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: 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 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.8

Two categories of surface characteristics 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 \textsuperscript{10} have classified implant surfaces as:

1.) Minimally rough (0.5-1\(\mu\)m)
2.) Intermediately rough (1-2\(\mu\)m)
3.) Rough (2-3\(\mu\)m)

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 \textsuperscript{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** \textsuperscript{12} : Blasting with particles of various diameters is one of the frequently used method of surface alteration.

It is mainly done by Al\(_2\)O\(_3\) 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 \textsuperscript{13} and also it has been found that fibroblasts adhere to the surface with difficulty and hence could limit soft tissue proliferation \textsuperscript{13} and increase bone formation.

**CHEMICAL ETCHING:**

Metallic implant is immersed into an acidic solution, which erodes its surface, creating pits of specific diameter and shape \textsuperscript{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** \textsuperscript{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 250-500\(\mu\)m 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 \textsuperscript{17,18,19} . These surfaces are known to have better bone integration as compared to the rest of the surfaces stated.

**Porous surfaces:** These are produced when spherical powder of metallic/ceramic material becomes coherent mass with the metallic core of implant body \textsuperscript{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** \textsuperscript{20} : 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

Improves primary stability

Ion-sputtering coating: 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.

Hydroxyapatite coating: HA coating was brought to dental profession by De Groot.

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

Have higher success rates in maxilla

Being osteoconductive in nature, more bone deposited is noted.

Disadvantages:

Delamination of coating leads to failure of implant.

Dissolution/ fracture of HA coating results in failure.

Predisposes to plaque retention.

VARIOUS METHODS OF COATING:

Functionally graded coating: The main disadvantage of plasma spraying coating is Delamination. But this disadvantage is overcome by the use of HA along with Ti6Al4V. 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: To control the morphology of coating of HA i.e. either crystalline or amorphous, this technique is best suited.

Pulsed laser deposition: Latest method of coating HA on to an implant surface. HA is deposited on to pure Ti substrates at 400°C in water vapour and oxygen atmosphere, the pressure valve in the range of 3.5-10⁻¹ torr.

Sputtering: 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.
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Ratio frequency sputtering (RF) Technique: This technique involves the deposition of HA in thin films. Studies have shown that these coatings 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: This technique shows strong HA titanium bonding associated with outward diffusion of Ti in to HA layer forming TiO2 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: 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.

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. 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. 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

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