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Implant surface modification: review of literature

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Abstract

The attachment of cells to titanium surfaces is an important phenomenon in the area of clinical implant dentistry. A major consideration in designing implants has been to produce surfaces that promote desirable responses in the cells and tissues. To achieve these requirements, the titanium implant surface can be modified in various ways. This review mainly focuses on the surface topography of dental implants currently in use, emphasizing the association of reported variables with biological outcome

INTRODUCTION

Major advances have occurred over the last 3 decades in the clinical use of oral and maxillofacial implants. Statistics on the use of dental implant reveals about 100,000 to 300,000 dental implants are placed per year, [1] which approximates the numbers of artificial hip and knee joints placed per year [2] . Implants are currently used to replace missing teeth, rebuild the craniofacial skeleton, provide anchorage during orthodontic treatments, and even to help form new bone in the process of distraction osteogenesis.

Despite the impressive clinical accomplishments with oral and maxillofacial implants—and the undisputed fact that implants have improved the lives of millions of patients—it is nevertheless disquieting that key information is still missing about fundamental principles underlying their design and clinical use. With some important exceptions, the design and use of oral and maxillofacial implants has often been driven by an aggressive, “copycat” marketing environment, rather than by basic advances in biomaterials, biomechanics, or bone biology.

CONTROLLING THE BONE IMPLANT INTERFACE BY BIOMATERIAL SELECTION AND MODIFICATION

Different approaches are being used in an effort to obtain desired outcomes at the bone-implant interface. As a general rule, an ideal implant biomaterial should present a surface that will not disrupt, and that may even enhance, the general processes of bone healing, regardless of implantation site, bone quantity, bone quality. As described by Ito et al [3] the approaches can be classified as physicochemical, morphologic, or biochemical.

Physicochemical Method: [456] . This method mainly involves the alteration of surface energy, surface charge, and surface composition with the aim of improving the bone-implant interface. The method employed is glow discharge method which increases the cell adhesion properties. The role of electrostatic interaction in biological events mainly proposed to be as conducive to tissue integration. But on the contra lateral side it has been found that it does not help in adhering selective cells/tissues and it has not been shown to increase bone implant interfacial strength.

Morphological methods: It mainly deals with alteration of surface morphology and roughness to influence cell and tissue response to implants. Many animal studies support that bone in growth into macro rough surfaces enhances the interfacial and shear strength. [7] In addition to that, surfaces with specially contoured grooves can induce contact guidance [8] whereby direction of cell movement is affected by morphology of substrate. This has got added advantage as it prevents the epithelial down growth on dental implants [9] .

Two categories of surface characteristics [6] commonly cited for determining tissue response are:

Surface topography/ morphological characteristics

Chemical properties.

Surface topography: Surface topography can produce orientation and guide locomotion of special cells and has the ability to directly affect shape and function of them.

A. Wennerberg and coworker [10] have classified implant surfaces as:

1.) Minimally rough (0.5-1µm)

2.) Intermediately rough (1-2µm)

3.) Rough (2-3µm)

B. Based on texture obtained

1.) Concave texture (mainly by additive treatments like HA coating and titanium plasma spraying)

2.) Convex texture (mainly by subtractive treatment like etching and blasting)

C. Based on orientation of irregularities [11]

1.) Isotopic surfaces: have the same topography independent of measuring direction.

2.) Anisotropic surfaces: have clear directionality and differ considerably in roughness.

Advantages of increased roughness:

Increased surface area of implant adjacent to bone

Improved cell attachment to bone

Increased bone present at implant interface

Increased biochemical interaction of implant with bone

METHODS TO INCREASE SURFACE ROUGHNESS

Blasting [12] : Blasting with particles of various diameters is one of the frequently used method of surface alteration.

It is mainly done by Al_2O_3 [68] and TiO_2 with particle size ranging from small, medium to large grit. Roughness depends upon particle size, time of blasting, pressure and distance from the source of particle to the implant surface.

Advantages:

Studies have shown that it allows adhesion, proliferation and differentiation of osteoblasts [52] and also it has been found that fibroblasts adhere to the surface with difficulty and hence could limit soft tissue proliferation [13] and increase bone formation.

Key facts:

Al_2O_3 particles are left after blasting. Studies have shown mixed results regarding its presence, in some it has been shown to have catalyzing Osseointegration [14] and in some it has been shown to impair bone formation by a possible competitive action on calcium ions.

CHEMICAL ETCHING:

Metallic implant is immersed into an acidic solution, which erodes its surface, creating pits of specific diameter and shape [15] .

Concentration of acidic solution, time and temperature are factor determining the result of chemical attack and microstructure of the surface.

Dual acid etched technique [16] : Proposed to produce a micro texture rather than macro texture.

Advantages:

Higher adhesion and expression of platelet and extracellular genes even which helps in colonization of osteoblasts at the site and promote osseointegration.

Sandblasted and acid etched: Surface is produced by a large grit 250-500µm blasting process followed by etching with hydrochloric/sulfuric acid. The main objective is sandblasting results in surface roughness and acid etching leads to micro texture and cleaning [171819] . These surfaces are known to have better bone integration as compared to the rest of the surfaces stated.

Porus surfaces: These are produced when spherical powder of metallic/ceramic material becomes coherent mass with the metallic core of implant body [10] . These are characterized by pore size, shape, volume and depth which are affected by size of spherical particles and the temperature and pressure of the sintering chamber.

Advantages:

A secure 3-D interlocking interface with bone is observed

Predictable and minimal crestal bone remodeling

Short healing time

Provide space, volume for cell migration and attachment and thus support contact osteogenesis

Plasma sprayed surfaces [2063] : This process involves the heating of hydroxyapatite by a plasma flame at a temp of approx 15000-20000K. Then HA is propelled on to the implant in an inert environment like argon to a thickness of about 50-100µm.

Advantages:

Reported to increase the surface area of bone implant interface and act similarly to 3D surface, which may stimulate adhesion osteogenesis

Surface area to increase by 600%

Increases tensile strength of bone implant interface [21]

Improves primary stability

Ion-sputtering coating [6162] : It is the process by which a thin layer of HA can be coated on to an implant substrate. This is done by directing a beam of ion onto an HA block which vaporized to create plasma and then re condensing this plasma on to implant.

Anodized surface: Oxidation process can be used to change the characteristic of oxide layer and make it more biocompatible. This is done by applying a voltage on the titanium implant immersed in electrolyte. This results in a surface with micropores of variable diameter and demonstrates lack of cytotoxicity and increased cell attachment and proliferation [22] .

Hydroxyapatite coating [5455565758] : HA coating was brought to dental profession by De Groot [23] .

Indication:

For type 4 bone

Fresh extraction sites

Newly grafted sites

Advantages:

HA coating can lower the corrosion rates of same substrate alloys

HA coating can be credited with enabling to obtain improved bone implant attachment [2425]

Have higher success rates in maxilla

Being osteoconductive in nature, more bone deposited is noted.

Disadvantages [60] :

Delamination of coating leads to failure of implant [26] .

Dissolution/ fracture of HA coating results in failure.

Predisposes to plaque retention.

VARIOUS METHODS OF COATING:

Functionally graded coating [51] : The main disadvantage of plasma spraying coating is Delamination. But this disadvantage is overcome by the use of HA along with Ti6Al4V. [27] The coating becomes mechanically strong, bioinert and biocompatible.

Antibiotic coating: Gentamycin along with the layer of HA can be coated onto the implant surface. Gentamycin acts as a local prophylactic agent along with the systemic antibiotics in dental implant surgery.

Laser ablation technique [294565] : To control the morphology of coating of HA i.e. either crystalline or amorphous, this technique is best suited.

Pulsed laser deposition [3043] : Latest method of coating HA on to an implant surface. HA is deposited on to pure Ti substrates at 400 [[[o]]] C in water vapour and oxygen atmosphere, the pressure valve in the range of 3.5 .10 $_1$ -10 $_1$ torr.

Sputtering [424964] : it is a process whereby, in a vacuum chamber, atoms or molecules of a material are ejected from a target by bombardment of high energy ions. The dislodged particles are deposited on a substrate also placed in a vacuum chamber. There are various sputtering techniques like diode sputtering ion sputtering, radiofrequent/direct current sputtering, magnetron sputtering and reactive sputtering. All these techniques are variant of above mentioned physical phenomenon. However an inherent disadvantage is deposition rate is very slow. The key advantages are:

high deposition rates.

Ease of sputtering of the most of the materials.

High purity films.

Extremely high adhesion of the films.

Excellent coverage of highly difficult surface geometry.

Ability to coat heat sensitive substrates.

Ease of automation and excellent uniform layers.

Ratio frequency sputtering(RF) Technique: This technique involves the deposition of HA in thin films [28474853] . Studies have shown that these coating are more retentive and chemical structure is precisely controlled. The other major advantage of this technique is that the design of implant particularly threaded implant is maintained.

Magnetron sputtering [4250] : This technique shows strong HA titanium bonding associated with outward diffusion of Ti in to HA layer forming TiO_2 at an interface.

SURFACE CHEMISTRY/ CHEMICAL TOPOGRAPHY

Commercially pure titanium and Ti-6Al-4V are commonly used dental implant materials, although new alloys containing niobium, iron, molybdenum, manganese and zirconia are developed.

Biomaterial surface interacts with water, ions and numerous biomolecules after implantation. The nature of these interaction such as hydroxylation of the oxide surface by dissociative adsorption of water, formation of an electrical double layer and protein adsorption and denaturation, determine how cells and tissues respond to the implant.

Biochemical method [34353637383940] : These methods offer an alternative/adjunct to physiochemical and morphological methods. This method mainly endeavors to utilize current understanding of biology and biochemistry of cellular function and differentiation.

The goal of biochemical surface modification is to immobilize proteins, enzymes/ peptides on biomaterial for the purpose of inducing specific cells and tissue response or in other words to control the tissue implant interface with molecules delivered directly to the interface [66] .

Two main approaches have been suggested to achieve the above stated goal:

First approach mainly directed to control cell-biomaterial interaction utilizing cell adhesion molecules [59] . A particular sequence i.e. Arg-Gly-Asp(RGD) has been known as mediator of attachment of cells to several plasma and extracellular matrix proteins including osteopontin, bone sialoprotein, fibronectin etc. researchers are trying to deposit this particular sequence on to implant to modulate the interface.

Second approach mainly deals with the biomolecules with demonstrated osteotropic effects. Molecules like interleukin, growth factor 1 and 2, platelet growth factor, BMP etc are known to have this effect.

SUMMARY

Dental implants are valuable devices for restoring lost teeth. Implants are available in many shapes, sizes and length using a variety of materials with different surface properties. Among the most desired characteristics of an implant are those that ensure that implant-tissue interface will be established quickly and can be maintained. Because many variables affect oral implant, so it is difficult to assess whether various modification in the latest implant deliver improved performance.

The continuing search for osseoattractive implants is leading to surface modification involving biological molecules [41] . By attaching these molecules desired cell and tissue response can be obtained. In future, similar approaches may also be used to promote interaction of mucosal and sub mucosal tissues with dental implant.

References

1. Dunlap J. Implants: Implications for general dentists. Dent Econ 78:101–112,1988
2. Graves E. Vital and Health Statistics, Detailed Diagnoses and Procedures, National Hospital Discharge Survey, 1993. Hyattsville, MD: National Center for Health Statistics, 1995
3. Ito Y, Kajihara M, Imanishi Y. Materials for enhancing cell adhesion by immobilization of cell-adhesive peptide. J Biomed Mater Res 25:1325–1337,1991
4. Baier RE, Meyer AE. Implant surface preparation. Int J Oral Maxillofac Implants 3:9–20,1998.
5. Krukowski M, Shively RA, Osdoby P, Eppley BL. Stimulation of craniofacial and intramedullary bone formation by negatively charged beads. J Oral Maxillofac Surg 48:468-475,1990
6. David A. Puleo, Mark V. Thomas: Implant Surfaces. Dent Clin N Am 50:323–338, 2006
7. Wennerberg Ann, Albrektsson: Suggested Guidelines for the Topographic Evaluation of Implant Surfaces. Int J Oral Maxillofac Implants 15: 331–344, 2000
8. Brunette DM. The effects of implant surface topography on the behavior of cells. Int J Oral Maxillofac Implants 3:231–46,1988.
9. Eric Rompen, Olivier Domken: The effect of material characteristics, of surface topography and of implant components and connections on soft tissue integration: a literature review. Clin. Oral Imp. Res. 17 (Suppl. 2):55–67, 2006
10. Nikitas Sykaras, Anthony M. Iacopino, Victoria A. Marker: Implant Materials, Designs, and Surface Topographies: Their Effect on Osseointegration. A Literature Review Int J Oral Maxillofac Implants 15:675–690, 2000
11. Brunette DM. The effects of implant surface topography on the behavior of cells. Int J Oral Maxillofac Implants 3:231–246,1998
12. Cochran DL, Nummikoski PV, Higginbottom FL, Hermann JS, Makins SR, Buser D. Evaluation of an endosseous titanium implant with sandblasted and acid-

etched surface in the canine mandible: Radiographic results. Clin Oral Implants Res 7:240–252,1996
13. Bowers KT et al. Optimization of surface micromorphology for enhanced osteoblast responses invitro. Int J Oral Maxillofac Implants 7:302-310,1992
14. Wennerberg A et al. bone tissue response to commercially pure titanium implants blasted with fine and course particles of aluminium oxide. Int J Oral Maxillofac Implants 11:38-45,1996
15. Giovanna Orsini, Bartolomeo Assenza: Surface Analysis of Machined Versus Sandblasted and Acid-Etched Titanium Implants. Int J Oral Maxillofac Implants 15:779–784, 2000
16. Klokkevold et al: early endosseous integration enhanced by dual acid etching of titanium: a torque removal study in the rabbit. Clin Oral Implants Res 12:350-357,2001
17. Galli C et al. comparison of human mandibular osteoblasts grown on two commercially available titanium implant surfaces. J Periodontol 76:364-372,2005
18. Buser D , Nydegger T et al . removal torque values of titanium implants in the maxillae of miniature pigs. Int J Oral Maxillofac Implants 13:611-619,1998
19. Cochran DL, Schenk RK, LussiA et al. bone response to unloaded and loaded titanium implant with a sandblasted and acid etched surface: a histometric study in the canine mandible. J Biomed Mater Res 40:1-11,1998
20. Hahn H, Palich W. Preliminary evaluation of porus meta surfaced titanium for orthopedic implants. J Biomed Mater Res 45:71-77,1970
21. Schroeder A, Van der Zypen E, Stich H et al. the reactions of bone, connective tissue and epithelium to endosteal implants with titanium sprayed surface. J Maxillofac Surg 9:15-25,1981
22. Zhu X, Chen J, Scheideler L et al. effect of topography and composition of titanium surface oxides on osteoblasts response. Biomaterials 25:4087-4103,2004
23. De Groot et al. plasma sprayed coating of hydroxyapatite. J Biomed Mater Res 21:1375-1381,1987
24. Strnad, Jakub Strnad, Karel Urban: Effect of Plasma-Sprayed Hydroxyapatite Coating on the Osteoconductivity of Commercially Pure Titanium Implants. Int J Oral Maxillofac Implants 15:483–490, 2000
25. Vercaigne S, Wolke JGC et al: Bone healing capacity of titanium plasma sprayed and hydroxylapatite coated oral implants: Clin. Oral Imp. Res 9:261-271,1998
26. Schwartz-AradD, Mardinger O, Levin L et al: marginal bone loss pattern around hydroxyapatite coated aresus commercially pure titanium implants after up to 12 years to follow up. Int J Oral Maxillofac Implants 20:238-244, 2005
27. Filiaggi MJ, Pillar RM, Coombs NA:characterization of the interface in the plasma sprayed HA coating/ Ti-6Al-4V implant system. Biomaterials 25:4601-4606,2004
28. Carl E Misch. Contemporary Implant Dentistry(ed 3) Mosby, 2008 p 614
29. Park CY, Kim SG, Kim MD et al. Surface properties of endosseous implants after NdYAg and CO2 laser treatment at various energies. J Oral Maxillofac Surg 63:1522-1577,2005
30. Roxana M. Piticescu et al. Biocompatibility of hydroxyapatite thin films obtained by pulsed laser deposition. Rev.Adv.Mater.Sci 8:164-169, 2004
31. Carlsson LV, Albrektsson T, Berman C. Bone response to plasma-cleaned titanium implants. Int J Oral Maxillofac Implants 4(3):199–204,1989
32. Lavos-Valereto IC, Costa I, Wolynec S. The electrochemical behavior of Ti-6Al-7Nb alloy with and without plasma-sprayed hydroxyapatite coating in Hank's solution. J Biomed Mater Res 63(5):664–70,2002
33. Yu SR, Zhang XP, He ZM, et al. Effects of Ce on the short-term biocompatibility of Ti-Fe-Mo-Mn-Nb-Zr alloy for dental materials. J Mater Sci Mater Med 15(6):687–91,2004.
34. Narong Lumbikanonda, Rachel Sammons: Bone Cell Attachment to Dental Implants of Different Surface Characteristics. Int J Oral Maxillofac Implants 16:627–636, 2001
35. Dietmar Sonnleitner, Peter Huemer: A Simplified Technique for Producing Platelet-Rich Plasma and Platelet Concentrate for Intraoral Bone Grafting Techniques: A Technical Note. Int J Oral Maxillofac Implants 15:879–882, 2000
36. Galante JO, Jacobs J. Clinical performances of ingrowth surfaces. Clin Orthop 276:41–49,1992
37. Puleo DA. Biochemical surface modification of Co-Cr-Mo. Biomaterials 17:217–222,1996
38. John B. Brunski, Aquilante F. Moccia et al: The Influence of Functional Use of Endosseous Dental Implants on the Tissue-Implant Interface. I. Histological Aspects. J Dent Res 58(10):1953-1969, October 1979
39. Mohan S, Baylink DJ. Bone growth factors. Clin Orthop 263:30–48,1991
40. Dee KC, Rueger DC, Andersen TT, Bizios R. Conditions which promote mineralization at the bone-implant interface: A model in vitro study. Biomaterials 17:209–215,1996
41. Cochran DL, Schenk R, Buser D, et al. Recombinant human bone morphogenetic protein-2 stimulation of bone formation around endosseous dental implants. J Periodontol 70(2):139–50,1999.
42. Jasen, Wolke et al: application of magnetron sputtering for producing ceramic coatings on implant material: Clin. Oral Imp. Res 4:28-34,1993
43. Olivier Blind, Lorena H. Klein et al: Characterization of hydroxyapatite films obtained by pulsed-laser deposition on Ti and Ti-6Al-4V substrates: Biomaterials 21:1017-1024,2005
44. Fernandez-Pradas JM, Cle`ries L, Martinez E, Sardin G, Esteve J, Morenza JL. Influence of thickness on the properties of hydroxyapatite coatings deposited by KrF laser ablation. Biomaterials 22:2171–2175,2001
45. Guillot O, Gomez-San Roman R, Perrie`re J,Hermann J, Craciun V, Boulmer-Leborgne C, et al. Growth of apatite films by laser ablation: reduction of the droplet a real density. J Appl Phys 80(3):1803–8,1996
46. Tong W, Yang Z, Zhang X, Yang A, Feng J, Cao Y, et al. Studies on diffusion maximum in X-ray diffraction patterns of plasma-sprayed hydroxyapatite coatings. J Biomed Mater Res 40:407–413,1998
47. Ong JL, Bessho K, Cavin R, Carnes DL. Bone response to radio frequency sputtered calcium phosphate implants and titanium implants in vivo. J Biomed Mater Res 59:184–90,2002
48. Wolke JGC, de Groot K, Jansen JA. In vivo dissolution behavior of various RF magnetron sputtered Ca-P coatings. J Biomed Mater Res 39:524–30,1998.
49. Porter AE, Rea SM, Galtrey M, Best SM, Barber ZH. Production of thin film silicon-doped hydroxyaptite via sputter deposition. J Mater Sci 39:1895–1898,2004
50. Wolke JGC, van Dijk K, Schaeken HG, de Groot K, Jansen JA. Study of the surface characteristics of magnetron-sputter calcium phosphate coatings. J Biomed Mater Res 28:1477–1484,1994.
51. Kanasniemi IMO, Verheyen CCPM, van der Velde EA, de Groot. In vivo tensile testing of fluorapatite and hydroxylapatite plasma sprayed coatings. J Biomed Mater Res 28:563–72,1994
52. Aparicio C, Gil FJ, Planell A. Human-osteoblast proliferation and differentiation on grit-blasted and bioactive

titanium for dental applications. J Mater Sci Mater Med 13:1105–11,2002
53. F. J. Kummer, J. L. Ricci, and N. C. Blumenthal, ‘‘RF plasma treatment of metallic implant surfaces,’’ J.Appl. Biomater.,3:39–44 ,1992.
54. B. Kasemo: Biocompatibility of titanium implants: Surface science aspects,’’ J. Prosthet. Dent., 49, 832–837,1983
55. Ducheyne P, Van Raemdonck W, Heughebaert JC, Heughebaert M. Structural analysis of hydroxyapatite coatings on titanium. Biomaterials 7: 97,1986
56. Manley MT, Koch R. Clinical results with the hydroxyapatite- coated omnifit hip stem. Dent Clin N Am 36(l): 257, 1992
57. Denissen HW, Kalk W, Veldhuis A H, van der Hooff A. Eleven years of study of hydroxyapatite implants. J Prosthet Dent 61(6): 706,1989
58. Gross, K.A., Berndt, C.C., Goldschlag, D.D. & Iacono, V.J. In vitro changes of hydroxyapatite coatings. Int J Oral Maxillofac Implants 12: 589– 597,1997
59. M. Yoshinari et al. Immobilization of bisphosphonates on surface modi"ed titanium. Biomaterials 22 :709-715,2001
60. Yoshinari M, Watanabe Y, Ohtsuka Y, DeHrand T. Solubility control of thin calcium-phosphate coating with rapid heating. J Dent Res 76:1486-9,1997
61. Yoshinari M, Klinge B, DeHrand T. The biocompatibility (cell culture and histologic study) of hydroxyapatite-coated implants created by ion beam dynamic mixing method. Clin Oral Impl Res 17:96-100,1996
62. Yoshinari M, Ohtsuka Y, DeHrand T. Thin hydroxyapatite coating produced by the ion beam dynamic mixing method. Biomaterials 15:529-35,1994
63. Gottlander, M., Johansson, C.B. & Albrektsson, T. Short- and long-term animal studies with a plasma-sprayed calcium phosphate-coated implant. Clin. Oral Imp. Res 8: 345–355,1997
64. Yang Y, Kim KH, Ong JL. A review on calcium phosphate coatings produced using a sputtering process—an alternative to plasma spraying. Biomaterials 26:327–37,2005
65. Cleries L, Martinez E, Fernandez-Pradas JM, Sardin G, Esteve J, Morenza JL. Mechanical properties of calcium phosphate coatings deposited by laser ablation. Biomaterials 21:967–71,2000.
66. Anselme K. Osteoblast adhesion on biomaterials. Biomaterials 21:667–81,2000
67. Ziats NP, Miller KM, Anderson JM. In vivo and in vitro interaction of cells with biomaterials. Biomaterials 9:5–13,1988
68. Ji H, Marquis PM. Preparation and characterization of Al2O3 reinforced hydroxyapatite. Biomaterials 13:744–8,1992
69. John B. Brunski et al Biomaterials and Biomechanics of Oral and Maxillofacial Implants: Current Status and Future Developments. Int J Oral Maxillofac Implants 15:17-46,2000

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