Review Article

Rational Design and Characterization of Novel Dental Implant and Surfaces: Mucointegration with Enhanced Osseointegration

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ABSTRACT

An ideal implant system should retain all the favorable features of existing implants that contributed to high survival rates, and introduction of novel features to facilitate new clinical applications like better integration of the peri-implant soft tissue and a transmucosal interface that can accommodate deficiencies or changes in the peri-implant mucosa profile. Surface properties largely contribute to the biological and clinical performance of implants and abutments as long-term success rate of a dental implant system depends on its integration with the patient's soft and hard tissues. Numerous manufacturing methods and surface managements have been developed for regulating the surface micro-topography, nanostructures, and chemistry. Among all, implants prepared by anodization have shown significant long-standing clinical performance. This article describes a recent implant system in dentistry with collective surface chemistry, topography, nanostructure, color, and surface energy features that are likely to address few limitations of foregoing implant systems.

Key words: Anodization, dental implant system, mucointegration, osseointegration, soft-tissue attachment, surface chemistry

INTRODUCTION

Implants in dentistry have been well recognized for treating a wide range of patients with fixed as well as removable treatment modalities. Commonly used implant system comprises of two parts: An implant, that is, fixture and an abutment. A prosthetic screw secures the abutment to the implant, providing an anchor point for a dental restoration similar to a natural tooth root and crown.[1] The integration of a dental implant system with the soft and hard tissues of the patient determines its long-term success rate. Tissue integration and adhesion to the implant and abutment are primarily determined by implant design and the material surfaces that come into contact with the surrounding tissues.[2]

At the beginning of modern implant dentistry, implant surfaces that were unaltered after the machining process today are referred to as "turned" or "machined" implant surface. Realizing the surface characteristics of dental implants are important determinants of short and long term clinical performance.[3] In this day and age, dental implant systems have attained acceptable survival rates as a result of numerous researches and application in implant design, surface properties, and prosthetic options.[4] The body's reaction and subsequent tissue integration are influenced by surface chemistry, topography, surface charge, oxide layer thickness, and wettability. At every level, a perfect implant system requires optimum surfaces that balance biological, clinical, and aesthetical design criteria, that is, abutment, implant collar, and implant apex.[2]

To maintain peri-implant tissues, retain crestal bone levels, and produce a tight soft-tissue barrier against microorganisms, abutments should have a surface that allows for strong soft-tissue adhesion in the trans-mucosal zone.[5] The surface of the mucosa should be unfavorable to bacterial adhesion and abnormal biofilm development during the healing process.[6] The abutment should have minimal shine-through if the mucosa is thin.[7] For regulating surface microtopography, nanostructures, and chemistry, a variety of manufacturing methods and surface treatments have been developed. Anodized implants, in particular, have established outstanding durable performance and, as per recent analysis, had minimum failure rate in comparison to other surface treatments such as plasma-spraying, sand-blasting, and acid-etching.[8] This review demonstrates a new dental implant system with combined surface chemistry, topography, nanostructure, and color characteristics that welcome in a *New Era of Mucointegration combined with Osseointegration.*

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TITANIUM

In dentistry, titanium and its alloys are widely used for implants due to their capability to support and stimulate tissue generation as well as integration, at the same time it is biologically inert (great biocompatibility, low level of toxicity potential, and high resistance to corrosion). Furthermore, it has high strength and is highly reactive when in pure state. On interacting with oxygen, though, a superficial layer of titanium oxide (TiO_2) is formed, resulting in stabilized surface that allows osseointegration to take place.[9]

ANODIZATION

Anodization or anodic oxidation is an electrochemical procedure which results in formation of oxide layer on the implant surface. When an anodic current is transmitted to a titanium implant is immersed in an electrolyte, process parameters such as electrolyte composition, strength, and duration of current can be carefully controlled to fine-tune the roughness, nanostructure, and chemical composition of the surface in a single process. Anodization results in the development of a highly crystalline oxide with an increased number of hydroxyl groups, which, depending on the electrolyte, can absorb particular molecules such as magnesium, calcium, or phosphates.[3]

In fact, resulting properties directly influence (promote) the phenomenon occurring at the interface for implanted device and biological environment.[9]

Few studies reported the influence of anodization on soft-tissue reaction. Latest *in vitro* studies suggests that anodized-surfaces results in primary growth of fibroblasts and preosteoblasts, and also adhesion of epithelial cells and fibroblasts. It was found that a wider connective tissue attachment is formed in anodized surface when compared to machined titanium surfaces in a canine model. Another study reported a considerably lower adherence of oral streptococci on anodized surface than commercially pure titanium disks. Collectively, these outcomes suggests that anodized abutments could add to soft-tissue healing that directly will reduce bacterial adhesion.[10]

Some authors describe the novel abutment surface prepared by electrochemical anodization. The novel surface has similar roughness to machined abutments, but presenting regularly distributed nanostructures. Studies in both preclinical as well as clinical grounds indicate that various surface modifications that alter the titanium dioxide layer by producing a comparatively more nanoporous surface (pore diameter ≤ 100 nm) may encourage soft-tissue attachment by restrictive epithelial down growth and providing an elongated connective tissue seal. Moreover, *in vitro* experiments have indicated that titanium oxide nanostructures enhance cell adhesion, migration, proliferation, and collagen secretion ability of human gingival fibroblasts.[11] In a randomized clinical trial, it observed that the novel abutment surface yield significantly lower bleeding after 6 weeks and higher keratinized mucosa height after 2 years than standard machined titanium abutments.[12]

Sul *et al*. described anodization as a process that alters the topography and composition of implant surface by thickening of oxide layer.[13] Oxide thickness of about 600, 800, and 1000 nm had significantly higher removal torque values that did implants with oxide thickness of 17 and 200 nm indicating that oxide properties of titanium implants influence bone tissue reactions.[14]

Furthermore, the probability of failure of anodized implants is lower than for turned implants, reason being more no. of undercuts present in oxidized surface that may result in improved osseointegration.[8]

ADVANCES IN OSSEOINTEGRATION

Despite its biocompatibility, titanium's capacity to positively modify biological processes is limited since it cannot induce bone apposition on its own (osteoinduction). As a result, current research has focused on improving surface treatments to encourage early integration and, as a result, reduce overall treatment time. Wound healing around implants is similar to bone repair after a fracture or trauma. Osseointegration is similar to direct ossification after a fracture or trauma, except that osseointegration involves the union of bone to a foreign substance (implant surface) rather than bone to bone. Early events related with post-implant bleeding, such as vasoconstriction and clot retraction, are crucial for implant wound healing. It was revealed that biological components and the implant surface interact. Ion, lipid, and sticky macromolecule binding are examples of this (e.g., albumin, fibrin, and fibronectin). The adsorption of proteins on the implant surface is the first stage in osseointegration, which is immediately followed by platelet adhesion to the implant surface. Platelets release biological mediators such as chemotactic factors for osteogenic cells. As a result, it is evident that the surface qualities of the implant will have a significant impact on the onset of osseointegration.[15]

Entering the era of mucointegration: Developments in anodized surfaces of implant surfaces, with Xeal and TiUltra

Cellular behavior to dental implants is influenced by implant material's surface, chemical and physical properties (i.e., hydrophilicity, stiffness, porosity, roughness, and topography). Surface has an important role in healing time for osseointegration and, ultimately, the success of implant treatment. This is the reason for considering implant system's surface as one of the most crucial factor that affect dental implant success both long term and short term. "Smooth" surfaces with roughness values smaller than the "critical threshold" of Sa = 0.2 μm are often preferred for abutments.[16]

After evidences, showing the success of anodized implants, research has innovated the ways to further utilize this technology. All this led to introduction of most recent Xeal [Figures 1 and 2] and TiUltra [Figure 3] surfaces, which provides fully anodized implant-abutment system.

These developments thought further than just microroughness or osseointegration. They discovered ways through which chemistry, nanostructure and porosity/morphology could be made to enhance cell attachment, and, even that to every level, that is, from cortical and cancellous bone osseointegration with the implant to a soft-tissue mucointegration with the abutment.

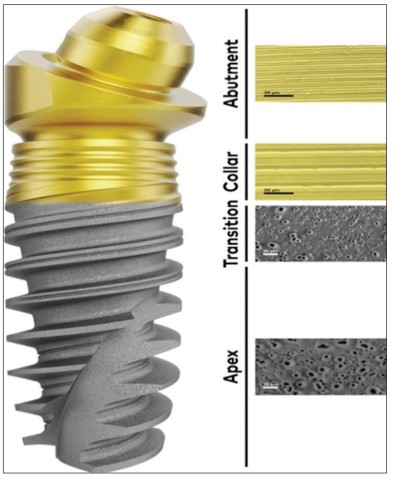

Figure 1: Xeal abutment surface: Smooth surface chemistry (Sa~0.2 μm) and non-porous, with enhanced surface chemistry, and a nanostructured oxide layer that results in a golden hue[3]

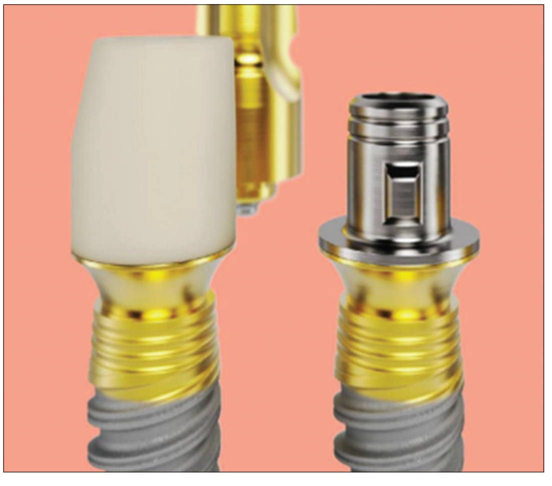

Figure 2: Xeal is a smooth, non-porous, nanostructured and anodized abutment surface. In this, dense soft-tissue contact with an abutment act as a barrier to underlying bone and is the foundation for long-term health and stability. The distinctive golden hue also presents a natural appearance in transmucosal zone

TiUltra implant collar: Minimally rough (Sa~0.5μm) and ultra-hydrophilic, with a nanostructured oxide layer.[3]

TiUltra implant body/apex: Moderately rough and ultra-hydrophilic, with gradual change in topography (from Sa~0.9 to 1.4 μm), and a low to high pore density.[3]

Surface for mucointegration process

The rapid formation of a soft-tissue seal at the abutment level is supposed to be one of the key requirements to aid in wound healing and to permit a healthy integration of the implant. Abutment should have a surface to allows close-fitting soft-tissue adaptation in the transmucosal zone to support peri-implant tissues, preservation of crestal bone, and creates a tight seal to prevent

Figure 3: TiUltra is an ultra-hydrophilic, multizone, anodized implant surface with gradual topography from collar to apex.[12] Gradual change in topography featuring minimally rough at the collar level (smooth surfaces reduce calculus formation), more rough and porous towards the implant apex (moderately rough surfaces exhibit the strongest bone response). TiUltra applied in the collar region features surface chemistry and topography that promote early osseointegration and are designed to support bone stability as clean implants with high surface free energy resembling an initial surface state show favorable tissue integration[3]

entry of microorganisms otherwise can lead to peri-implantitis and bone resorption culminating in dental implant failure.[17] Oxidized nanostructured titanium surfaces stimulate adhesion, proliferation, and extracellular matrix secretion of human gingival fibroblasts compared with machined surfaces.[3] With this in mind, Xeal's surface chemistry and topography were designed to promote soft tissue attachment. Furthermore, studies on Xeal abutments done in recent times showed consistently healthier mucosa in comparison to machined abutments.[18]

More than roughness: TiUltra implant surface

The coronal section of a dental implant is located in the dense cortical bone. It shall permit faster osseointegration along with minimal marginal bone loss. In addition, it shall allow a straight-forward exclusion of tissue and biofilm in the unlikely scenario that an exposed implant collar necessitates cleaning, in case of an infection.

The apical surface of a dental implant, which is located in cancellous bone, is a key driver of secondary stability. It shall thus be osteoconductive, to allow for faster osseointegration and also to support immediate-loading protocols.

CONCLUSION

Next-generation anodized surfaces for abutments and implants were designed by selecting specific surface modifications to justify clinical and biological needs. Modifications to improve quality and patient experience are virtuous, supplementing to that changes in surface chemistry, roughness, and color provides major improvements for newer generation of dental implants. The novel surfaces having specific chemistry and physical properties at every level of the implant could satisfy the needs associated to maintenance, aesthetics, and rapid and strong tissue integration maximize tissue biocompatibility with dental implants and reduce soft-tissue inflammation adjacent to abutment surfaces.[3]

Compared to the machined surface implants, moderately rough implant surfaces have shown to increase bone-implant contact and long-term survival.[19] However, these innovations provide enhanced dental improvement that will ultimately improve bone and soft-tissue health adjacent to dental implants still more clinical studies are necessary to confirm the effectiveness of this new implant-abutment system.

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