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UV-A and UV-C light induced hydrophilization of dental implants

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ARTICLE INFO

Article history:
Received 8 September 2014
Received in revised form
10 April 2015
Accepted 24 April 2015

Keywords:
Dental implants
Wettability
Roughness
Hydrophilicity
UV
Photocatalysis
Titanium
Anatase
Zirconia
PEEK

ABSTRACT

Objectives. Wettability is increasingly considered to be an important factor determining biological responses to implant materials. In this context, the purpose of this study was to compare the dynamic wettability of dental implants made from different bulk materials and modified by different surface modifications, and to analyze the respective changes of wettability upon irradiating these implants by UV-A or UV-C light.

Methods. Four original screw-type implants were investigated: One grit-blasted/acid-etched and one anodically oxidized titanium, one zirconia and one polyetheretherketone implant. Additionally, experimental, screwless, machined titanium cylinders were included in the study. Part of that cylinders and of blasted/etched implants were further modified by a magnetron-sputtered photocatalytic anatase thin film. Scanning electron microscopy was used to investigate the surface micro- and nanostructures. Samples were treated by UV-A (382 nm, 25 mW cm^{-2}) and UV-C (260 nm, 15 mW cm^{-2}) for entire 40 min, respectively, and their wettability was quantified by dynamic contact angle (CA) analysis from multi-loop Wilhelmy experiments.

Results. All implants are characterized by submicron- and nanosized surface features. Unexposed implants were hydrophobic (CA > 90°). Upon UV-A, solely the implants with anatase coating became superhydrophilic (CA < 5°). Upon UV-C, the blasted/etched implants turned superhydrophilic, the anodized titanium and the zirconia implants were considerably (CA = 34° and 27°, respectively) and the PEEK implants slightly (CA = 79°) hydrophilized.

Significance. The wettability of implant surfaces can be improved by UV irradiation. The efficiency of UV-A and UV-C irradiation to lower the CA by photocatalysis or photolysis, however, is strongly dependent on the specific material and surface. Thus, attempts to photofunctionalize these surfaces by irradiation is expected to result in a different pattern of bioresponses.

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http://dx.doi.org/10.1016/j.dental.2015.04.011
0109-5641/

1. Introduction

Wettability of biomaterial and implant surfaces influences the interaction between the material and surrounding physiological environment, as very recently reviewed [1,2]. Surface wettability, which generally represents surface energy, is affected by surface chemical composition and topography. Surface energy and hydrophilicity will influence a couple of different physiological interactions following implant insertion, the first one being protein/surface interactions during initial conditioning of the surface immediately after implant insertion, followed by subsequent cell/surface interactions [3–5]. Histological observations indicated the thickness of protein films formed on implant surfaces with high surface energy was greater than on those with low energy [6]. Hydrophilic materials can increase fibronectin adsorption, in addition, the more hydrophilic the surface is, the more osteoblastic cells adhered during the initial stage of osseointegration. Cell spreading was also more pronounced on hydrophilic surfaces than on hydrophobic ones [7]. Generally, highly hydrophilic surfaces seem more desirable regarding hard and soft tissue integration than hydrophobic ones [8,9].

Since a hydrophilic surface has been supposed to positively affect the biological reaction, a lot of methods have been developed to enhance the material wettability. Among these methods, UV-A irradiation served as an efficient way to improve wettability on photocataytic titanium dioxide (TiO_2) surfaces [10]. First reported by Wang and Hashimoto, the surface of crystalline TiO_2 films changed, in addition to induced photocataytic properties, from hydrophobic to hydrophilic when subjected to UV-A irradiation [11]. In numerous studies, this hydrophilization effect was basically investigated [12–15]. Recent studies indicate that changes of the titanium surface state upon UV irradiation could accelerate protein adsorption and further promote osseointegration on TiO_2 compared with untreated surfaces [16,17]. Besides the UV-A effect on crystalline TiO_2, UV-C irradiation of titanium surfaces has also been confirmed to be a suitable method to induce hydrophilicity. Hydrophilization upon UV-C may be explained by its direct photolysis of carbon contaminations [18]. Also, UV-C irradiation shows the potential to promote the bone-to-implant contact and the amount of bone growth during the early healing period [19]. What's more, UV treatment can reverse the hydrophobic state of the titanium surface resulting from the so-called "aging effect" to superhydrophilic and even give rise to greater biocompatibility than the state immediately after manufacturing [20,21].

At present, most of the investigations concerning the impact of wettability for tissue integration or the photofunctionalization of implants focus on titanium or titanium oxides. However, biocompatibility research also draws increasing attention to zirconia as a material for dental implants. It is suggested that UV treatment also has the potential to create superhydrophilic surfaces and to enhance initial attachment of osteoblast-like cells on zirconia [22]. Besides zirconia, a kind of rigid semi-crystalline thermoplastic polymer, a polyetheretherketone (PEEK), which has been widely employed as a biomaterial for orthopedic, trauma and spinal implants [23], is under discussion as a potential dental implant material for its excellent mechanical properties. Yet, till now, few studies have been conducted about its wetting behavior.

Based on the above introduced issues, the purpose of this study was first to thoroughly characterize the surface topography and roughness and to compare the dynamic wetting behavior of dental implants manufactured from different materials (metallic titanium, ceramic zirconia, and polymeric PEEK) or further modified by photosensitive TiO_2 thin films in the anatase modification. The second aim was to study the effectivity of UV-A and UV-C irradiation concerning the hydrophilization of the different materials and surface modifications, respectively; thus, the focus is here on comparing the respective potential degree of photo-functionalization of these implants. We expect to shed new light on the material dependent, clinically relevant possibilities to hydrophilize dental implants for improved osseointegration.

2. Material and methods

2.1. *Investigated original implants and experimental cylinders*

Four kinds of original screw-type implants from four different manufacturers were investigated (Table 1). The length of the implants ranged from 12 to 18 mm and the diameter varied between 4.0 and 4.5 mm, according to the manufacturers' given description. Serving as a screwless reference without superimposed microroughness, machined titanium cylinders with a diameter of 4.3 mm were also under investigation.

Part of the grit-blasted/acid-etched titanium implants and the machined titanium cylinders were coated with a 500 nm fully transparent, stoichiometric TiO_2 anatase layer by reactive pulse magnetron sputtering in bipolar pulse mode with a frequency of 20 kHz as previously described in detail [10].

2.2. *Scanning electron microscopic analysis*

The surface microstructures of the implants and cylinders were evaluated using a scanning electron microscope (SEM) LEO 1430 (Zeiss, Germany), respectively. Samples were prepared in a sputter coater SCD 050 (Bal-Tec, Liechtenstein) with 60 mA for 120 s, and a layer of gold-palladium was deposited on the surface of implant or cylinder per group. After sputter coating, samples were subjected to SEM using an accelerating voltage of 10 kV, aperture 30 μm, and magnifications between 25× and 5000×.

To get the wetted length L, which is used for calculating CAs based on tensiometric force data (see 2.3), the major diameter of each kind of screw implant was manually measured first by a caliper. After acquiring the thread height through SEM, the diameter used to estimate L was calculated generally by subtracting one thread height from the major diameter as suggested previously [24]. Aberrant was the calculation for the PEEK implants due to their complex surface design that does not resemble usual threaded screws. Major diameters and thread heights were calculated from 3 independent measurements located in the middle of the respective immersion depth during the CA analysis. The calibrated diameter for each sample is listed in Table 2.