Surface Modification of Dental Implants - A Review

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ABSTRACT

The use of dental implants for the replacement of missing teeth has increased in the last 30 years. The success rates for implant placement depend on a series of both biological and clinical steps which starts with primary stability that is being provided by the amount, quality and the distribution of bone within the proposed implant site. The most important factor in implant osseointegration is surface roughness, which shows increased osteoblast activity at 1 to 100 μm of the surface roughness when compared to a smooth surface. Rough surfaces have excellent osseointegration than smooth surfaces, but the results of research have been diverse, and it is evident that multiple treatments provide good results. The surfaces of a dental implant have been modified in several ways to improve its biocompatibility and speed up osseointegration. Literature says that any surface modification provides a good surface for osseointegration of the implant when the surface roughness is about 0.44 ~ 8.68 μm . It is also said that acid etching and coating are the most preferred methods for creating good roughness of the implant surface. From animal studies, it is known that implant surface modifications provided by biomolecular coating seemed to enhance the osseointegration by promoting peri-implant bone formation in the early stages of healing. It also seemed to improve histomorphometric analysis and biomechanical testing results. This article reviews the surface modifications of dental implants for the achievement of better success rates. Various methods are used to modify the topography or the chemistry of the implant surfaces which includes acid etching, anodic oxidation, blasting, treatment with fluoride, and calcium phosphate coating. These modifications provide a faster and a stronger osseointegration.¹ Recently, hydrophilic properties added to the roughened surfaces or some osteogenic peptides coated on the surfaces shows higher biocompatibility and have induced faster osseointegration compared to the existing modified surfaces. With development in surface engineering techniques, new information on the properties, behaviour, and the reaction of various materials could be discovered which in turn allows the discovery of new materials, modification techniques and design of bio implants for the future.

KEY WORDS

Dental Implants, Surface Modifications, Biocompatibility, Surface Topography

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BACKGROUND

Use of implants for oral and maxillofacial region continues to grow. Implants are used for several purposes which include, replacement of missing teeth, rebuilding craniofacial skeleton, providing anchorage for orthodontic treatments and helping in the formation of bone in the process of osteogenesis. More than 220 brands of implants produced by 80 manufacturers have been known. With the various materials, the surface modification, shapes, lengths, and widths of the implants that are available, clinicians are able to choose from more than 2000 implants. This variety of options is good but it might complicate the selection of the correct implant based on sound evidence. The usage of metallic biomaterials for biomedical implants has been traced back from the 19th century.² In recent years, manufacturing and fabrication features of implants are of primary concern in biomaterial engineering.³ The selection of implants relies mainly on the proposed application.⁴ Despite the wide variety of metals and alloys that are available in the materials industry, only a few metals and alloys fit the requirements for development as bio implants. The commonly used metallic biomaterials are 316L stainless steel (316L SS),⁵ cobalt-based (Co-Cr) alloys,⁶ titanium and its alloys.⁷ Apart from these metals, NiTi,⁸ magnesium (Mg)⁹ and tantalum (Ta)¹⁰ which are known as the “miscellaneous material” implants are also becoming a potential candidate for developing into bioimplants.

Endosseous dental implants have created tremendous changes in the approach of dental care for patients with missing teeth. The success rates for implant occurs through a series of both clinical and biological steps which starts with stability that is provided by the amount, quality and distribution of bone.¹¹ After the implant placement a series of bone remodelling steps take place. Bone adaptation of an implant starts with the bone turnover at the interface. The clinical end point of this process is measured by the lack of signs and symptoms of aggressive chronic inflammation and an assessment of bone adapted to the interface of the dental implant which is determined radiographically. The long-term success rate of an implant depends on the enhanced osseous stability. In recent years, transmucosal dental implant or implant abutment interfaces has gained popularity. The mechanical and biological stability plays a major role in maintaining a sufficient volume of connective tissue with minimal inflammatory infiltrate and it is provided by design and the surfaces in the connective tissue and junctional epithelial environment. In order to increase the success rates of implant therapy, significant researches have been done on implant biomaterials.¹² The technologies has now evolved from a simple modification of the oxide surface to nano-scale modifications which forms a uniform and consistent surface. There are developing technologies to utilise the changes in surface chemistry to assist in the stability of osseous and transmucosal environment.¹³ This review discusses the surface modification of these implants.

THE TISSUE IMPLANT INTERFACE

The goal of research in the field of implantology is to design the implants that bring about controlled and rapid integration

into the surrounding tissues.¹⁴ Events that leads to the stability of an implant takes place mainly at the tissue-implant interface. Formation of the tissue-implant interface is complex process and requires a number of factors which includes the implant-related factors, such as materials, shapes, topography, and surface chemistry and the mechanical loading, surgical technique. Patient factors such as the quantity and quality of bone also matters. Dental implants must also interact with the epithelium and submucosal soft connective tissues in contrast to the orthopaedic prostheses, which are designed to interact with only the bone.

Following implant placement, events take place on the biological side as well as on the materials side. On the implant side, electrochemical events take place and cause the oxide layer to double or triple in its thickness. The electrochemical reactions cause biological ions such as calcium, phosphorus, and sulphur to get incorporated and there is release metal ions. Information about the metals released from dental implants are less when compared to other implant devices. On the biological side, water molecules and hydrated ions react with implant surface within nanoseconds.¹⁵ The presence of the substrate alters the organisation of water molecules. Hundreds of biomolecules from our body fluids interacts with the surface of the implant. A complex and a cascade of events takes place; during which smaller molecules replace high affinity molecules. There may be alteration in the orientation and conformation of these biomolecules due to their interaction with implant surface. With time, the cells will encounter an implant surface that should have been preconditioned with biomolecules. Formation of a peri implant soft tissue barrier is important for protection of the bone-implant interface from microbiological changes. Lack of a peri mucosal seal can cause apical migration of the epithelium and encapsulation of the root of the implant. The peri-implant mucosa forms a cuff-like barrier and adheres to the implant.¹⁶

IMPORTANT SURFACE CHARACTERISTICS OF IMPLANTS

Two surface characteristics are commonly cited as an important determinant for tissue responses.¹⁷ One which is the topographic or the morphological features of the implant while the other is the chemical properties. Independent studies of the topographic and chemical properties are confounded as the methods used to alter the surface morphology mostly leads to changes in surface chemistry.¹⁸ In the newer methods for altering the surface characteristics, great attention has been focused on the changes in surface roughness and chemistry.¹⁹

The surface topography describes surface of implants as “rough” or “smooth”. Terms like contact guidance and rugophilia have been used to describe the interaction between the tissue and textured implant surfaces.²⁰ Contact guidance is directional guidance provided by a substrate and rugophilia means “rough-loving”.²¹ Porous materials are examples of surface roughness and they allow growth of tissues into implants and enhance its integration.²² Researches on bioactive materials show that bone may grow into smaller pores and that the size and volume density of these

interconnections are critical considerations for proper blood circulation and extracellular liquid exchange.

The surface energy, charge and composition are physicochemical properties that can be manipulated to improve the interaction of implants with the surrounding cells and tissues of the site of implant placement.²³ Glow discharge treatment process is one which causes the materials to be exposed to ionized inert gas like argon.²⁴ During collisions with the substrate, high-energy species, “scrub” contaminants from the surface, thereby non saturating the surface bonds and increase the surface energy.²⁵ The higher surface energy will cause the adsorption of biomolecules, which in turn affects subsequent cell and tissue behaviour.²⁶

MACRO RETENTIVE FEATURES OF AN IMPLANT

Dental implants have one of the three important types of macro-retentive features: screw thread design (tapped or self-tapping), solid body press-fit designs and / or sintered bead technologies. These features enhance the initial implant stability and create a volumetric space for growth of bone into the implant. A notable biological property of bone is that it responds favourably to compressive forces but not to shear forces. The screw thread implants have been designed to achieve a compressive loading of the surrounding cortical or cancellous bone and the thread designs focuses on reducing the surrounding shear forces by reducing height of the thread profile and increasing the number of threads per unit area. This increases the strength of the implant body by increasing the amount of remaining wall thickness of the implant body.²⁷ The application of sintering technology to create a meshwork or sintered beads as a surface for bone to grow into, may increase the success rates of short implants which are less than 10 mm in length. This is applied to only dental implant systems with very short implants lengths.²⁸

MICRO RETENTIVE FEATURES OF AN IMPLANT

When an implant is placed there is a cascade of cellular processes that causes growth and differentiation of new bone along the surface of the biomaterial. Following the placement of the implant, the bone surrounding the implant undergoes necrosis, resorption and replacement. A mature haversian bone replaces woven like cell rich bone by remodelling.²⁹ The current goal is to provide enhanced osseous stability through micro-surface of the implants. These strategies can enhance the immigration of new bone (i.e., osteoconduction) by changes in the surface topography of the implant (i.e., surface roughness), biological methods that manipulate the type of cells that grow onto the implant surface and strategies to utilise the implant as a vehicle for local delivery of a bioactive coating.³⁰ The success rate of an implant is done by increasing the amount of bone that contacts the implant. In the design of a dental implant, it is assumed that greater the surface area, greater is the surface roughness of the implant which enhances the surface area and allows a greater area for load

transfer by the bone against the implant.³¹ Micromechanical features of the implant enhances the secondary integration which is bone growth, turnover and remodelling. Acid etching increases the roughness of the grit blasted surface of the implant and creates the potential for a nanometre-scale topography on top of the macroscale roughness thereby allowing bone to adapt to the surface under the elevated shear forces.³² The features of an implant design were thought to require diameter of pores to be 100 µm or greater for the ingrowth of bone although clinically, surface roughness may actually be much finer as on the nanoscale level.

SURFACE ROUGHNESS BY ACID ETCHING / BLASTING

Titanium implants acquire surface roughness by either grit blasting and etching or by blasting of the surface alone. A modification of the titanium dioxide grit blasted surface is done by hydrofluoric acid etching to create surface roughness on the blasted surface of the implant. The optimisation criteria requires the maintenance of the macro roughness caused by the blasting process and surface etching of the implant to influence the secondary osseointegration.³³

Currently there are two main, but interrelated approaches that can be checked to enhance bone adaptation to surface of dental implant.³⁴ These involve either the addition of biological mediators such as cell adhesion or bioactive peptides or creating reproducible nanoscale surface features.³⁵ Both the approaches improves the adaptation of the implant into the trabecular bone.³⁶ The addition of cell adhesion peptides or growth factors to the implant surface aids as a local drug delivery device.³⁷ The changes in the fibrin scaffold is key to the future of implant surface technology.³⁸ Modifying the titanium oxide surface requires placement of various configurations of peptide sequences which is present in the extracellular matrix proteins.³⁹ Manipulating the biological responses creates topographical features at a nanoscale level. Relevant features are at nanometre scale of the range of 1 – 100 nm in dimension. Researches state that the conventional Newtonian characteristics of materials are different for a nanomaterial that shows increased number of atoms at the surface and surface area and electron delocalisation.⁴⁰ At the nanoscale, molecular interactions implant can be targeted to cause certain cell level response.

SURFACE MODIFICATION TO REDUCE CORROSION

To be chosen as biomedical implants, the metals used for the implant must be compatible with the human body.⁴¹ The process of corrosion is the degradation of the material into its constituent atoms due to chemical reactions that happens between the materials and its surroundings. Corrosion causes changes in the unstable metal under the thermodynamic state of the material and electrochemical oxidation of metals in reaction with oxygen. Various metallic implants are known to have great resistance to corrosion which enhances the life of the implant. However, studies show that corrosion slowly takes place once a metal is implanted in the human bodies due

to electrochemical reactions. The internal environment of our body is tissue fluid which produces reactive interstitial fluid and responds ionically to the biomaterials due to the presence of water, chloride ions, sodium ions, plasma, proteins and amino acid present in the saliva. The metal ions from bioimplants cause not only serious infections and other health issues but also to the statutory authority in the biomedical industry.⁴² It is essential that the material of an implant undergoes a screening test to identify its performance in various environments.⁴³

There are three types of corrosion that can occur on the metallic surface of an implant: uniform corrosion, pitting corrosion and corrosion that occurs due to electrochemical or mechanical processes. Several techniques of surface modification have been identified to overcome and improve the performance of the implant due to internal corrosive human body surroundings. Several researches have been focused on the improvement of surface engineering tools to make the implants more bio functional and resistant to corrosion for superior mechanical properties. The techniques that are used include the deposition of a uniformly thin coating, development of a stable passivation oxide layer, ion beam processing and surface texturing.

The hydroxyapatite coating on the surface of the implant might start to degrade with time⁴⁴ which affects the behaviour of the metals. Before the development of a coating and surface treatment metals, a stable surface oxide layer on the passivated metal surface should be formed. This oxide layer plays an important role in corrosion resistance and changing the surface oxide layer through the release of metal ions.⁴⁵ The surface oxide layer has ability to change its composition due to the responses with the surfaces of living tissues and the metallic materials. The surface oxide layer on metallic implants plays a vital role in the biocompatibility.⁴⁶

Ion beam methods which is one of the surface modification techniques contributes in the alteration of metallic implant surfaces. This ion beam method improves the biocompatibility with wear resistance and corrosion resistance by the formation of an appetite layer such as titanium dioxide (TiO₂) and titanium nitride (TiN) film.⁴⁷ Ion implantation processes on the surface of the bio implants reduces the release of the metal ions thereby producing low friction coefficient which hardens the surface of the implant and eventually improve the wear tendency of the implant.⁴⁸ Several studies shows that implantation of oxygen and nitrogen ion show improved surface properties of the implant

In recent years, surface texturing method has been introduced to reduce corrosion, increase the biocompatibility and promote osseointegration of the implant.⁴⁹ Techniques such as acid etching, plasma spraying, electropolishing, anodic oxidation, and bioactive coatings can be used to enhance the interaction between bone and surface implants.⁵⁰ Rough surfaces of implants encourage bone healing and biocompatibility and promotes rapid integration of the implants.

CONCLUSIONS

The use of implants to replace missing teeth has progressed immensely over the past few years. Recent developments in

the area of surface technology aim to enhance the tissue surface interactions furthermore. One of the most desired characteristics of implants is the quick establishment of tissue implant interface and the firm maintenance of the same. Since many variables are associated with the success rates of the dental implants, it becomes difficult to predict the success rates of an implant. Current development in surface engineering techniques aims at gaining information on the properties, behaviour, and the reaction of various materials allowing the discovery of various new materials, modification of existing techniques and design of bio implants for the future.

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