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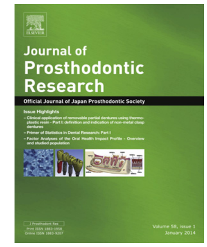

Review

A review of improved fixation methods for dental implants. Part I: Surface optimization for rapid osseointegration

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ABSTRACT

Purpose: Titanium is a primary metallic biomaterial used in load-bearing orthopedic or dental implants because of its favorable mechanical properties and osseointegration capability. This article reviews the current status of surface optimization techniques for titanium implants, whether such concepts are in the form of sufficiently evidence-based, and highlights the related experimental tools.

Study selection: A strong emphasis was placed on the enhanced biological responses to titanium implants by modifying the surface finishing process. On this basis, a clear partition of surface chemistry and topography was critical.

Results: The intrinsic host tissue response to titanium implants is facilitated by the chemistry or topography of a passive oxide film, although the extent to which the surface characteristics enable rapid osseointegration is still uncertain.

Conclusion: Besides the fundamental requirements, such as the promotion of osteogenic differentiation, the titanium implant surface should accelerate wound-healing phenomena prior to bone ingrowth toward the surface. Moreover, because initial bacterial attachment to the implant surface is unavoidable, infection control by surface modification is also an important determinant in reducing surgical failure. A desirable surface–biological relationship often needs to be characterized at the nanoscale by means of advanced technologies.

Contents

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1. Introduction

Titanium is the most prevalent material for use in orthopedic and dental implants because of its mechanical properties and intrinsic osteoconductivity, generally termed ‘‘osseointegration’’ [1,2]. Titanium's passive oxide layer imparts a distinctive resistance to corrosion, making it suitable for biomedical applications [3,4]. Over the past three decades, researchers such as Albrektsson et al. [2] have sought to create a superior biological response to titanium implants by modifying the surface finishing process (Fig. 1). More recently, the focus has shifted to biological activity associated with surface chemistry or topography [5–8]. Surface characteristics such as chemistry and topography have often been discussed in isolation, despite the fact that these characteristics are virtually inseparable, as the surface oxide layer is affected during mechanical processes such as sand blasting [9,10]. Additionally, the susceptibility of the passive oxide layer and its electroconductivity enables a range of surface modifications to be undertaken, such as titanium plasma-spraying, sandblasting, acid-etching, oxidation, and calcium phosphate coating, alone or applied in combination [7]. These surface modifications have usually been undertaken to promote osteogenic differentiation; however, to promote wound healing and osseointegration, it is highly desirable to enhance the antibacterial properties of the implant surface [11]. Moreover, these biological qualities need to be maintained over time. The key mechanism behind the degradation of biological function results from inactivation of titanium dioxide (TiO_2) over time [12–14]. This, in turn, impedes wound healing, osseointegration and antibacterial efficacy as a function of time. Current researchers have been developing a range of surface modification techniques to optimize titanium implants, and further research is required to fully elucidate the efficiencies and partition of surface characteristics such as surface chemistry and topography. In this context, this review tackles these issues, which have been overlooked for many years. We predict that scientists and clinicians alike will begin to adjust to the concept of current surface optimization techniques for titanium implants, whether such concepts are in the form of evidence-based research, and hope that young researchers may explore the new market in collaboration with clinicians.

2. Basic surface chemistry of the titanium passive oxide layer

Titanium forms a passive and protective surface oxide film when exposed to air or moisture. This TiO_2 film has surface free energy [14], which is a result of the electrostatic potential or hydrophilic functional groups on TiO_2. When TiO_2 comes into contact with water (or ambient atmosphere), the surface spontaneously generates hydrogen peroxide and its oxidation products, such as hydrophilic functional groups, because of trapped electron hole pairs (Ti^{4+} and e^-) within the TiO_2, according to the following equations [15,16]:

$$TiO_2 \rightarrow TiO_2\,(h_{vb} + e_{cb}) \quad (1)$$

$$h_{vb}{}^{+} + OH^{-} \rightarrow HO\bullet \quad (2)$$

$$e_{cb}{}^{-} + O_2 \rightarrow O_2\bullet \quad (3)$$

$$2O_2\bullet \rightarrow H_2O_2 + O_2 \quad (4)$$

$$H_2O_2 + e_{cb}{}^{+} \rightarrow HO\bullet + OH^{-} \quad (5)$$

The original surface chemistry of bare titanium is most likely associated with the equations above. The TiO_2 surface reacts under illumination (or even in the dark) to decompose surface organic impurities, reducing contamination of the titanium surface [14,17,18]. On this basis, TiO_2 has also been used in environmental pollution removal [19–21]. A superior decontamination function is often observed when the diameter of the particles is smaller, such as with nanoscale particles. This observation also implies an enhanced biological activity in nanotextured titanium implants related to the increase in the effective surface area [22,23].

2.1. *Surface hydrophilicity (wettability)*

Hydrophilic surfaces are more desirable than hydrophobic ones in view of their interactions with biological fluids, cells and tissues [7,24,25]. Therefore, researchers have trialed surface modification techniques to increase surface wettability [26]. Surface wettability is most likely related to surface energy and functional groups based on the five equations listed above, while micro- or nanotopography could also be a determinant in the apparent surface hydrophilicity or hydrophobicity (see Section 3) [27–29]. Pure surface hydrophilicity associated with surface chemistry needs to be investigated on an ideal flat sample surface. The most common approach when examining the surface wetting behavior of titanium is the sessile drop technique [30]. Briefly, a specific wetting liquid is placed on the titanium surface and the contact angle between the tangent of the dropped liquid and the horizontal baseline of the titanium samples is measured. The contact angles ranging from 0° to 180° characterize the extent of surface wettability (Fig. 2). For instance, a water contact angle