Review Article

Ceramic dental implants: A review

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ABSTRACT

The most advanced methodology to replace a failed natural organ with an artificial, high-functioning prostheses that replicate the same function that of the failed organ into a living organism is called an implant. An ideal implant material should be biocompatible, with properties such as toughness, strength, corrosion, wear, and fracture resistance. The design principles of the implant should be compatible with the physical properties of the material. It is very difficult to combine all these properties in only one material. However, in due course of time and technology dental implant materials and procedure has been improved to meet the future generation. Now the dentists, mechanical engineers, and dental technicians and various others have looked beyond the usual mechanism of dental implants with titanium and tried to create a breakthrough by introducing ceramic implants into the field of dental implantology. The aim of this study is to understand the alternative dental implants material such as ceramic dental implants, compare them with titanium dental implants, and provide information osseointegration and mechanical strength. Ceramic dental implants have the potential to become alternative dental implants to titanium dental implants, but they are not yet in clinical use. It does need *in vivo* and *in vitro* successful experiments before going into commercials.

KEY WORDS: Biocompatibility, Ceramic, Dental implants, Zirconia

INTRODUCTION

The most advanced methodology to replace a failed natural organ with an artificial, high-functioning prostheses that replicate the same function that of the failed organ into a living organism is called an implant. An ideal implant material should have the following properties such as biocompatible, toughness, strength, corrosion, wear, and fracture resistance.[1,2] The design protocol for an implant should go hand in hand with the physical properties of the material. Materials used for the fabrication of dental implants can be categorized according to their chemical composition or the biological responses they elicit when implanted.[3] The chemical property for dental implants can possess is that it can be made from metals, ceramics, or polymers. An ideal biomaterial is seemed to exhibit properties such as biocompatibility, as in no tissue response and with a density lower than that of bone, high mechanical strength, fatigue resistance, low elastic modulus, and good wear resistance. It is very difficult to combine all these properties and produce one good material.[4] At present, 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 due to their excellent biocompatibility, favorable mechanical properties, and well documented beneficial results.[4-6] When exposed to air, titanium immediately develops a stable oxide layer, which forms the basis of its biocompatibility. The properties of the oxide layer are of great importance for the biological outcome of the osseointegration of titanium implants.[7] However, as time goes by and in this advancing technology dental implant materials and procedure has been improved to meet the future generation. Now the dentists, mechanical engineers, and dental technicians and various others have looked beyond the usual mechanism of dental implants with titanium and tried to create a breakthrough by introducing ceramic implants into the field of dental implantology. The aim of this study is to understand the alternative dental implants material such as ceramic dental implants, compare them with titanium dental implants, and provide information osseointegration and mechanical

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strength. Ceramic dental implants have the potential to become alternative dental implants to titanium dental implants, but they are not yet in clinical use. It does need *in vivo* and *in vitro* successful experiments before going into commercials.

DISADVANTAGE OF TITANIUM IMPLANTS

The primary disadvantage of titanium is the dark gray color which can be seen through the peri-implant mucosa, therefore, affecting esthetic outcomes in the presence of a thin mucosal biotype.[8] Gingival recessions may lead to compromised esthetics. Gingival recession and apical bone loss connected to implants frequently expose portions of the metal implant, disclosing a bluish discoloration of the superimposing gingiva. This is of great concern on replacing maxillary incisors.[7,9-11] Rarely few cases have been reported that metals have certain non-specific immunomodulation and autoimmunity. The mechanical effects of galvanization are also encountered under the environment of saliva pooling and fluoride contacts. On saliva and mucosal contacts, metal ions will be released from implants, where they form chains with native proteins and causes hypersensitivity reactions. Allergy to titanium in the studies has been described in the form of pruritus of the skin or mucosa, impaired healing of fractures and pain, necrosis, facial eczema, dermatitis, rashes, non-keratinized edematous hyperplastic gingiva and rapid implant exfoliation, impaired healing, and overload on weak implants.[12,13] However, allergic reactions for titanium are quite infrequent; cellular sensitization is validated. One rare sought of titanium dental implant failure is a fracture; the potential causes of implant fracture may be of three major categories: (a) Implant design, (b) manufacturing defects, or (c) non-passive fit of the framework or physiological and biomechanical overload.[14-17] In literature, the proposed mechanism of titanium implant failure is metal fatigue from high cyclic occlusal loading.[18] Accelerated peri-implant marginal bone loss is maybe due to an increase in the bending moments and torque force on the implants. This finally leads to increased implant mobility and an eventual structural failure of the implant. It has been unclear whether marginal bone loss is an effect of implant fracture or due to unfavorable loading.[19] It has been reported that titanium implants may adsorb hydrogen from the biological environment, eventually becoming more brittle and prone to fracture it has been unclear whether marginal bone loss is a cause or an effect of implant fracture or if they are both consequences of unfavorable loading.[20] From a chemical point of view, it has been suggested that titanium implants may adsorb hydrogen from the biological environment, consequently becoming more brittle and prone to fracture the state of the periodontium is important for a successful outcome. As we mentioned earlier, galvanic reactions caused by oral environment and titanium dental implant creates cytotoxic reaction, as well as potentially assist with fatigue crack initiation. Such reactions result in accelerated peri-implant bone resorption and affecting the soft tissue surrounding the titanium dental implant. There have been studies stating that improper dental implant installation affects the oral condition causing peri-implantitis.[21]

PERI- IMPLANTITIS

Peri-implant mucosa is composed of well-keratinized oral epithelium, sulcular epithelium, and junctional epithelium, as well as the underlying connective tissues. Between the implant surface and the epithelial cells are the hemidesmosomes and the basal lamina. Early bacterial colonization around implants by microorganisms associated with periodontitis has been reported, and this colonization of implant surfaces and peri-implant tissues can occur within minutes after implant placement. Hence, with microbial colonization occurs inside the microgap in between the titanium implant surfaces and the peri-implant tissues discussed above. This microgap is addressed as fixture-abutment interface microgap, leading to be a bacterial reservoir, and causing peri-implantitis.[21]

NEW ALTERNATIVE TO TITANIUM: ZIRCONIA

Coating on Titanium Implants

According to literature, ceramic was introduced into dental implantology as coatings and abutments. Over the past 15 years, various forms of ceramic coatings have been used on dental implants, which involved the utilization of both bioactive ceramics, such as:

- Hydroxyapatite – $Ca10(PO4)6(OH)2$.
- Tricalcium phosphate – α, β, $Ca3(PO4)2$.
- Fluorapatite – $Ca10(PO4)6F2$.
- Tetra calcium phosphate – $Ca4P2O9$.
- Calcium pyrophosphate – $Ca4P2O7$.
- Brushite – $CaHPO4$, $CaHPO4.2H2O$.
- Bioglasses – $SiO2$-CaO-$Na2O$-$P205$-MgO.
- Aluminum oxide – $Al2O3$.
- Zirconium oxide – $ZrO2$.

Bioactive ceramics have been studied that they release calcium phosphate ions around the implants, resulting in enhanced bone apposition compared with the more inert ceramic and metallic surfaces.[22] Hence, different physical and chemical surface modifications were developed for improving osseous healing on zirconia dental implants. For improving surface properties, two key approaches can be used such as application of bioactive coatings and optimization of micro-roughness. Ceramic coatings prove to show that on coating metal-based endosseous implants they improve osseointegration. Denser coatings are characterized by higher strengths and lower solubility. Inert ceramic materials are rarely used as coatings because they do not appear to be as osteoconductive as the more bioactive calcium phosphate materials. As we mention about coatings, experts put forward the idea of ceramic implants. Yttrium-stabilized tetragonal zirconia polycrystals seem to provide benefits over aluminum oxide for dental implants due to their higher flexural strength and their higher fracture resilience.[22-25]

ZIRCONIA AS AN IMPLANT

Zirconia appears to be an appropriate dental implant material due to its mechanical properties, tooth like color and hence biocompatibility. However, the material composition of a biomaterial implant plays an essential role in osseointegration. We know that the implant surface's quality is a key factor which influences the healing of wound at the site of implantation and affects osseointegration. Various studies have been conducted on animals; these studies showed that healthy peri-implant mucosa was obtained in the groups of single freestanding implants and tooth supported implants with very encouraging values for clinical parameters. The direct bone-implant interface was obtained in all studied implants of zirconia, histologically, and analyzed at time intervals. The zirconia implants showed a little higher degree of bone deposition in comparison with titanium implants at the point of 2 weeks.[26] However, bone apposition was higher in titanium in comparison with zirconia at 4 weeks. The zirconia implants showed bone contact which was 20% higher compared to that of titanium implants at 2 weeks. It was improved toward 4 weeks and reduced at 8 weeks. Even though it is not significant statistically, a strong tendency was observed for the pharmacologically and chemically altered implants to present better values of Bayesian information criterion (BIC) at 8 weeks than the anodic plasma-treated surface of zirconia implants. Every titanium implant contained a similar amount of BIC at 2 weeks. It was found that only zirconia was better.[27] A considerable quantity of freshly formed bone was observed with zirconia surfaces. The results showed that the zirconia implants with altered surfaces caused osseointegration which could be compared with the likes of titanium implants. These examinations resulted in understanding that zirconia implants are greatly osteoconductive and biocompatible. Moreover, a composite material processed with 80% tetragonal zirconia polycrystals (ZrO_2-TZP) and 20% alumina (Al_2O_3) is discovered that it has outstanding mechanical and tribological properties. On adding alumina to zirconia clearly hinders aging or at least drastically reduces its kinetics, as it changes the grain-boundary chemistry and limits the tetragonal grain growth during sintering which results in a more stable composition.[28]

Types of Zirconia Used in Dentistry

1) Yttrium-stabilized tetragonal zirconia polycrystals (3Y-TZP)

   The microstructure of 3Y-TYP consists of 98% small equiaxed tetragonal grains (0.2–0.5 µm) and combined with a little cubic phase, and 3 mol% Yttria (Y_2O_3) as a stabilizer. The mechanical properties of 3Y-TZP depend on the size, a grain size of 1 µm, 3Y-TZP is less stable and more susceptible to spontaneous tetragonal to monoclinic transformation, the size of 0.2 µm, transformation toughening is not possible, which results in reduced fracture toughness.[29]

2) Glass-infiltrated zirconia-toughened alumina

   On adding alumina to zirconia clearly hinders aging or at least drastically reduces its kinetics, as it changes the grain-boundary chemistry and limits the tetragonal grain growth during sintering which results in a more stable composition. The material is developed by adding 33 vol% of 12 mol% ceria-stabilized zirconia (12Ce-TZP) to In-Ceram alumina. The material is developed by adding 33 vol% of 12 mol% ceria-stabilized zirconia (12Ce-TZP) to In-Ceram alumina.[30]

3) Alumina toughened zirconia (ATZ)

   A composite material processed with 80% tetragonal zirconia polycrystals (ZrO_2-TZP) and 20% alumina (Al_2O_3) is discovered that it has outstanding mechanical and tribological properties. The addition of alumina as low as 0.25 wt% to TZP ceramics significantly improves the resistance of the material to surface degradation. ATZ exhibits the highest bending strength known for ceramics, both at room temperature and elevated temperatures at 1000°C.[25] Such high strength properties result in a high thermal shock resistance of ATZ ceramics as it prevents strength reduction on rapid cooling from elevated temperatures.

CONCLUSION

This article shows the disadvantages of titanium dental implants and the advantages of ceramic dental implants. However, the titanium dental implant materials are a gold standard for >200 years from ancient dentistry, ceramic, and glass infused hi-tech ceramic dental implants to provide adequate stability and biocompatibility in *in vitro* studies. Ceramic dental implants too will have a good impact in the future dentistry which provides efficient and esthetic rich dental treatment.

REFERENCES

1. Smith DC. Dental implants: Materials and design considerations. Int J Prosthodont 1993;6:106-17.
2. Parr GR, Gardner LK, Toth RW. Titanium: The mystery metal of implant dentistry. Dental materials aspect. J Prosthet Dent 1985;54:410-4.
3. Shasmitha R, Dhanraj M. Biocompatible dental implant materials: An review. Int J Adv Res 2017;5:273-6.
4. Sykaras N, Lacopino 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;15:675-90.
5. Depprich R, Zipprich H, Ommerborn M, Naujoks C, Wiesmann HP, Kiattavorncharoen S, *et al.* Osseointegration of zirconia implants compared with titanium: An *in vivo* study. Head Face Med 2008;4:30.
6. Steinemann SG. Titanium-the material of choice? Periodontol 2000 1998;17:7-21.
7. Heydecke G, Kohal R, Glaser R. Optimal esthetics in single tooth replacement with the re-implant system: A case report. Int J Prosthodont 1999;12:184-9.
8. 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 1999;15:675-90.
9. Stejskal J, Stejskal VD. The role of metals in autoimmunity and the link to neuroendocrinology. Neuroendocrinol Lett 1999; 20:351-64.
10. Tschernitschek H, Borchers L, Geurtsen W. Non alloyed titanium as a bioinert metal-a review. Quintessence Int 2005; 36:523-30.
11. Tamai K, Mitsumori M, Fujishiro S, Kokubo M, Ooya N, Nagata Y, *et al*. A case of allergic reaction to surgical metal clips inserted for postoperative boost irradiation in a patient undergoing breast conserving therapy. Breast Cancer 2001;8:90-2.
12. Thomas P, Bandl WD, Maier S, Summer B, Przybilla B. Hypersensitivity to titanium osteosynthesis with impaired fracture healing, eczema, and T-cell hyperresponsiveness *in vitro*: Case report and review of the literature. Contact Dermatitis 2006;55:199-202.
13. Haug RH. Retention of asymptomatic bone plates used for orthognathic surgery and facial fractures. J Oral Maxillofac Surg 1996;54:611-7.
14. Mitchell DL, Synnott SA, van Dercreek JA. Tissue reaction involving an intraoral skin graft and CP titanium abutments: A clinical report. Int J Oral Maxillofac Implants 1990;5:79-84.
15. Du Preez LA, Bütow KW, Swart TJ. Implant failure due to titanium hypersensitivity/allergy? Report of a case. SADJ 2007; 62:22-5.
16. Müller K, Valentine-Thon E. Hypersensitivity to titanium: Clinical and laboratory evidence. Neuro Endocrinol Lett 2006; 27:31-5.
17. Kohal RJ, Klaus G, Strub JR. Zirconia-implant supported all-ceramic crowns withstand long-term load: A pilot investigation. Clin Oral Implants Res 2006;17:565-71.
18. Kohal RJ, Wolkewitz M, Tsakona A. The effects of cyclic loading and preparation on the fracture strength of zirconium-dioxide implants: An *in vitro* investigation. Clin Oral Implants Res 2011;22:808-14.
19. Kohal RJ, Finke HC, Klaus G. Stability of prototype two piece zirconia and titanium implants after artificial aging: An *in vitro* pilot study. Clin Implant Dent Relat Res 2009;11:323-9.
20. Watanabe M, Iio S, Fukuura I. Ageing behaviour of Y-TZP. In: Claussen N, Ruhle M, Heuer AH, editors. Science and Technology of Zirconia II, Advances in Ceramics. Vol. 12. Columbus, OH, USA: The American Ceramic Society, Inc.; 1984. p. 391-8.
21. Shasmitha R. Microbial profile of peri-implantitis-A review. J Pharm Sci Res 2016;8:1223.
22. Samodurova A, Andraž K, Swain MV, Tomaž K. The combined effect of alumina and silica co-doping on the ageing resistance of 3Y-TZP bioceramics. Acta Biomater 2014;11:477-87.
23. Piconi C, Burger W, Richter HG, Cittadini A, Maccauro G, Covacci V, *et al*. Y-TZP for artificial joint replacements. Biomaterials 1998;19:1489-94.
24. Lee SK, Tandon R, Ready MJ, Lawn BR. Scratch damage on zirconia ceramics. J Am Cream Soc 2000;83:1428-32.
25. Ruiz L, Readey MJ. Effect of heat-treatment on grain size, phase assemblage, and mechanical properties of 3 mol % Y-TZP. J Am Ceram Soc 1996;79:2331-40.
26. Heuer AH, Claussen N, Kriven WM, Ruhle M. Stability of tetragonal ZrO2 particles in ceramic matrices. J Am Ceram Soc 1982;65:642-50.
27. Cottom BA, Mayo MJ. Fracture toughness of nanocrystalline ZrO2–3 mol % Y2O3 determined by Vickers indentation. Scr Mater 1996;34:809-14.
28. Filser F, Kocher P, Gauckler LJ. Net-shaping of ceramic components by direct ceramic machining. Assembly Autom 2003;23:382-90.
29. Ross IM, Rainforth WM, McComb DW, Scott AJ, Brydson R. The role of trace additions of alumina to yttria-tetragonal zirconia polycrystal (Y-TZP). Scr Mater 2001;45:653-60.
30. Li LF, Watanabe R. Influence of a small amount of Al2O3 addition on the transformation of Y2O3-partially stabilised ZrO2 during annealing. J Mater Sci 1997;32:1149-53.

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