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Comparative Analysis between Zirconia Implant and Titanium Implant

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Various ceramic implant systems made of yttria-stabilized tetragonal zirconia polycystal (Y-TZP) have become commercially available in recent years. A search of the literature was performed to assess the clinical success of dental Y-TZP implants and whether the osseointegration of Y-TZP is comparable to that of titanium, the standard implant material. No controlled clinical studies in humans regarding clinical outcomes or osseointegration could be identified. Clinical data were restricted to case studies and case series. Only 7 animal studies were found. Osseointegration was evaluated at 4 weeks to 24 months after placement in different animal models, sites and under different loading conditions. The mean bone-implant contact percentage was above 60% in almost all experimental groups. In studies that used titanium implants as a control, Y-TZP implants were comparable to or even better than titanium implants. Surface modifications may further improve initial bone healing and resistance to removal torque. Y-TZP implants may have the potential to become an alternative to titanium implants but cannot currently be recommended for routine clinical use, as no long-term clinical data are available.

Key Words: Comparison; Implant; Titanium; Zirconia

Introduction

As a substitute of titanium, alumina (Al_2O_3), hydroxyapatite (HA), and zirconia (ZrO_2) ceramic have been studied for a long time. In particular, HA has been investigated as a dental implant material because it has osteoconduction ability, facilitates the growth of bone around the implant,

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and leads chemical incorporation with bone1). Nonetheless, its clinical application is limited due to its insufficient mechanical properties. Therefore, it is generally used as coating material for the surface of titanium2). On the other hand, zirconia has been studied as a dental implant material because it is inactive in a living body, providing high resistance to corrosion and abrasion and having high flexural strength and fracture toughness. It can also be used for aesthetic restoration since its color is similar to that of natural tooth. Compared to alumina, yttria-stabilized tetragonal zirconia polycystal (Y-TZP) has high flexural strength (~1200 MPa), low elastic coefficient (~200 GPa), and high fracture toughness (KIC: ~6-10 MPam). Preclinical research on the stability of the Y-TZP dental implant proved that it can sustain intraoral load for a long time.

Material Properties of Titanium and Zirconia

1. Titanium

Commercially pure titanium is the most common implant material due to its good biocompatibility. Titanium is very reactive, oxidizing upon contact with air or body fluid. Such reaction is a good property for implant material by minimizing bio-corrosion. Oxide film as thick as 10 Å is generated within 1/1,000 second on the section of commercially pure titanium. Typically, titanium becomes more inactive in nitric acid solution, thereby generating thick, durable oxide film. Commercially pure titanium contains oxygen (maximum 0.5%) as well as a small amount of impurities such as nitrogen, carbon, and hydrogen. The most common alloy is 90% titanium (weight ratio), 6% aluminum, and 4% vanadium. The density of titanium is 4.5 g/cm^3, i.e., 40% lighter than steel, but it has high strength and elastic coefficient that is half of that of stainless steel and cobalt-chrome alloy. Though the elastic coefficient of titanium is 5~10 times that of bone, the design of implant is very important in distributing stress properly.

2. Zirconia

Zirconium oxide (ZrO_2) is classified chemically as oxygen and technically as ceramic. Basically, it is insoluble in water but soluble in H_2SO_4 and hydrofluoride. It is found abundantly in nature (0.02% of Earth's crust). The baddeleyite (monoclinic zirconia) type is mostly buried in Brazil, with zircon sand of $ZrSiO_4$ mostly buried in Australia and India. Pure zirconia is characterized by allotrophy. In other words, it has the same chemical composition, but its atom arrangement varies according to the crystallographic structure. For instance, the cubic structure is a form of fluorite whose simple cubic lattice is filled with oxygen ion. Zirconium ion has a center anionic cubic structure. In cooling, conversions from cubic into tetragonal system (c-t) and from tetragonal into monoclinic system (t-m) are athermal and diffusionless.

Comparison between Zirconia Implant and Titanium Implant

1. Animal Studies on Unloaded Implants

The following research studies used an unloaded Y-TZP dental implant for animals:

1) Dubruille et al.3)

Implants were placed in the mandible, with the quality of interface between implant and structure investigated. First, calcium carbonate of animal origin (Biocoral 450; Inoteb, Saint-Gonnery, France) was injected into the placement site, and 6 pieces of Y-TZP, 6 pieces of alumina, and 6 titanium implants were then placed after 6 months and left for 10 months. There was no significant difference between the implant materials in the visual, radioactive, and microscopic inspections. The authors divided the bone-implant interface into cervical, central, and apical areas, with the cervical area recording higher value (85~89%) than the central area (44~72%). The overall average of the bone-implant interface of the Y-TZP implant was 64.6±12.7%, that of the alumina implant was 68±13.9%, and that of the titanium implant was 54±12.9%.

2) Schultze-Mosgau et al.[4)]

The osseointegration of Y-TZP cone and titanium cone was examined for application in root resection. Twenty zirconia cones (Friadent) and twenty titanium cones (Straumann) were placed in the mandible of four miniature pigs and removed en bloc after six months. The bone-implant interface and bone-fiber connective tissue interface were quantified and calculated. Both materials had no difference in terms of the form and mechanics of bone cure under optical and fluorescence microscopes. In the quantitative analysis, however, Y-TZP showed higher ratio (1.47±1.12) than titanium (0.97±1.10).

3) Scarano et al.[5)]

Y-TZP implants were placed in rabbits' tibia, and bone reaction was analyzed. A total of 20 Y-TZP implants were placed in 5 rabbits and removed en bloc after 4 weeks. The generation of osteoid on the surface of the implant was examined, and the average bone-implant interface was 68.4±2.4%. According to the authors, all implants integrated without inflammation and mobility.

4) Sennerby et al.[6)]

In the rabbit test, the bone tissue reaction of the Y-TZP implant was examined histologically and biomechanically. Two methods of surface treatment (Zr-A and Zr-B) - unprocessed Y-TZP (Zr-Ctr) and oxidized titanium implant (modified TiUnite implants, Nobel biocare) - were compared. The average surface roughness was highest in titanium (R_a=1.30 μm), followed by Zr-A implant (R_a=1.24 μm), Zr-B implant (R_a=0.93 μm), and Zr-Ctr implant (R_a=0.75 μm). A total of 96 implants were placed in 12 rabbits.

The removal torque value was significantly higher in the surface-treated zirconia implant and titanium implant than in the machined surface zirconia implant.

2. Animal Studies on Loaded Implants

1) Akagawa et al.[7)], 1993

The osseointegration of loaded and unloaded Y-TZP implants placed in beagles (dog) was studied. In the 1st stage, 12 implants (Goei Industry, Akitsu-Hiroshima, Japan) were placed. For 2 dogs, soft foods were provided without planned occlusal load. For the 2 other dogs, a metallic prosthesis connecting 2 implants was installed 1 week after the placement of implant. One occlusal contact area was then created on the round crown, and solid foods were provided. There was no significant difference in the clinical criteria for loaded and unloaded implants as well as in the average bone-implant interface.

2) Akagawa et al.[8)], 1998

The osseointegration of the same implant design under different load conditions was surveyed after 12 or 24 months using primates. The prosthesis was divided into single implant, connection of 2 implants, and connection of 1 natural tooth and 1 implant. Metallic prosthesis was cemented directly at the head of the implant as the central occlusal contact. There was no significant difference in groups with different loads, 2 measurements, and comparison with natural tooth. Marginal bone resorption was relatively high (after 12 months: 1.6~2.3 mm; after 24 months: 1.7~2.1 mm). The average bone-implant interface was 54~82%.

3) Kohal et al.[9)]

The osseointegration of loaded split-mouth zirconia and titanium implants and values of soft tissue around implants in primates were surveyed. Titanium abutment was attached to titanium implant, and zirconia abutment, to zirconia implant. After 3 months, a single metallic dental crown was attached to the abutment and loaded after 5 months. Implants were removed along with surrounding hard and soft tissues. There was no significant difference in the average height of the outer surface of soft tissue around the implant (titanium: 5.2±1.0 mm; zirconia: 4.5±0.6 mm) and average bone-implant interface (titanium: 72.9±14%; zirconia: 67.4±17%). Neither was there any implant fracture.

Osseointegration of Y-TZP Dental Implants

In the aforesaid animal research studies, osseointegration was evaluated 4 weeks~24 months after placement under different animal models, placement locations, and loading conditions. The average bone-implant interface ratio was more than 60% in almost every test group. This is evidence of successful osseointegration10).

In other research wherein the titanium implant was used as the comparison group, the zirconia implant was found to be similar to or better than the titanium implant. Kohal et al.9) did not cite fast marginal bone resorption for the loaded Y-TZP implant, but Akagawa et al.8) reported the exposure of thread and evident marginal bone resorption in the initially loaded Y-TZP implant group. This was confirmed in the 2nd research on loaded implants 3 months after placement (marginal bone resorption of 1.6~2.3 mm). The osseointegration of bio-incompatible zirconia implant is generally described as the inner growth of bone from the surrounding bone surface. In the early healing stage, Scarano et al.5) noted direct osteogenesis on the surface implant, but Sennerby et al.6) observed it only on the surface-treated implant. Davies emphasized the importance of de novo bone formation on the surface of the implant, implant surface design, and microtopography in the inner growth of bone from the surrounding bone surface11).

Rough surface supports osteoconduction, which leads osteogenesis on the surface of the implant. In the overall review of the surface of the dental implant, Albrektsson and Wennerberg12,13) reported that a medium-rough surface of titanium implant (R_a~1.5 μm) showed stronger bone reaction than soft (machined) surface (R_a: 0.5~1.0 μm). Moreover, according to Sennerby et al.6), a medium-rough surface of Y-TZP implant had 4~5 times' resistance to torque force after 6 weeks of healing. Unfortunately, out of 7 research studies, only 1 provided detailed information on surface microtopography. Hao et al.14) researched on the correction of the surface of Y-TZP, which utilizes laser for improved cell adhesion, using the osteoblast cell line of an infant. The laser treatment created softer surface (average R_a of 0.2 μm) than the untreated sample (average R_a of 0.35 μm). Higher laser intensity decreased surface roughness.

In addition to the physical properties, the chemical properties of implant surface can affect the initial osteogenesis process since calcium phosphate-treated implant is proven to accelerate bone healing in the surrounding area15). To improve the osseointegration process, Aldini et al.16) created the Y-TZP implant coated with bioactive glass and observed better bone healing and better osseointegration in osteoporosis patients.

Clinical Success and Prosthetic Considerations

Blaschke and Volz17) placed 66 implants in 34 patients during the period 2000~2003 and recovered zirconia ceramic prosthesis. Although this research was a 5-year implant research study on humans, it only reported the success of implant during 1~2 years after placement. One implant was fractured due to external impact. Additional information on the criteria for inclusion/exclusion, withdrawal of patients, implant location, re-osteogenesis, and criteria for success was not provided. The conclusion that "these implants show significant improvement than titanium implant" was not supported by the result of research. The aesthetic advantages of the 1-piece zirconia implant were promoted by some manufacturers. The marginal location of prosthetic restoration can be determined by clinicians using diamond equipment based on intraoral generation, such as the generation of natural tooth's abutments. Nonetheless, the grinding of Y-TZP ceramic is known to be likely to cause monoclinic conversion and microcrack that induces the deterioration of the physical properties of materials[18-20]. Likewise, the fact that the low-temperature dissolution of Y-TZP ceramic is still being investigated should be considered. The only solution to the "Aging problem" may be zirconia-alumina compound[21]. It has been investigated not only in orthopedics but in dental clinics as well[22].

Conclusion

As mentioned above, like the existing titanium implant, implant using Y-TZP has good osseointegration ability, good environment for the growth of osteoblast, and good influence on soft tissue. The biocompatibility of the zirconia implant was already verified, with some researchers reporting that it provides better osteoinduction ability than machined titanium implant. As a result, the implant product market has increased gradually. Even though the transformation of the surface and microstructure improves the initial bone healing and resistance to the removal torque, there was not enough data, and commercial implants do not support it. It may be too early to commercialize the zirconia implant because long-term clinical study is insufficient.

When citing the clinical success rate of implant, there is a need to check not only the bone reaction on the surface but also prosthetic restoration and resistance to occlusal load. Therefore, the treatment of occlusion after placing the zirconia implant can be an important consideration. In other words, occlusion is regarded as an important factor for success during the period of prosthetic restoration treatment and follow-up. The occlusion of ZrO_2 implant combined with porcelain fused metal crown should be regarded as stronger occlusion than natural teeth. In this sense, huge occlusal load can cause depression, pain, abrasion, or fracture of antagonist teeth; as a result, light infraocclusion may be a good method of restoration. After attaching the final restoration, i.e., prosthetic, the occlusion of prosthesis must be tested by checking the bite, and the final occlusion adjustment must be performed under large occlusal load. In addition, occlusion must be checked and adjusted regularly after treatment. For bruxism patients, a solid occlusal stabilization device must be provided.

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