Atomic Layer Deposition Coatings on Ti Implants with Nanocrystalline TiO_2 for Enhancing Osteoblast Functions and Reducing Bacteria Growth

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Introduction

Titanium (Ti) and its alloys have been extensively used as implant materials in orthopedic applications. Nevertheless, implants may fail due to a lack of bone osseointegration or infection [1]. Therefore, it is of great significance to produce an implant surface with favorable biological properties by dual modification of surface chemistry and topography. Alternatively, the application of a nanoscale titanium dioxide (TiO_2) coating to Ti-based materials has been proposed to enhance tissue-implant interactions while inhibiting bacterial colonization due to its chemical stability, cytocompatibility, and antimicrobial properties [2-3]. Thus, the objective of the present study was to investigate the effect of nanoscale TiO_2 coatings on human osteoblast functions and bacteria activities. In this study, atomic layer deposition (ALD) was utilized for the synthesis of highly-adherent, highly crystalline, thin coatings composed of TiO_2, providing favorable nanoroughness and wettability.

Materials and Methods

TiO_2 coatings were deposited on 99.5% titanium (Ti) foils (Alfa Aesar) in thermal ALD processes (Fig. 1) with different reactor temperatures (120 °C, 160 °C and 190 °C) for 2500 cycles. Surface morphogy and roughness of the samples were characterized by scanning electron microscopy (SEM) and atomic force microscopy (AFM), respectively. Water contact angle tests were used to determine the surface wettability. The adhesion and proliferation of osteoblasts (PromoCell, C-12720) were quantified using an MTS assay (Promega, Madison, WI). *In vitro* bacteria studies using *Staphylococcus aureus* (ATCC 25923) and *Escherichia coli* (ATCC 25922) were conducted to assess the effectiveness of these TiO_2 coatings at inhibiting bacterial adhesion and growth. All cell and bacteria studies were conducted in triplicate and repeated at least three times. Data were collected and the significant differences were assessed with the probability associated with one-tailed Student's t-tests. Statistical significance was considered at $p<0.05$.

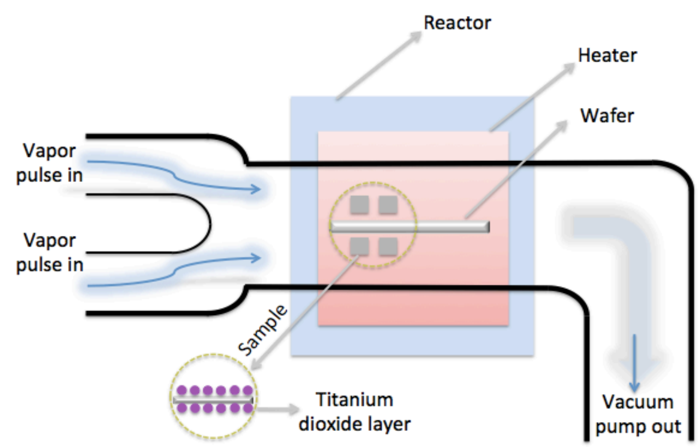

Figure 1: Schematic of an ALD system for TiO_2 deposition. Adapted from [4]

Results and Discussion

During the deposition process, TiO_2 goes from amorphous to crystalline with an increase in temperature from 120 °C to 190 °C. The surface roughness values obtained by AFM showed increased surface roughness from 12.7 nm (plain-Ti) to 40 nm (Ti-TiO_2) as expected. Analysis of contact angle data indicated that the TiO_2-coated surface is slightly more hydrophilic (~60 °) than the plain control surface (~70 °). It is well known that biological events are influenced by surface chemistry, surface topography (roughness), and surface wettability as well. Cell results indicated that initial osteoblast adhesion (after 4 hours of culture) on Ti-TiO_2 samples was doubled relative to that measured from plain-Ti samples. After 5 days of culture, the osteoblast cell numbers on Ti-TiO_2 samples were 50% higher than those measured on plain-Ti samples. For the antibacterial studies, it was observed that the Ti-TiO_2 samples inhibited (exceeding 80%) the adhesion and growth of both *S. aureus* and *E.coli* compared to the results obtained from plain-Ti samples (Fig. 2). Impressively, this was accomplished without the use of antibiotics and only based on nanoscale surface features alone.

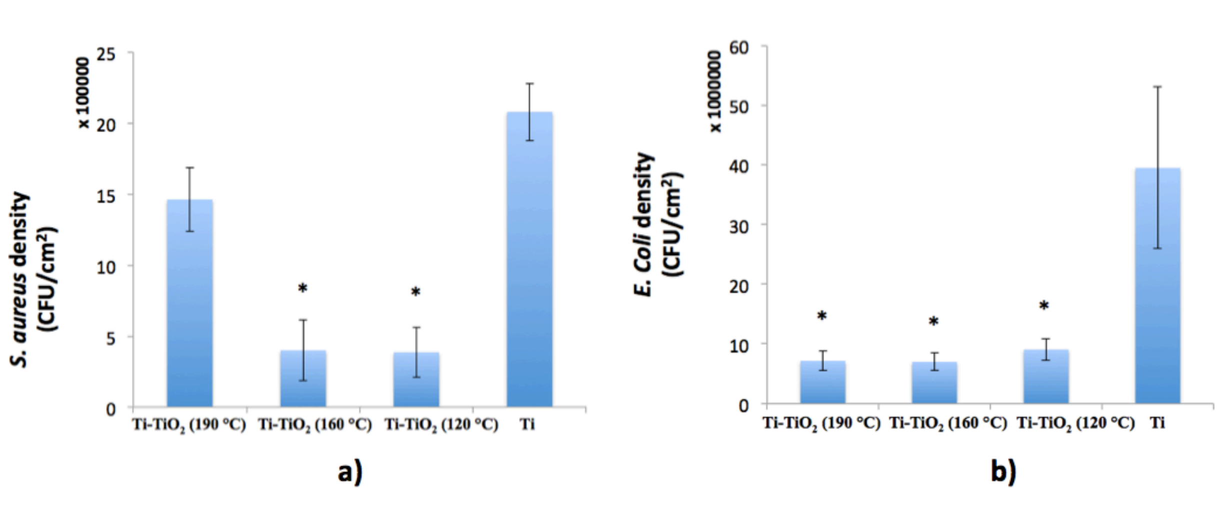

Figure 2: a) *S. aureus* and b) *E. coli* adhesion (24 hours) on Ti samples with different TiO_2 coatings. Data represents mean ± SD, N=3. *$p < 0.05$ compared with Ti control.

Conclusions

Nanocrystalline TiO_2 coatings on Ti substrates using well-established ALD techniques showed promising antimicrobial efficacy in addition to their ability to enhance osteoblast functions. As a result, there is a strong potential to apply this technology to the field of orthopedic implants.

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