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Implant Surface Characteristics and Effects on Osseointegration – A Review

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Abstract

Osseointegration of a dental implant is a pre-requisite for their short and long term success. Since it largely depends on the implant material and composition, design and surface treatment techniques, a thorough knowledge of the same is required for selecting the correct implant for the specific clinical scenario. The surface treatment of the implant may be done by grit blasting, acid etching, surface coating, sand blasting, sputter deposition, laser ablation etc. These modifications increase the implant surface roughness or act as osseoconductive agent. This article aims to review the various materials, surface designs and surface treatment techniques for an endosseous dental implant. Ceramic implants as a substitute for conventional titanium implants have also been discussed in this review.

Introduction

Since their introduction almost over 50 years ago, implants have gained immense popularity in dentistry, with over one million dental implantations per year.[1]Due to its excellent biocompatibility and mechanical properties, titanium is still the material of choice for endosseous dental implants. Most dental implants are made from grade 4 commercially pure titanium which is stronger than other grades.[2]Due to their high versatility, endosseous implants are used as a treatment modality for oral and craniofacial reconstruction, transmucosal structure to support single teeth[3], fixed partial dentures[4], complete-arch reconstructions[5], and complete removable dentures[6].

The early clinical success of the implant relies on osseointegration of titanium to the host bone tissue.[7]However, the surface topography and geometry are critical for a short and long term success. The rate and quality of osseointegration are related to the surface properties. As implant dentistry is continuously evolving, new levels of biological technology lead to modifications in the surface topography which result in achieving better osseointegration and shorten the healing period.[8]This review focuses on the various materials, designs and surface treatments used for dental implants along with a brief outlook on ceramic implants.

OSSEOINTEGRATION

Initially defined as a direct structural and functional connection between ordered, living bone and surface of a load-carrying implant, osseointegration is a pre-requisite for the overall success of an implant.[9] When the surgical instrumentation is performed, the osteotomy site is immediately filled with blood. Subsequently, when the implant is being placed, it forces the bioliquid to escape and thus saturate the entire implant surface.[10] A myriad of adhesive proteins such as fibronectin, vitronectin, osteopontin, fibrinogenand other biomolecules are absorbed over the implant surface which result in a series of well-orchestrated events involved in cell adhesion mechanism. These events may be divided into

- Inflammatory phase – Platelets come in contact with the implant surface and the clotting cascade is initiated. A non-specific inflammatory response by the neutrophils is followed by a specific inflammatory response by the lymphocytes and macrophages.
- Proliferative phase – Neovascularization occurs by vascular ingrowth into the surgical site. The extracellular matrix is laid down and the fibro-cartilaginous callus is formed which subsequently transforms into the bone callus.
- Maturation phase – Immature woven bone is laid down in the peri-implant space followed by the ossification of the fibro-cartilaginous callus. Simultaneous resorption of the composite trabeculae along with deposition

of mature concentric lamellae results in bone remodelling.[11]

At the microscopic level, the topography of the implant surface influences the biomechanical interlocking with the bone. In a study by Cooper et al,[12] it was noted that the surface treatment and topography of the implant surface affected the ability of the osteoblasts to produce mineralising matrix. Thus, it was concluded that cells respond differently to various surfaces and a less than optimal implant surface would reduce the osteogenic potential. The quality of this osseointegration achieved may be tested either by the biomechanical test (pull-out test, push-out test and torque measurement) or the histomorphometric analysis.

IMPLANT MATERIALS

Historically, gold, silver, aluminium, platinum and porcelain were used as implants for replacing missing teeth. However, they would cause a foreign body or inflammatory reaction and result in formation of fibrous tissue.[13] Chemically, dental implants belong to 1 of the following 3 primary groups –

1) Metals – Commercially pure titanium has been used for more than 30 years and is still the material of choice for dental implants showing a high success rate in various indications.[14] On exposure to air, titanium forms a stable oxide layer of about 2-10 nm which is biocompatible and provides corrosion resistance, passivity and resistance to chemicals.[15]

2) Ceramics – Plasma-sprayed hydroxyapatite ceramic is the most popular ceramic and has been claimed to enhance cohesive chemical bonding with bone as compared to uncoated metal implants.[16] The entire implant can be made of ceramic, or metal implants may be coated by a layer of ceramic. However, flexural strength and solubility are the main concerns in ceramic implants and hence, ceramic coated metal implants are preferred. This may be achieved by hot isostatic pressing and surface-induced mineralisation.

3) Polymers – Polyurethane, polymethylmethacrylate, polyamide fibres and polytetrafluoroethylene are a few polymers that have been used historically.[17] They were fabricated so as to replicate the micro-movements of the periodontal ligaments and thus transfer stress to the bone.[18]

Based on the biological response they elicit in the host tissue, implants may also be classified as

1) Biotolerant – The implanted material is surrounded by a fibrous capsule.

2) Bioinert – The implanted material allows close apposition of bone on its surface.

3) Bioactive – Ion exchange with host tissue results in formation of chemical bond along with formation of new bone onto the implanted surface.

IMPLANT SURFACE

The surface of the dental implant is designed with the objective of improving the clinical long-term success of the osseointegrated interface and accomplish uncomplicated prosthetic replacement. The implant may be solid or hollow, have a parallel, tapered or stepped shape and a flat, rounded, or pointed apical end. Depending on the surface design, implants are categorised as threaded or non-threaded (press-fit). These threads are essential in the primary stability as they maximise the contact and increase the implant surface area. They also help in dissipation of interfacial stress in the bone.[19] In combination, a number of additional features such as perforations of various shapes and dimensions, vents, ledges, grooves, flutes and indentations may be incorporated into the implant body to accentuate or replace the threads.

It has been noted, at a nanoscale, that a more textured surface topography increases the surface energy and wettability of the implant surface, thus promoting adhesion of the cells. Cell differentiation, migration and proliferation and thus, osseointegration, is promoted by nanotopography.[20] This can be achieved by treating the implant surfaces through various methods –

1) Machined dental implants (turned surface) – These were the first generation implants described by Brannemark. On a macroscopic level, they have a smooth surface; but on scanning electron microscope analysis, grooves and ridges can be noted which are made during the manufacture process. Various randomized clinical trials and systematic reviews have shown a positive correlation between surface roughness and bone-implant contact and thus, these implants are not preferred in poor bone quality sites.[21]

2) Plasma spraying (Grit blasting) – Rough implant surface is created by titanium plasma spraying, wherein titanium powder is injected into a plasma torch at a high temperature. These particles of about30µm thickness are projected on the implant surface where they condense and fuse to form a film. Thus, a rough surface is created which increases the surface area and the tensile strength of the implant.[22] However, a consensus report displays clinical advantages of moderately rough (in micrometric range) implant surfaces over plasma-sprayed implant surfaces.[23]

3) Acid etching – Strong acids are used to roughen the surface of titanium implants along with removal

of the oxide layer. Usually, a mixture of nitric acid and hydrofluoric acid or hydrochloric acid and sulphuric acid is used for acid etching which creates micro-pits of 0.5-2µm diameter.[24] A homogenously irregular surface is created due to acid treatment and thus increase in the surface area that enhances bioadhesion and facilitates osteoblastic retention.[25] It also lowers the surface energy and reduces the contamination possibility as no particles are encrusted on the surface. Acid etching has shown to cause a rapid osseointegration along with a clinical success on a long term basis.[26] However, chemical treatment can cause titanium to become brittle and create micro cracks on the surface.[27]

4) Dual-etching–It is a variant of acid etching wherein the titanium implants are inserted in a mixture of concentrated hydrochloric acid and sulphuric acid and heated above 100°C. Direct bone formation is enhanced by this method, due to the attachment of osteogenic cells and fibrin resulting in an overall increase in the osteoconductive process.[28]

5) Hydroxyapatite surface coating – A bioactive layer of hydroxyapatite can be coated over the implant surface which forms a calcium phosphate rich layer through a solid solution ion exchange.[29] According to Biesbrock, these implants are beneficial in lower density bone, short implants or in grafted regions where more rapid bone-implant contact is needed.[30] In a study by Vercaigne et al, it was noted that bone reaction to hydroxyapatite coated implants was much more than roughened implants.[31]

6) Sol-gel surface coating –A homogenous chemical composition is deposited on the surface of the implants. Better osseointegration with minimal adverse effects was noted using this technique of surface treatment.[32]

7) Sandblasting and acid-etching – This is the technique commonly employed by most of the implant manufacturers. Large grit particles of 250-500µm are sandblasted over the implant surface which is followed by acid etching. The sandblasting creates macrostructures whereas the acid etching causes micro-irregularities.[33] Significant more bone apposition is noted in such implants and thus they can be used for patients requiring early implant loading.

8) Oxidised surface (Anodization) – Implants may be placed in strong acids to produce micro or nano porous surfaces by galvanization at a high current density of 200 A/m^2 and potential of 100 V. This causes the oxide layer to become more than 1000nm in thickness on the titanium surface. Microstructure and crystalline modifications of the titanium oxide layer is caused by this process.[34] The osteoblast cell adhesion is enhanced by the anodised surface

producing a faster osseointegration. This is due to the mechanical interlocking by bone growth in the pores, and biochemical bonding. A strong reinforcement of bone response with higher biomechanical properties are thus seen by this technique.[35]

9) Fluoride treatment – Titanium is highly reactive to fluoride forming titanium tetrafluoride. This provides a more stable bone-implant contact and also reduces the healing time when compared to grit blasted implants.[36] Fluoride treated titanium implants also showed improved biocompatibility and better retention.[37,38]

10) Laser ablation – It creates microstructures with enhanced hardness, corrosion resistance and a thick oxide layer to enhance the implant surface. They may be indicated in immediate implant placements especially in the anterior maxilla.[39]

11) Sputter deposition – It is a process of bombardment of molecules over a surface under vacuum. Hydroxyapatite crystals are usually sputtered using radio frequency or magnetron sputtering over the implant surface which increases the bone-implant contact.[31]

12) Bioactive drug incorporation – A variety of osteogenic drugs may be applied to the implant surface to improve the osseointegration

a) Bisphosphonates – Increases bone density around implants.[40]

b) Simvastatin – This anti-cholesterol drug has shown to promote bone formation by inducing the expression of bone morphogenetic protein-2 gene in an animal model.[41] Several studies using simvastatin on implant surfaces have shown improved osseointegration.[42,43]

c) Antibiotics – Tetracycline has been evaluated due to its efficacy in removing smear layer and inhibition of collagenase activity.[44]

d) Synthetic peptide – Titanium implants coated with proline rich synthetic peptide have been shown to promote osseointegration.[45]

CERAMIC IMPLANTS

Although titanium implants have been shown to have high success rates through various designs and surface modifications, the esthetic outcome of the restoration supported by it may be compromised in case of thin gingival biotypes, particularly in the esthetic zone. This may be accentuated in case of gingival recession in areas of implant placement. Some research has even revealed a potential health hazard due to titanium as increased concentrations were detected in adjacent tissues and lymph nodes.[46,47,48] These issues have led to the relatively recent development of ceramics as a replacement to titanium for dental implants. Various ceramic implant systems of yttria-stabilized tetragonal zirconia polycrystals are commercially available.Zirconia ceramic seem to be a suitable material for dental implant due to its tooth-like colour, biocompatibility and mechanical properties.[49]

In a systematic review by Wenz in 2008[50], available literature suggested that osseointegration of these implants may be comparable to titanium implants. However, when these ceramic implants are restored and loaded with all-ceramic restorations, they may not be able to withstand long term static and cyclic loading. These implants are also susceptible to low temperature degradation. Despite these shortcomings, ceramic implants have the potential to become an alternative to titanium implants, particularly in the esthetic, non load-bearing areas.

CONCLUSION

Implant dentistry is in a constant state of flux and always evolving. The knowledge about cellular and molecular events that occur during the process of osseointegration must be attained by clinicians as they relate the clinical findings to basic mechanisms. There are a number of commercially available implant surfaces which have proven >95% of clinical success. The ultimate choice of implant selection is to be balanced between the available literature information and the clinician's judgement about the quality and quantity of bone, biomechanics of the implant and type of final restoration.

REFERENCES

1Le Guéhennec L, Soueidan A, Layrolle P, Amouriq Y. Surface treatments of titanium dental implants for rapid osseointegration. Dental materials. 2007 Jul 1;23(7):844-54.

2McCracken M. Dental implant materials: commercially pure titanium and titanium alloys. Journal of prosthodontics. 1999 Mar;8(1):40-3.

3 Sabri R. Four single-tooth implants as supernumerary premolars in the treatment of diastemas and microdontia: Report of a case. Int J Oral Maxillofac Implants 1998;13: 706–709.

4 Knabe C, Hoffmeister B. The use of implant-supported ceramometal titanium prostheses following sinus lift and augmentation procedures: A clinical report. Int J Oral Maxillofac Implants 1998;13:102–108.

5 Balshi TJ, Wolfinger GJ, Balshi SF II. Analysis of 356 pterygomaxillary implants in edentulous arches for fixed prosthesis anchorage. Int J Oral Maxillofac Implants 1999;14: 398–406.

6 Mericske-Stern R. Treatment outcomes with implant-supported overdentures: Clinical considerations. J Prosthet Dent 1998;79:66–73.

7Le Guéhennec L, Soueidan A, Layrolle P, Amouriq Y. Surface treatments of titanium dental implants for rapid osseointegration. Dental materials. 2007 Jul 1;23(7):844-54.

8Wennerberg A, Albrektsson T. Suggested guidelines for the topographic evaluation of implant surfaces. Int J Oral Maxillofac Implants 2000; 15: 331–344.

9Brånemark P I. Introduction to osseointegration. In Brånemark P I (ed) Tissue integrated prostheses: osseointegration in clinical dentistry. pp 11–76. Chicago: Quintessence Publishing Co., 1985.

10 Cooper LF. Biologic determinants of bone formation for osseointegration: Clues for future clinical improvements. J Prosthet Dent 1998;80:439–449.

11Vaidya P, Mahale S, Kale S, Patil A. Osseointegration—a review. IOSR Journal of Dental and Medical Sciences. 2017;16(1):45-8.

12Cooper L F, Masuda T, Whitson S W, Yliheikkilä P, Felton D A. Formation of mineralizing osteoblast cultures on machined, titanium oxide grit-blasted, and plasma-sprayed titanium surfaces. Int J Oral Maxillofac Implants 1999; 14: 37–47.

13Donath K, Laaß M, Günzl H J. The histopathology of different foreign-body reactions in oral soft tissue and bone tissue. Virchows Archiv A Pathol Anat Histopathol 1992; 420: 131–7.

14Esposito M, Hirsch J, Lekholm U, Thomsen P. Differential diagnosis and treatment strategies for biologic complications and failing oral implants: A review of the literature. Int J Oral Maxillofac Implants 1999;14:473–490.

15Donley T G, Gillette W B. Titanium endosseous implant-soft tissue interface: a literature review. J Periodontol 1991; 62: 153–160.

16Lacefield WR. Current status of ceramic coatings for dental implants. Implant Dent 1998; 7: 315–322.

17Lemons J. Dental implant biomaterials. J Am Dent Assoc 1990; 121: 716–719.

18Meijer G, Heethaar J, Cune M, De Putter C, Van Blitterswijk C. Flexible (Polyactive) versus rigid (hydroxyapatite) dental implants. Int J Oral Maxillofacial Surg 1997; 26: 135–140.

19Ivanoff C-J, Sennerby L, Johansson C, Rangert B, Lekholm U. Influence of implant diameters on the integration of screw implants: An experimental study in rabbits. Int J Oral Maxillofac Surg 1997; 26: 141–148.

20Dalby M J, Andar A, Nag A et al. Genomic expression of mesenchymal stem cells to altered nanoscale topographies. J R Soc Interface 2008; 5: 1055–65.

21Junker R, Dimakis A, Thoneick M, Jansen J A. Effects of implant surface coatings and composition on bone integration: a systematic review. Clin Oral Implants Res 2009; 20(Suppl 4): 185–206.

22 Buser D, Schenk R, Steinemann S, Fiorellini J, Fox C, Stich H. Influence of surface characteristics on bone integration of titanium implants. A histomorphometric study in miniature pigs. J Biomed Mater Res 1991;25:889–902.

23 Ong JL, Carnes DL, Bessho K. Evaluation of titanium plasma-sprayed and plasma-sprayed hydroxyapatite implants in vivo. Biomaterials 2004;25:4601–6.

24MacDonald D E, Rapuano B E, Deo N, Stranick M, Somasundaran P, Boskey A L. Thermal and chemical modification of titaniumaluminumvanadium implant materials: effects on surface properties, glycoprotein adsorption, and MG63 cell attachment. Biomaterials 2004; 25: 3135–3146

25Braceras I, De Maeztu M A, Alava J I, Gay-Escoda C. In vivo low-density bone apposition on different implant surface materials. Int J Oral Maxillofac Surgery 2009; 38: 274–278.

26Le Guéhennec L, Soueidan A, Layrolle P, Amouriq Y. Surface treatments of titanium dental implants for rapid osseointegration. Dent Mater 2007; 23: 844–854.

27 Yokoyama K, Ichikawa T, Murakami H, Miyamoto Y, Asaoka K. Fracture mechanisms of retrieved titanium screw thread in dental implants. Biomaterials 2002;23:2459–65.

28Park J Y, Davies J E. Red blood cell and platelet interactions with titanium implant surfaces. Clin Oral Implants Res 2000; 11: 530–539.

29Ogiso M, Tabata T, Ichijo T, Borgese D. Examination of human bone surrounded by a dense hydroxyapatite dental implant after long-term use. J Long term Eff Med Implants 1991; 2: 235–247.

30Biesbrock A R, Edgerton M. Evaluation of the clinical predictability of hydroxyapatite-coated endosseous dental implants: a review of the literature. Int J Oral Maxillofac Implants 1995; 10: 712–720.

31Vercaigne S, Wolke J G, Naert I, Jansen JA. A histological evaluation of TiO2-gritblasted and Ca-P magnetron sputter coated implants placed into the trabecular bone of the goat: part 2. Clin Oral Implants Res 2000; 11: 314–324.

32Gan L, Wang J, Tache A, Valiquette N, Deporter D, Pilliar R. Calcium phosphate solgelderived thin films on porous-surfaced implants for enhanced osteoconductivity. Part II: short-term in vivo studies. Biomaterials 2004; 25: 5313–5321.

33Galli C, Guizzardi S, Passeri G et al. Comparison of human mandibular osteoblasts grown on two commercially available titanium implant surfaces. J Periodontol 2005; 76: 364–372.

34 Sul YT, Johansson CB, Roser K, Albrektsson T. Qualitative and quantitative observations of bone tissue reactions to anodised implants. Biomaterials 2002;23:1809–17.

35 Rocci A, Martignoni M, Gottlow J. Immediate loading of Branemark System TiUnite and machined-surface implants in the posterior mandible: a randomized open-ended clinical trial. Clin Implant Dent Relat Res 2003;5:S57–63.

36Ellingsen J E, Johansson C B, Wennerberg A, Holmén A. Improved retention and bone-to implant contact with fluoride-modified titanium implants. Int J Oral Maxillofac Implants 2004; 19: 659–666.

37 Lamolle SF, Monjo M, Rubert M, Haugen HJ, Lyngstadaas Sp, Ellingsen JE. The effect of hydrofluoric acid treatment of titanium surface on nano-structural and chemical changes and the growth of MC3T3-E1 cells. Biomaterials 2009; 30: 736-742.

38Schade R, Sikiri M D, Lamolle S et al. Biomimetic organic – inorganic nanocomposite coatings for titanium implants in vitro and in vivo – biological testing. J Biomed Mater Res A 2010; 95: 691–700.

39Guarnieri R, Placella R, Testarelli L, Iorio-Siciliano V, Grande M. Clinical, radiographic, and esthetic evaluation of Immediately loaded laser microtextured implants placed into fresh extraction sockets in the anterior maxilla: a 2-Year retrospective multicentric study. Implant Dent 2014; 23: 144–154.

40Josse S, Faucheux C, Soueidan A et al. Novel biomaterials for bisphosphonate delivery. Biomaterials 2005; 26: 2073–2080.

41Mundy G, Garrett R, Harris S et al. Stimulation of bone formation in vitro and in rodents by statins. Science 1999; 286: 1946–1949.

42Ayukawa Y, Okamura A, Koyano K. Simvastatin promotes osteogenesis around titanium implants. Clin Oral Implants Research 2004; 15: 346–350.

43Yang F, Zhao S F, Zhang F, He F M, Yang G L. Simvastatin-loaded porous implant surfaces stimulate preosteoblasts differentiation: an in vitro study. Oral Surg Oral Med Oral Path Oral Radiol Endod 2011; 111: 551–556.

44Herr Y, Woo J, Kwon Y, Park J, Heo S, Chung J. Implant surface conditioning with tetracycline-HCl: a SEM study. Key Eng Mater 2008; 361: 849–852.

45Petzold C, Monjo M, Rubert M et al. Effect of proline-rich synthetic peptide-coated titanium implants on bone healing in a rabbit model. Int J Oral Maxillofac Implants 2013; 28: e547–555.

46Valentine-Thon E, Schiwara HW. Validity of MELISA for metal sensitivity testing. Neuro Endocrinol Lett 2003;24:57–64.

47Bianco PD, Ducheyne P, Cuckler JM. Local accumulation of titanium released from a titanium implant in the absence of wear. J Biomed Mater Res 1996;31:227–234.

48Weingart D, Steinemann S, Schilli W, et al. Titanium deposition in regional lymph nodes after insertion of titanium screw implants in maxillofacial region. Int J Oral Maxillofac Surg 1994;23:450–452.

49 Sennerby L, Dasmah A, Larsson B, Iverhed M: Bone tissue responses to surface-modified zirconia implants: A histomorphometric and removal torque study in the rabbit. Clin Implant Dent Relat Res 2005, 7(Suppl 1):S13-20

50Wenz HJ, Bartsch J, Wolfart S, Kern M. Osseointegration and clinical success of zirconia dental implants: a systematic review. International Journal of Prosthodontics. 2008 Jan 1;21(1).