

วัสดุที่ใช้ในการผลิตรากเทียม: ไททาเนียมและเซอร์โคเนีย

An Overview of Dental Implant Materials: Titanium and Zirconia

หัตถ์ธรรณ คำใจ¹, ภัทรพรรณ จันทรเทวี², พจนารถ พุ่มประกอบศรี², ทองนารถ คำใจ²

¹คณะทันตแพทยศาสตร์ มหาวิทยาลัยเชียงใหม่

²คณะทันตแพทยศาสตร์ มหาวิทยาลัยกรุงเทพมหานคร

Hattanas Kumchai¹, Patrapan Juntavee², Pojanart Poomprakobsri², Thongnard Kumchai²

¹Faculty of Dentistry, Chiang Mai University

²Faculty of Dentistry, Bangkokthonburi University

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บทคัดย่อ

การเชื่อมประสานของกระดูกและรากเทียม จะขึ้นอยู่กับวัสดุที่ใช้ในการผลิตรากเทียมร่วมกับคุณสมบัติพื้นผิวของวัสดุรากเทียมซึ่งถือเป็นปัจจัยที่สำคัญ บทความนี้มุ่งเน้นทบทวน ความรู้สำคัญที่เกี่ยวข้องกับวัสดุที่ใช้ในการผลิตรากเทียม คุณสมบัติด้านต่างๆของวัสดุทั้งสองชนิดได้นำมาสรุปและอภิปรายเปรียบเทียบในรายละเอียด มีการนำเสนอระบบรากเทียมชนิดใหม่ในทุกๆ เดือน ดังนั้นการวิเคราะห์ระบบรากเทียมชนิดต่างๆ รวมทั้งงานวิจัยที่เกี่ยวข้องและวัสดุที่ใช้จึงเป็นสิ่งจำเป็น เพื่อลดปัญหาแทรกซ้อนจากการนำมาใช้ในทางคลินิก

คำสำคัญ: ไททาเนียม, เซอร์โคเนีย, รากเทียม

Abstract

Osseointegration is highly dependent on the specific dental implant materials together with their surface properties. This article reviews the essential knowledge related to dental implant materials. The required properties for implant material are summarized and two implant materials are discussed thoroughly together with the significant information in the article. With the introduction of new implant systems every month, a thorough analysis of dental implant systems, including important research and materials utilized is crucial in minimizing possible complications.

Keywords: Titanium, Zirconia, Dental Implant

Corresponding Author:

ทองนารถ คำใจ

รองศาสตราจารย์ คณะทันตแพทยศาสตร์
มหาวิทยาลัยกรุงเทพมหานคร

Thongard Kumchai

Asso. Prof., Faculty of Dentistry, Bangkokthonburi University
E-mail: thongnard@hotmail.com

Dental implants have been used in dentistry for over 40 years for the rehabilitation of edentulous patients. This therapy is now well documented, as well as being a scientifically accepted method of treatment. Osseointegration is highly dependent on the dental implant material together with their surface properties.⁽¹⁾ Table 1 summarizes the properties that are desired for dental implant materials.⁽²⁾

ตารางที่ 1 คุณสมบัติที่พึงประสงค์ของวัสดุที่ใช้ในการผลิตรากเทียม

Table 1 Desired properties of dental implant materials

Physical and Mechanical Properties
High resistance to degradation and corrosion
High compressive strength
High tensile strength
High elastic modulus
Biological properties
Biosafety (no carcinogenicity, no toxicity, no hypersensitivity)
Bioactivity (new bone formation, suitable for cell adhesion, etc.)

In general, there are two fundamental categories of materials that are used for dental implants, metals and ceramics. Most dental implants are created from commercially pure (c.p.) titanium and titanium alloys. Currently, there has been a development where zirconia dental implants are attracting the interest of many dentists. Both titanium and zirconia dental implants are discussed in this review.

Titanium

Titanium implants are now the gold standard for the replacement of teeth in the dental implantology field.^(3,4) These materials have acquired this status due to their favorable mechanical properties, their biocompatibility and their well-documented beneficial results.⁽⁵⁻⁷⁾

C.p. titanium has been used in applications that need high corrosion resistance, good welding and shape capability and mechanical resistance.⁽⁸⁾ The American Society for Testing and Materials (ASTM; F67) has categorized c.p. titanium based on maximum oxygen percentage. C.p. titanium grade 1 is the purest, since it has low iron content and low oxygen, unlike c.p. titanium grade 4 that has the highest iron percentage and oxygen.⁽⁹⁾ C.p. titanium grade 1 reveals a material with the highest ductility, the highest corrosion resistance, the highest workability, the highest shape-ability but has the least strength. Grade 4 (titanium) on the other hand indicates a material that has greater yield strengths, but the other properties, such as ductility and workability are at low levels. The mechanical properties of c.p. grades 1–4 titanium are indicated in Table 2.⁽¹⁰⁾

ตารางที่ 2 คุณสมบัติเชิงกลของไททาเนียม

Table 2 Mechanical properties of Titanium

ASTM grade	Tensile strength (MPa)	Yield strength (MPa)
Grade 1	240	170-310
Grade 2	345	275-450
Grade 3	440	380-550
Grade 4	550	480-655

The limitations that are related to monophasic-alpha alloys, like c.p. titanium, that possess the characteristics of low formability, fragility, and limited mechanical strength have led to the development and study of biphasic alpha/beta alloys, like Ti-6Al-4V. Alloys of titanium have been developed from the complete range of different c.p. titanium alloys and titanium grades (ASTM grades from 5 to 29).

Ti-6Al-4V is an important material to use in general surgery due to its good tensile and fatigue properties, biological compatibility and low modulus. However, this material is not used as often as c.p. titanium in dental applications because the loads

borne by dental implants are not as high as in other surgical applications and because Ti-6Al-4V is not as resistant to corrosion as is c.p. titanium.⁽¹⁰⁾

Zirconia

The use of ceramic dental implants was introduced several decades ago. At that time, the material of choice was an aluminum oxide that has a high modulus of elasticity together with moderate bending strength and toughness, making it prone to fracture. This proneness to fracture is the reason alumina implant systems were removed from the market and left the material of choice to be 3% Yttria-tetragonal zirconia polycrystals (3Y-TZP). Zirconia flexural strength ranges from 800 to 1000 MPa, which is high if matched to other ceramics used in dentistry. Moreover, Y-TZP provides a transformation toughening mechanism that improves this material's resistance to crack propagation because of the transformation of its tetragonal phase to monoclinic. This results in volumetric expansion that seals crack tips and superimposes the compressive stresses upon the existing stress field. Laboratory tests relating to the fracture strength of 3Y-TZP implants have indicated that 3Y-TZP has the capability of enduring masticatory forces.^(11,12) In most studies,⁽¹³⁻¹⁶⁾ the values for the bone-to-implant interaction of zirconia implants does not differ from those of titanium implants. However, in 2001, many orthopedic zirconia elements failed without a comprehensive clarification, raising worries in relation to the long-term performance of the material.⁽¹⁻⁵⁾ Therefore, there is a need for more long-term clinical studies.

Titanium has always been the best choice for dental implant fabrication, and various investigations have displayed its long-term efficacy. However, recently, tooth-colored ceramic has gained popularity among patients and dentists.⁽⁶⁾ There have also been some reports relating to allergic reactions to titanium dental implants.^(7,8) Gingival recession and apical bone loss related to implants usually expose

parts of the metal implant that cause discoloration of the gingiva. Using zirconia implants has a potential to prevent this. The inflammatory response that ceramics induce is less than those induced by Titanium, indicating ceramics biocompatibility.^(1,2,9)

One-piece dental implant

Most of zirconia dental implants are made in a one-piece configuration, in which the fixture and abutment parts are combined. As far as the properties related to one-piece implant design are concerned, it should be known that when using one-piece implants in daily practice, the surgery can be flapless, involving little surgical invasion, and advantages in the preservation of soft tissue. In addition, the most familiar documented screw joint issues, involving mainly abutment screw fracture or screw loosening, are prevented with one-piece implants. Another advantage of a one-piece implant design is that it can be inserted and quickly restored using a provisional crown. This procedure can be of significance in the instance of single-tooth replacement within the esthetic region.

Regarding implantation, one limitation is that the implants need to be inserted in perfect anatomical positions because there is only a small chance for corrections of the abutment's inclination. In this case, the initial placement in the esthetic zone becomes very critical due to the one-piece design. Without the same abutment flexibility, the implants prevent the use of any attachments, and hence a conversion of fixed restorations to overdentures.⁽¹⁾

Mechanical properties of zirconia dental implants

Laboratory studies have demonstrated fracture strength of zirconia implants comparable to that of titanium.^(10,11) However, the long-term aging properties of the material are still questionable.^(12,13) One caution is to minimize the preparation on the zirconia implants as it is found to significantly re-

duce the strength of the implants.⁽¹⁴⁾ Kohal, et al.⁽¹⁵⁾ analyzed the impacts of preparation and cyclic loading on the fracture strength of a one-piece zirconia implant system and found that the grinding of the abutment substantially reduced the fracture strength of the zirconia implant. In addition, the fracture strength of the zirconia implant was significantly reduced after cyclic loading with five million loading cycles. However, they concluded that the implants utilized in their study seemed to survive average occlusal forces, even after an extended interval of artificial loading. The same team⁽¹⁶⁾ also found that the failure load of two-piece zirconia implants was relatively low after aging them in a chewing simulator. They concluded that using two-piece zirconia implants in the clinic is not recommended.

Biological bone tissue response of zirconia dental implants

A profound knowledge of the bone tissue response at zirconia implant surfaces is necessary, as it plays an important role in long-term stability. Clinical success of implants is based on proper osseointegration, characterized by new bone formation and remodeling, resulting in high bone-to-implant-contacts.⁽¹⁷⁻¹⁹⁾

Borman, et al.⁽²⁰⁾ examined the response of biomechanical bone tissue to novel micro-structured zirconia implants compared to sandblasted and acid-etched (SLA) titanium implants by evaluating removal torque (RTQ) measurements in an animal model. They found that there were no statistical differences between the two materials after four- and 12-week healing periods. The RTQ values of both implant types improved significantly from week 8 to week 12. Additionally, Nevins et al.⁽²¹⁾ examined the histological and clinical outcomes of bone and soft tissue healing around a two-piece zirconia dental implant in a human model. The radiographic and clinical evaluations at six months showed stable, osseointegrated zirconia and titanium dental im-

plants. The results suggest that the bone-to-implant interaction with a zirconia implant surface is sufficient to give histological and clinical evidence of osseointegration.

Within the available evidence,⁽²²⁻²⁵⁾ zirconia implants seem to be capable of establishing close bone-to-implant contact rates similar to what is known from the osseointegration behaviour of roughened titanium implants. Improving surface characteristics of zirconia implants is an active research topic and it is believed to eventually provide improved clinical outcomes of the use of the zirconia implants.

Stress distribution of zirconia dental implants

It is believed that high stress concentration or distribution in peri-implant cortical bone should be avoided to maintain the long-term functioning of implant loading.⁽²⁶⁾ According to Choy, et al.⁽²⁷⁾, a rise of 2-3% in the average compressive and tensile stress and a rise of 8% in the average von Mises stress within the bone-implant interface was found when partially stabilized zirconia dental implants were used instead of Ti-6Al-4V dental implants. Another study⁽²⁸⁾ reported a different outcome, that zirconia implants led to lower peri-implant stresses than did titanium implants. Given the scarcity and heterogeneity of the available scientific data, the results comparing the stress distribution between zirconia and titanium dental implants seem to be inconclusive.

Clinical study of zirconia dental implant

Long-term clinical data on the use of zirconia implants is currently unavailable. One systemic review of the clinical survival of zirconia implants⁽²⁹⁾ reported a 92% overall survival rate after one year of function. In comparison, the overall survival rates of titanium implants supporting single crowns were 97.2 % at five years and 95.2 % at 10 years.⁽³⁰⁾ Gahlert,

et al.⁽³¹⁾ also researched the microscopic and macroscopic failure evaluation of clinically fractured, one-piece zirconia dental implants. They reported a fracture rate of 10% within a period of 36.75 months. Ninety-two per cent of the fractured implants were from small diameter implants (less than 3.25 mm). They concluded that mechanical overloading led to the fracturing of implants. Small diameter implants are not recommended for use clinically.

Further studies on the long-term clinical use of zirconia implants are necessary in order to justify the use of zirconia dental implants as an alternative to titanium dental implants.

Conclusions

This paper reviews the fundamental insight related to dental implant materials. With the introduction of new implant systems to the market on a monthly-basis, thorough study of dental implant systems, including relevant research and the materials used before making the decision is critical in order to minimize potential complications.

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