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Search For A Viable Alternative To Titanium Implants – A Literature Review

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Abstract
Titanium and titanium alloys are widely used for fabrication of dental implants. Because of potential immunologic and possible esthetic compromises with titanium implants, novel implant technologies are being developed. However, these novel technologies must maintain the characteristics that provide titanium implants with their high success rates. Zirconia and Polyetherketone (PEEK) implants were introduced into dental implantology as an alternative to titanium implants. They seem to be a suitable implant material because of their tooth like color, mechanical properties, biocompatibility, and tailorability of PEEK implants. Although they possess sufficient merits, longitudinal studies with large sample sizes and systematic evaluation will provide a more comprehensive view of zirconia and PEEK dental implants.

Key Words
Yttria-stabilized tetragonal zirconia polycrystals (Y-TZP), HIP: hot isostatic postcompaction, bone-to-implant contact (BIC), bone levels (BL), poly-ether-ether-ketone (PEEK), isoelastic

Quick Response Code

Introduction

The rehabilitation of completely and partially edentulous patients with dental implants is a scientifically accepted and well documented treatment modality.[1] The material of choice for oral endosseous implants has been and still is commercially pure titanium. Currently, titanium and titanium alloys are the materials most often used in implant manufacturing and have become a gold standard for tooth replacement in dental implantology. These materials have attained mainstream use because of their excellent biocompatibility, favourable mechanical properties, and well documented beneficial results.[2],[3]

Despite the various advantages of this material, few disadvantages have lead to search for new materials which can replace titanium and its alloys in medical field as well as implant dentistry. The principal disadvantage of titanium is its dark greyish colour, which often is visible through the peri-implant mucosa, therefore impairing esthetic outcomes in the presence of a thin mucosal biotype. Unfavourable soft tissue conditions or recession of the gingival may lead to compromised esthetics. This is of great concern when the maxillary incisors are involved.[4] Furthermore, it has been suggested by various investigators that metals are able to induce a nonspecific immunomodulation and autoimmunity. Galvanic side effects after contact with saliva and fluoride are also described.[5] Although allergic reactions to titanium are very rare, cellular sensitization has been demonstrated.[6]

To overcome these limitations and minimize negative biological reactions, researches have been focused on designing alternative substitutes to titanium. The promising novel materials include zirconia ceramics and composites.

Zirconia Dental Implants

In recent years, high strength zirconia ceramics have become attractive as new materials for dental implants. Yttria-stabilized tetragonal zirconia polycrystals (Y-TZP) with or without the addition of a small percentage of alumina are used for producing dental implants.[7] They are considered to be inert in the body and exhibit minimal ion release compared with metallic implants. Y-TZP appear to offer advantages because of their higher fracture resilience and higher flexural strength.[8] Zirconia seems to be a suitable dental implant material because of its tooth like colour, mechanical properties, and therefore biocompatibility.[2]

The fact that ceramic materials are white and mimic natural teeth better than the gray titanium allows an 'improved' esthetic reconstruction for patients. Using white ceramic implants would preclude the dark shimmer of titanium implants when the soft periimplant mucosa is of thin biotype or recedes over time.[7]

Y-TZP has a higher bending strength (~1200MPa), a lower modulus of elasticity (~200GPa) and higher fracture toughness (KIC: ~6–10MPam1/2). 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.[9],[10],[11].

The introduction of the HIP process (HIP: hot isostatic postcompaction) enabled the production of highly compacted structures with fine grain size and high purity of Y-TZP improving the material properties.[7]

The inflammatory response and bone resorption induced by ceramic particles are less than those induced by titanium particles, suggesting the biocompatibility of ceramics.[12],[13]

Animal experiments testing the biocompatibility and bone integration of zirconia ceramics are promising. However, as for any implant system, clinical performance (i.e. survival and success rates) of zirconia oral implants is of great interest when advising on the clinical use of such ceramic implants in daily practice.

Various investigations have been conducted on zirconia dental implants, comparing them with titanium dental implants, and provide information on zirconia dental implant osseointegration. Hoffmann et al[14] histologically assessed the degree of early bone apposition around zirconia dental implants (Z-system, Konstanz, Germany) at 2 and 4 weeks following insertion. The zirconia implants demonstrated a slightly higher degree of bone apposition (54%–55%) compared with the titanium implants (42%–52%) at the 2-week time point, but bone apposition was higher in titanium (68%–91%) than in zirconia (62%–80%) at 4 weeks.

Deprich et al[15] demonstrated that zirconia implants with modified surfaces resulted in an osseointegration that was comparable with that of titanium implants. In a clinical study investigating zirconia implants, Blaschke et al[16] reported that dental implants made from zirconia were a feasible alternative to titanium dental implants. In addition to excellent cosmetic results, zirconia implants allowed a degree of osseointegration and soft tissue response that was superior to that of titanium dental implants.

In vitro studies performed by various authors have shown that zirconia did not show any cytotoxic or carcinogenic effects.[17] The good biocompatibility of zirconia was confirmed by their results. No signs of foreign body reaction were evident.

Koch FP et al[17], in an animal study, concluded that zirconia implants were capable of establishing close bone-to-implant contact (BIC) rates similar to what was known from the osseointegration behaviour of roughened titanium implants with the same surface modification and roughness. The result showed that calcium liberation from the zirconia surface may preserve the bone levels (BL) at the crestal implant part.

The search of literature revealed that animal studies dealing with zirconia implants outnumbered the clinical studies. Although studies have shown promising results, 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.[10]

Composites In Dental Implants (Peek)

When two or more substances such as polymer, fibbers, or powder are combined at a microscopic level, the resulting material may demonstrate macroscopic physical properties that are superior to those of either of the constituent parts. Such combinations are termed as composite materials. The term composite is usually used when the reinforcing component comprises long, continuous fibers.

One such composite i.e. fiber-reinforced poly-ether-ether-ketone (PEEK) polymer has been of interest to the medical implant community since the late 1980s, substantially because of the material's versatility, compatibility with modern imaging technologies, excellent mechanical properties, and biocompatibility.[18] PEEK is a relatively new family of high temperature thermoplastic polymers, consisting of an aromatic backbone molecular chain, interconnected by ketone and ether functional groups. The chemical structure of polyaromatic ketones confers stability at high temperatures (exceeding 300°C), resistance to chemical and radiation damage, compatibility with many reinforcing agents (such as glass and carbon fibers) and greater strength (on a per mass basis) than many metals.[19]

Historically, the availability of polyaromatic polymers arrived at a time when there was growing interest in the development of "isoelastic" hip stems and fracture fixation plates with stiffness comparable to bone.[20] By the late 1990s, PEEK had emerged as the leading high-performance thermoplastic candidate for replacing metal implant components, especially in orthopedics and trauma.

In 1992, PEEK was used for dental applications, first in the form of esthetic abutments and later as implants. Since then many variations in the composition have been carried out to modify and improve upon the working characteristics of the implant.

The reinforcing agents used may be carbon fibers, beta-tricalcium phosphate, hydroxyapatite or titanium dioxide contained within a PEEK matrix. The filler content makes the implant isoelastic, i.e. density and elasticity (Young's modulus) identical to bone. Although pure polyaromatic polymers exhibit elastic modulus that varies from 3 to 4 GPa, this value can be modified to achieve a modulus close to cortical bone (18 GPa) with the addition of fibers.[20]

On the other hand the Young's modulus of titanium and its alloys vary from 110 to 150 GPa.[21] It has been proven that a big difference between the elasticity of the implant material and bone leads to greater stress generation due to differential deformation under load. This stiffness mismatch can lead to bone resorption as a result of stress shielding. The isoelasticity of PEEK composites ensures that they warp identically to bone and thus produce a more homogenous distribution of stress along the implant bone interface.

In addition to matching the stiffness of bone, PEEK with reinforcing continuous fibers has excellent strength, fatigue resistance, and durability. Also research has shown that this material is resistant to the effects of steam, gamma irradiation, and boiling saline solution with no significant effect on transverse flexural strength.[22] Additionally, PEEK polymer carbon composites have excellent compression strength durability following conditioning in the physiological saline. It has been shown to be strong and durable composite material in extremely aggressive environment of the human body.[22]

Various medical imaging methods, such as computer tomography (CT) and magnetic resonance imaging (MRI) are not metal friendly; the presence of metallic implants i.e. titanium and its alloys significantly and negatively impacts the quality of the resulting images. On the other hand the implants made of reinforced PEEK polymer are radiolucent and this feature allows avoiding scatter in further CTs or MRIs, something that has proved to be a great boon for this material in its neurosurgical and orthopedic applications.[19]

Their white colour makes them ideal for use in the esthetic zone. Another matter of great convenience is the fact that polymer-composites do not generate heat when they come in contact with a high speed rotary cutting bur. As a result, the coronal portion of the single piece implant can be immediately modified (like crown preparation for FPD) to meet the prosthetic requirement.

Polyetheretherketone has shown promise in its many forms in medical application. It has osteointegration potential through osteoconduction that has been confirmed by clinical results.

Anneaux et al[23] reported that modulus effects and surface phosphonylation support osseointegration and bone formation on PEEK polymer surfaces. They concluded that the carbon fiber reforced-poly ether ether ketone (CFR PEEK) polymer, having surface immobilized calcium ions, should be viewed as a clinically preferred alternative to titanium alloys. Histolopathologically and histomorphically no discernible difference was observed between titanium alloy and CFR-PEEK polymer endosseous dental implants.

Conclusion

Zirconia and PEEK implants possess sufficient merits to warrant further clinical investigation. A few short-term clinical reports are available and provide satisfactory results, controlled clinical trials with a follow-up of 5 years or longer should be performed to properly evaluate the clinical performance of zirconia and PEEK implants and to recommend them for routine clinical use. Their use in the esthetic zone can be of significant advantage to the surgeon as well as patient. Longitudinal studies with large sample sizes and systematic evaluation will provide a more comprehensive view of zirconia and PEEK dental implants.

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