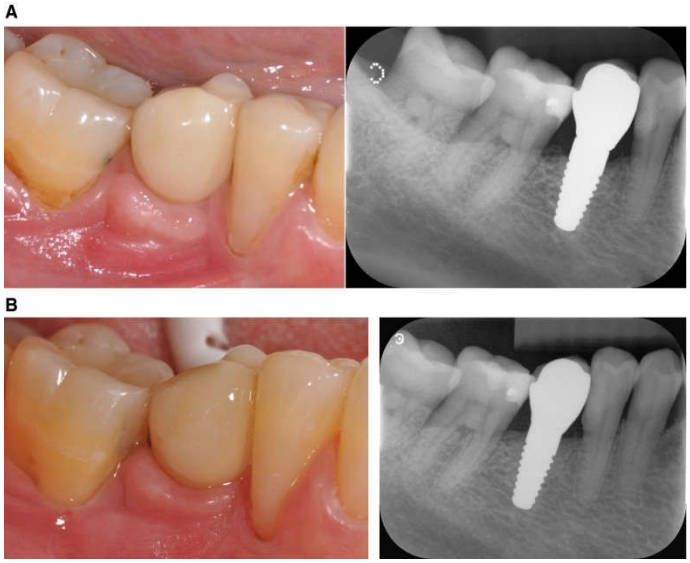

Figure 1. (A) Clinical photograph (left image) and radiograph (right image), 1 year after loading (two-piece zirconia implant). (B) Clinical photograph (left image) and radiograph (right image), 4 years after loading (two-piece zirconia implant)

Figure 1: Shows clinical pictures and radiographic images of a premolar (45) restored with a two-piece zirconia implant system, at 1 year and 4 years respectively after loading (Cionca *et al.,* 2015). Olivia *et al.* reported the first clinical evaluation on a hundred zirconia implants (Cera Root, Spain) with two seperate surface roughness' in humans post a one year follow-up. Two failures were seen after fifteen days. Success rates were reported to be 98%. Picker et al. placed a zirconia implant in the region of the maxillary premolars and evaluated the clinical outcome of the implant. After a two year follow up, the implant was found to be stable and unaltered implant marginal bone levels were noted (Liñares *et al.,* 2016; Linkevicius *et al.,* 2013).

Conclusion

Through in vitro and in vivo studies, it can be concluded that zirconia has managed to earn its place as a valuable alternative to titanium as a material for dental implants. From a biological point of view, zirconia presents with impressive assets. It has demonstrated a low affinity towards bacterial plaque, less amount of inflammatory infiltrate and healthy soft-tissue integration. These properties may prove to lower the risk for

peri-implant diseases. The biomechanical properties of zirconia implants have shown success in numerous experiments. However, early failure rates of zirconia implant systems have been encountered occasionally. Confirming data on long-term outcomes are limited. Technical failure as a result of fracture of the material is an impending issue as a critical factor for usability and acceptance in every-day practice. There is scope for further progress of currently available zirconia implant systems. Two-piece implant systems with screw-retained abutments are desirable, though they are technically challenging due to limitations in the materials. Further innovation can definitely lead to enhanced biomechanical characteristics, allowing new solutions that are presently at high-risk. More clinical investigations need to be carried out to identify all relevant biological and technical factors with impact on clinical success and patient satisfaction. At present, the evidence for a final verdict is incomplete, and the field is still growing in many ways. Patients are aware of the availability of zirconia implants on the market and we should to be ready to respond to their demands.

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