World Journal of Clinical Cases

Submit a Manuscript: http://www.wjgnet.com/esps/
Help Desk: http://www.wjgnet.com/esps/helpdesk.aspx
DOI: 10.12998/wjcc.v3.i1.52

World J Clin Cases 2015 January 16; 3(1): 52-57
ISSN 2307-8960 (online)

MINIREVIEWS

Implant biomaterials: A comprehensive review

Monika Saini, Yashpal Singh, Pooja Arora, Vipin Arora, Krati Jain

Monika Saini, Yashpal Singh, Department of Oral and Maxillofacial Rehabiliatation, Al Qaseem Pvt. Colleges, Buraydah, Qassim 51431, Saudi Arabia

Pooja Arora, Krati Jain, Department of Prosthodontics, Subharati Dental College, Meerut 250003, India

Vipin Arora, Department of Operative Dentistry and Endodontics, Subharati Dental College, Meerut 250003, India

Author contributions: Singh Y designed research; Saini M, Singh Y, Arora P and Jain K performed research; Arora V contributed new reagents or analytic tools; Singh Y and Arora V analyzed data; Saini M, Arora P and Jain K wrote the paper.

Correspondence to: Dr. Yashpal Singh, Associate Professor and Head of Department of Oral and Maxillofacial Rehabiliatation, Al Qaseem Pvt. Colleges, P.O. box No. 156, Buraydah, Qassim 51431,
Saudi Arabia. dryashpal.singh@gmail.com
Telephone: +966-53-8921650
Fax: +966-53-6326066

Received: July 23, 2014
Peer-review started: July 25, 2014
First decision: September 16, 2014
Revised: September 29, 2014
Accepted: November 17, 2014
Article in press: December 23, 2014
Published online: January 16, 2015

Abstract

Appropriate selection of the implant biomaterial is a key factor for long term success of implants. The biologic environment does not accept completely any material so to optimize biologic performance, implants should be selected to reduce the negative biologic response while maintaining adequate function. Every clinician should always gain a thorough knowledge about the different biomaterials used for the dental implants. This article makes an effort to summarize various dental biomaterials which were used in the past and as well as the latest material used now.

Key words: Biomaterials; Zirconium; Surface roughness; Ceramic; Corrosion

Core tip: This article makes an effort to review and summarize all the biomaterials used for dental implants. Materials in this article are discussed according to the era in which they were used. This review also covers the pros and cons related to these materials. Recent trends in the field of dental implants biomaterials and why these materials are superior over the previous ones. The content of the article are clinically significant and will prove to be helpful for readers to make decision while choosing implant system.

Saini M, Singh Y, Arora P, Arora V, Jain K. Implant biomaterials: A comprehensive review. *World J Clin Cases* 2015; 3(1): 52-57 Available from: URL: http://www.wjgnet.com/2307-8960/full/v3/i1/52.htm DOI: http://dx.doi.org/10.12998/wjcc.v3.i1.52

INTRODUCTION

In attempt to replace a missing tooth many materials have been tried as an implant . With all the advancements and developments in the science and technology, the materials available for dental implants also improved[1].

Implants are traceable to early Egyptians and South Central American cultures and with all the developments in material and biological science we have come a long way. Improvements in both the quality and quantity of the implant material have made this treatment modality very promising, budding and highly practiced in today's era. The Earliest dental implants of stone and ivory were

Table 1 Implant materials can be classified based on the type of material used and the biologic response they elicit when implanted[3]

Biodynamic activity	Chemical composition		
	Metals	Ceramics	Polymers
Biotolerant	Gold Co-Cr alloys Stainless steel Niobium Tantalum		Polyethylene Polyamide Polymethylmethacrylate Polytetrafluroethylene Polyurethane
Bio inert	Commercially pure titanium Titanium alloy (Ti-6AL-4U)	Al oxide Zirconium oxide	
Bioactive		Hydroxyapatite Tricalcium phosphate Bio glass Carbon-silicon	

reported in China and Egypt. Also Gold and Ivory dental implants were reported in the 16th and 17th centuries[2]. Metal Implants of Gold, Lead, Iridium, Tantalum, stainless steel and cobalt alloy were also mentioned in the early 20th century. Between these two periods a variety of polymers, including ultrahigh molecular weight polyurethane, polyamide, polymethylmethacrylate resin, polytetrafluoroethylene, and polyurethane, have been used as dental implant. In the present era, due to the extensive research work and advancements in the field of biomaterials available for dental implants, newer materials came into being such as zirconia, roxolid, surface modified titanium implants. These materials not only fulfill the functional requirements but are also esthetically pleasing. This article makes an effort to review various implant materials, their properties and the various pros and cons associated to those materials. To identify relevant literature an electronic search was performed of Pubmed database using the following keywords, implant biomaterials, implant material biocompatibility, recent trends in implant dentistry. The searches were limited to full text articles in English and those with associated abstracts. All the articles published from 1955 to 2012 are included in this review. All the articles in the language other than English and the articles related to surface coated implants and case reports are excluded.

Materials in this article are divided according to the era they were evolved as an implant material[3-6] (Table 1).

PROPERTIES OF AN IMPLANT BIOMATERIAL

Bulk properties[2,7]

Modulus of elasticity: Implant material with modulus of elasticity comparable to bone (18 GPa) must be selected to ensure more uniform distribution of stress at implant and to minimize the relative movement at implant bone interface.

Tensile, compressive and shear strength: An implant material should have high tensile and compressive strength to prevent fractures and improve functional stability. Improved stress transfer from the implant to bone is reported interfacial shear strength is increased, and lower stresses in the implant.

Yield strength, fatigue strength: An implant material should have high yield strength and fatigue strength to prevent brittle fracture under cyclic loading.

Ductility: According to ADA a minimum ductility of 8% is required for dental implant. Ductility in implant is necessary for contouring and shaping of an implant.

Hardness and Toughness: Increase in hardness decreases the incidence of wear of implant material and increase in toughness prevents fracture of the implants.

Surface properties

Surface tension and surface energy: It determines the wettability of implant by wetting fluid (blood) and cleanliness of implant surface. Osteoblasts show improved adhesion on implant surface. Surface energy also affects adsorption of proteins[2].

Surface roughness: Alterations in the surface roughness of implants influence the response of cells and tissue by increasing the surface area of the implant adjacent to bone and thereby improving cell attachment to the bone.

Implant surfaces have been classified on different criteria, such as roughness, texture and orientation of irregularities[8,9]: (1) Wennerberg and coworkers have divided implant surfaces according to the surface roughness as: Minimally rough (0.5-1 m), Intermediately rough (1-2 m), Rough (2-3 m); (2) The implant surface can also be classified according to their texture as: concave texture (mainly by additive treatments like hydroxyapatite (HA) coating and titanium plasma spraying),convex texture (mainly by subtractive treatment like etching and blasting); and (3) The implant surface can also be classified according to orientation of surface irregularities: Isotropic surfaces: have similar topography independent of measuring direction; Anisotropic surfaces: have clear directionality and vary considerably in roughness.

Biocompatibility

This is property of implant material to show favorable response in given biological environment in a particular function. It depends on the corrosion resistance and cytotoxicity of corrosion products.

Corrosion and corrosion resistance[9-11]**:** It is the loss of metallic ions from metal surface to the surrounding environment. Following types of corrosion are seen.

Crevice corrosion: It occurs in narrow region like implant screw-bone interface. When metallic ions dissolve, they can create a positively charged local environment in the crevice, which may provide opportunities for crevice corrosion.

Pitting corrosion: Pitting corrosion occurs in an implant with a small surface pit. In this the metal ions dissolve and combine with chloride ions. Pitting corrosion leads to roughening of the surface by formation of pits.

Galvanic corrosion: This occurs because of difference in the electrical gradients. Nickel and chrome ions from artificial prosthesis may pass to peri-implant tissues due to leakage of saliva between implant and superstructure .This may result in bone reabsorption and also affect the stability of the implant and eventually cause failure.

Electrochemical corrosion: In this anodic oxidation and cathodic reduction takes place resulting in metal deterioration as well as charge transfer *via* electrons. This type of corrosion can be prevented by presence of passive oxide layer on metal surface.

Clinical significance of corrosion: Implant bio-material should be corrosion resistant. Corrosion can result in roughening of the surface, weakening of the restoration, release of elements from the metal or alloy, toxic reactions. Adjacent tissues may be discolored and allergic reactions in patients may result due to release of elements.

ANCIENT ERA (through AD 1000)

Implants are traceable to ancient egyptian and south American civilization. There is a skull form pre Columbian era in which artificial tooth is carved with dark stone. Albucasis de condue Arabian surgeon, credited with a written paper of transplants as a means of replacing missing teeth[12].

Foundational period (1800-1910)

This era is the beginning of Endosseous oral implantology. Maggiolo in 1809 used gold in the shape of the tooth root. In 1887 Harris reported the use of teeth made of porcelain into which lead coated platinum posts were fitted. In 1890, Zamenski reported the implantation of teeth made of porcelain, gutta-percha, and rubber and in 1898 R.E payne places silver capsule in the tooth socket. In the early 1900's lambotte fabricated implants of aluminum, silver, brass, red copper, magnesium, gold and soft steel plated with gold and nickel[11,12].

Premodern era (1901-1930)

In 1901 a technique of capsule implantation was reported in dental cosmos which was presented by R.E payne at the clinics of third international dental congress. In 1903, Sholl in Pennsylvania, implanted porcelain tooth which was having a corrugated porcelain root. In 1913, Dr. Edward J. Greenfield introduced into the alveoli the basket of iridium and 24 carat gold. E. J Greenfield also introduced the concept of submerged implant, the healing tissue and dental implant immobility[12].

Dawn of the modern era (1935-1978)

In this era, synthetic polymers, ceramics and metal alloys started replacing the naturally derived materials because they have better performance and more predictable results than the natural ones.

Strock anchored a vitallium screw within bone and immediately mounted it with a porcelain crown. He was the first one to achieve an implant survival for 15 years[12,13].

POLYMERS

The early work with the methyl methacrylate resin implants met mostly with failures[14-18]. However, in 1969, Hodosh reported that polymers were biologically tolerable substances[16,17]. Research on polymethacrylate tooth-replica implants led to the development of the polymer dental implant concept by Milton Hodosh. In replacing a natural tooth, the polymer replica proved to be ideal for the restoration of function and appearance[18].

Polymers were selected for the following reasons[17]: (1) The physical characteristics of the polymers can be altered based on their use as their composition may be changed easily. Polymers can be changed in to more porous or softer form; (2) Polymers can be manipulated easily and allow better reproduction; (3) Polymers do not generate microwaves or electrolytic current as do metals; (4) They show fibrous connective tissue attachment; (5) They can be easily microscopically evaluated than with metals; and (6) They are more esthetically pleasing. There are some disadvantages: (1) inferior mechanical properties; (2) lack of adhesion to living tissues; and (3) adverse immunologic reactions.

Metals and metal alloys

Metals have biomechanical properties which made them suitable as an implant material. Besides these properties metals are also easy to process and have good finish. Metallic implants can be sterilized by the common sterilization procedure which makes them easy to use. But due to advancements with time and low success rates with metals (gold, stainless steel, cobalt-chromium), these materials have now become obsolete and are now replaced by newer ones. Titanium (Ti) and its alloys (mainly Ti-6Al-4V) have become the metals of choice for dental implants. However, prosthetic components of the implants are still made from gold alloys, stainless steel, and cobalt-chromium and nickel-chromium alloys[3].

Cobalt chromium alloys

They are used in cast or cast and annealed metallurgic conditions. It allows the manufacture of customized implants, such as subperiosteal frames. The elemental composition of this alloy includes cobalt, chromium and molybdenum as the major elements. Cobalt provides continuous phase for basic properties. Chromium provides corrosion resistance through the oxide surface. Molybdenum provides strength and bulk corrosion resistance. Nickels biocorrosive product and carbon must be accurately controlled to enhance mechanical properties, such as ductility[19,20].

Iron-Chromium-Nickel Based Alloys

Stainless steel alloys are used for orthopedic and implant devices. Iron based alloys are used for ramus blade, ramus frame, stabilizer pins and some mucosal insert. The alloy is most prone to pitting corrosion and care must be taken to use and retain the passiviated (oxide) surface condition, as this alloy contains nickel as a major element. Its use in allergic patients must be avoided. They have high galvanic potentials and corrosion resistance.This can result in galvanic coupling and biocorrosion, if titanium, cobalt, zirconium or carbon implant biomaterials are used with it[8].

IMPLANTS IN 21ST CENTURY

Titanium

Titanium has a good record of being used successfully as an implant material and this success with titanium implants is credited to its excellent biocompatibility due to the formation of stable oxide layer on its surface[21,22].

The commercially pure titanium (cpTi) is classified into 4 grades which differ in their oxygen content. Grade 4 is having the most (0.4%) and grade 1 the least (0.18%) oxygen content. The mechanical differences that exist between the different grades of cpTi is primarily because of the contaminants that are present in minute quantities. Iron is added for corrosion resistance and aluminum is added for increased strength and decreased density, while vanadium acts as an aluminum scavenger to prevent corrosion. Hexagonal close-packed crystal lattice of Ti is called the α-Ti (α-phase). On heating it at 883 ℃ phase transformation occurs from hexagonal close packed to body-centered cubic lattice or β- phase. Ti is a reactive as it forms spontaneously a dense oxide film at its surface. Ti is a dimorphic metal i.e. below 882.5 ℃ it exists as α-phase and above this temperature it changes form α- phase to β phase. Because of the high passivity, controlled thickness, rapid formation, ability to repair itself instantaneously if damaged, resistance to chemical attack, catalytic activity for a number of chemical reactions, and modulus of elasticity compatible with that of bone o, Ti is the material of choice for intraosseous applications[3,22-25].

Disadvantage: There is esthetic issue due to gray color of titanium and this is more pronounced when soft tissue situation is not optimal and the dark color shines through the thin mucosa.

Titanium alloys Ti6Al4V

Titanium reacts with several other elements for eg: silver, Al, Ar, Cu, Fe, Ur, Va and Zn to form alloys. Titanium alloys exists in three forms alpha, beta and α-β. These types originate when pure titanium is heated with elements Al, Va in certain concentrations and cooled, these type originate. These added elements play like Phase- condition stabilizers. Aluminum is alpha-phase condition stabilizer and it also increases the strength and decrease the weight of the alloy. Vanadium acts as beta-phase stabilizer. The temperature at which α-to β transformation occurs changes to a range of temperatures as Al or Va is added to Ti. Both α and β forms exist in this range. Temperatures to which the desired form is present can be obtained by quenching alloy at room temperature.To increase the strength, these alloys may be heat treated. The alloys most commonly used for dental implants are of the alpha-beta variety. The most common contains 6% Al and 4% Va. (Ti 6 Al 4V)[3,26].

Ceramics

Ceramics were used for surgical implant devices because of their inert behavior and good strength and physical properties such as minimum thermal and electrical conductivity. Certain properties of ceramics like low ductility and brittleness has limited the use of ceramics[3].

Aluminum, titanium and zirconium oxides

Root form or endosteal plate form, and pin-type dental implants are generally made from High ceramics from aluminum, titanium and zirconium oxides. The compressive, tensile and bending strengths exceed the strength of compact bone by 3 to 5 times. These properties combined with high moduli of elasticity and especially with fatigue and fracture strength have resulted in specialized design requirements for this class of biomaterials[8].

MODERN ERA

Modern Implant dentistry is delineated from the period of mid 1930's to the present. Today's popularity of implants in dentistry is attributed to the developments and the research work which laid the foundation of this field. It is because of all this work in the past that we are seeing the emergence of implant concepts developing into the most refined and popularly utilized systems.

In recent years the treatment options and modalities for achieving optimal functional and aesthetic outcomes with implant restorations have clearly changed. Pure titanium is generally preferred for dental implant because of its excellent biocompatibilty and mechanical properties. There might be aesthetic problems due to the gray color of titanium. In some situations, there may be a soft tissue recession; in such situations there is an unaesthetic display of the metal components. Therefore, implant research has focused on discovering tooth-colored implant material that improves the aesthetic appearance of dental implants and, at the same time, is highly biocompatible and able to withstand the forces present in the oral cavity and therefore zirconia came into being[27-29].

Zirconia

Zirconia was used for dental prosthetic surgery with endosseous implants in early nineties. Cranin and coworkers published first research work on Zirconia in 1975. Ceramic implants were introduced for osse-ointegration, less plaque accumulation resulting in improvement of the soft tissue management, and aesthetic consideration as an alternative to titanium implants[30,31].

Monoclinic (M), cubic (C), and tetragonal (T) are the three crystal forms in which polymorphic Zirconia structure is present. Zirconia,on room temperature, acquires a monoclinic structure and changes into tetragonal phase at 1170 ℃, followed by a cubic phase at 2370 ℃. At room temperature these phases are unstable and break into pieces,on cooloing. The C-phase of pure Zirconia can be stabilized by adding CaO, MgO, and Y_2O_3 (Yttrium) resulting in multiphase material called partially stabilized zirconia (PSZ) combining cubic, monoclinic, and tetragonal phases in the order of importance. Tetragonal zirconia polycrystals (TZP), containing tetragonal phase only can be obtained by adding Yttrium at room temperature. Yttria stabilized TZP possesses low porosity, high density, high bending, and compression strength and is suitable for biomedical application[32].

Titanium-zirconium alloy (Straumann Roxolid)

Titanium zirconium alloys with 13%-17% zirconium (TiZr1317) have better mechanical attributes, such as increased elongation and the fatigue strength, than pure titanium. Growth of osteoblasts, that are essential for osseointegration is not prevented by Titanium and Zirconium. Straumann developed Roxolid that fulfills requirements of dental implantologists and is 50% stronger than pure titanium.

Sandblasting and acid-etching on, TiZr1317 with a monophasic a structure results in a topographically identical surface as on pure titanium implants. Because of its superior mechanical properties.Thin implants and implant components that can be subjected to high strains can be produced using TiZr1317 due to its better mechanical properties, provided that the material shows a similar good biocompatibility as pure titanium[33].

CONCLUSION

In evaluating the present and predicting the future, one must also reconsider the past. The implant materials, their composition and properties are not talked about in most of the implant related literature. The literature also lacks the effect of the material properties on success and failure of implants and its effects on the tissues surrounding the implants.

Modern dentistry is beginning to understand, realize, and utilize the benefits of biotechnology in health care. Study of material sciences along with the biomechanical sciences provides optimization of design and material concepts for surgical implants[34].

Implants have been gaining popularity amongst the patients and frequently are being considered as a first treatment option. In the last decade implants have dominated the other treatment modalities and moved into the mainstream of dental practice. "We have come a long way but there is still more to achieve".

REFERENCES

1 **Hulbert SF**, Bennett JT. State of the art in dental implants. *J Dent Res* 1975; **54** Spec No B: B153-B157 [PMID: 1055740 DOI: 10.1177/00220345750540021001]

2 **Misch CE.** Contemporary implant dentistry. *Implant Dentistry* 1999; **8**: 90 [DOI: 10.1097/00008505-199901000-00013]

3 **Sykaras N**, Iacopino AM, Marker VA, Triplett RG, Woody RD. Implant materials, designs, and surface topographies: their effect on osseointegration. A literature review. *Int J Oral Maxillofac Implants* 2000; **15**: 675-690 [PMID: 11055135]

4 **Lemons JE**. Dental implant biomaterials. *J Am Dent Assoc* 1990; **121**: 716-719 [PMID: 2277157]

5 **Carvalho TL**, Araújo CA, Teófilo JM, Brentegani LG. Histologic and histometric evaluation of rat alveolar wound healing around polyurethane resin implants. *Int J Oral Maxillofac Surg* 1997; **26**: 149-152 [PMID: 9151174 DOI: 10.1016/S0901-5027(05)80838-0]

6 **Kawahara H**. Cellular responses to implant materials: biological, physical and chemical factors. *Int Dent J* 1983; **33**: 350-375 [PMID: 6581129]

7 **Muddugangadhar BC,** Amarnath GS, Tripathi S, Divya SD. Biomaterials for Dental Implants: An Overview. *International Journal of Oral Implantology and Clinical Research* 2011; **2:** 13-24 [DOI: 10.5005/jp-journals-10012-1030]

8 **Wennerberg A**, Albrektsson T. On implant surfaces: a review of current knowledge and opinions. *Int J Oral Maxillofac Implants* 2010; **25**: 63-74 [PMID: 20209188]

9 **Chaturvedi TP**. An overview of the corrosion aspect of dental implants (titanium and its alloys). *Indian J Dent Res* 2009; **20**: 91-98 [PMID: 19336868 DOI: 10.4103/0970-9290.49068]

10 **Manivasagam G,** Dhinasekaran D, Rajamanickam A. Biomedical Implants: Corrosion and its Prevention - A Review. *Recent Patents on Corrosion Science* 2010; **2:** 40-54 [DOI: 10.2174/1877610801002010040]

11 **Adya N,** Alam M, Ravindranath T,Mubeen A, Saluja B. Corrosion in titanium dental implants: literature review. *Journal of Indian Prosthodontic Society* 2005; **5**: 126-131 [DOI: 10.4103/0972-4052.17104]

12 **Block MS,** Kent JN, Guerra LR. Implants in dentistry. Philadelphia: W.B. Saunders company, 1997: 4

13 **Huebsch N**, Mooney DJ. Inspiration and application in the evolution of biomaterials. *Nature* 2009; **462**: 426-432 [PMID: 19940912 DOI: 10.1038/nature08601]

14 **Waerhaug J**, Zander HA. Implantation of acrylic roots in tooth sockets. *Oral Surg Oral Med Oral Pathol* 1956; **9**: 46-54 [PMID: 13297364 DOI: 10.1016/0030-4220(56)90173-6]

15 **Gettleman L**, Nathanson D, Myerson RL. Effect of rapid curing procedures on polymer implant materials. *J Prosthet*

Dent 1977; **37**: 74-82 [PMID: 264323 DOI: 10.1016/0022-3913(77)90195-0]
16 **Ashman A**. Acrylic resin tooth impant: a progress report. *J Prosthet Dent* 1971; **25**: 342-347 [PMID: 5276857 DOI: 10.1016/0022-3913(71)90197-1]
17 **Hodosh M**, Povar M, Shklar G. The dental polymer implant concept. *J Prosthet Dent* 1969; **22**: 371-380 [PMID: 4979523 DOI: 10.1016/0022-3913(69)90200-5]
18 **Shklar G,** Hodosh M, Povar M. Tissue reactions to polymer-coated Vitallium pin Implants. *J Prosth Dent* 1970; **24**: 636-645 [PMID: 4991130 DOI: 10.1016/0022-3913(70)90100-9]
19 **Arvidson K**, Cottler-Fox M, Hammarlund E, Friberg U. Cytotoxic effects of cobalt-chromium alloys on fibroblasts derived from human gingiva. *Scand J Dent Res* 1987; **95**: 356-363 [PMID: 3476989]
20 **Phillips RW.** Skinner's science of dental materials. 8th ed. Philadelphia: WB Saunders, 1982
21 **Cranin AN,** Silverbrand H, Sher J, Satler N. The requirements and clinical performance of dental implants. *Biocompatibility of dental materials* 1982; **4**: 92-102
22 **Tschernitschek H**, Borchers L, Geurtsen W. Nonalloyed titanium as a bioinert metal--a review. *Quintessence Int* 2005; **36**: 523-530 [PMID: 15997933]
23 **Wennerberg A**, Albrektsson T, Andersson B. Bone tissue response to commercially pure titanium implants blasted with fine and coarse particles of aluminum oxide. *Int J Oral Maxillofac Implants* 1996; **11**: 38-45 [PMID: 8820121]
24 **Meffert RM**, Langer B, Fritz ME. Dental implants: a review. *J Periodontol* 1992; **63**: 859-870 [PMID: 1453301 DOI: 10.1902/jop.1992.63.11.859]
25 **Williams DF**. Implants in dental and maxillofacial surgery. *Biomaterials* 1981; **2**: 133-146 [PMID: 7023554 DOI: 10.1016/0142-9612(81)90039-9]
26 **Ravnholt G**. Corrosion current and pH rise around titanium coupled to dental alloys. *Scand J Dent Res* 1988; **96**: 466-472 [PMID: 3201121]
27 **Prithviraj DR**, Deeksha S, Regish KM, Anoop N. A systematic review of zirconia as an implant material. *Indian J Dent Res* 2012; **23**: 643-649 [PMID: 23422612 DOI: 10.4103/0970-9290.107383]
28 **Depprich R**, Zipprich H, Ommerborn M, Naujoks C, Wiesmann HP, Kiattavorncharoen S, Lauer HC, Meyer U, Kübler NR, Handschel J. Osseointegration of zirconia implants compared with titanium: an in vivo study. *Head Face Med* 2008; **4**: 30 [PMID: 19077228 DOI: 10.1186/1746-160X-4-30]
29 **Kohal RJ**, Weng D, Bächle M, Strub JR. Loaded custom-made zirconia and titanium implants show similar osseointegration: an animal experiment. *J Periodontol* 2004; **75**: 1262-1268 [PMID: 15515343 DOI: 10.1902/jop.2004.75.9.1262]
30 **Hoffmann O**, Angelov N, Gallez F, Jung RE, Weber FE. The zirconia implant-bone interface: a preliminary histologic evaluation in rabbits. *Int J Oral Maxillofac Implants* 2008; **23**: 691-695 [PMID: 18807566]
31 **Özkurt Z**, Kazazoğlu E. Zirconia dental implants: a literature review. *J Oral Implantol* 2011; **37**: 367-376 [PMID: 20545529 DOI: 10.1563/AAID-JOI-D-09-00079]
32 **Adatia ND**, Bayne SC, Cooper LF, Thompson JY. Fracture resistance of yttria-stabilized zirconia dental implant abutments. *J Prosthodont* 2009; **18**: 17-22 [PMID: 19166544 DOI: 10.1111/j.1532-849X.2008.00378.x]
33 **Chiapasco M**, Casentini P, Zaniboni M, Corsi E, Anello T. Titanium-zirconium alloy narrow-diameter implants (Straumann Roxolid(®)) for the rehabilitation of horizontally deficient edentulous ridges: prospective study on 18 consecutive patients. *Clin Oral Implants Res* 2012; **23**: 1136-1141 [PMID: 22092806 DOI: 10.1111/j.1600-0501.2011.02296.x]
34 **Smith DC**. Dental implants: materials and design considerations. *Int J Prosthodont* 1993; **6**: 106-117 [PMID: 8329086]

P- Reviewer: Cho SY, Haraszthy V, Taheri S **S- Editor**: Tian YL
L- Editor: A **E- Editor**: Lu YJ

Published by **Baishideng Publishing Group Inc**
8226 Regency Drive, Pleasanton, CA 94588, USA
Telephone: +1-925-223-8242
Fax: +1-925-223-8243
E-mail: bpgoffice@wjgnet.com
Help Desk: http://www.wjgnet.com/esps/helpdesk.aspx
http://www.wjgnet.com