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Review

A review of the application of anodization for the fabrication of nanotubes on metal implant surfaces

Sepideh Minagar [a], Christopher C. Berndt [a], James Wang [a], Elena Ivanova [b], Cuie Wen [a,*]

[a] IRIS, Faculty of Engineering and Industrial Sciences, Swinburne University of Technology, Hawthorn, Victoria 3122, Australia
[b] Faculty of Life and Social Sciences, Swinburne University of Technology, Hawthorn, Victoria 3122, Australia

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ABSTRACT

Metal implants are the best choice for the long-term replacement of hard tissue, such as hip and knee joints, because of their excellent mechanical properties. Titanium and its alloys, due to their self-organized oxide layer, which protects the surface from corrosion and prevents ion release, are widely accepted as biocompatible metal implants. Surface modification is essential for the promotion of the osseointegration of these biomaterials. Nanotubes fabricated on the surface of metal implants by anodization are receiving ever-increasing attention for surface modification. This paper provides an overview of the employment of anodization for nanotubes fabricated on the surface of titanium, titanium alloys and titanium alloying metals such as niobium, tantalum and zirconium metal implants. This work explains anodic oxidation and the manner by which nanotubes form on the surface of the metals. It then assesses this topical research to indicate how changes in anodizing conditions influence nanotube characteristics such as tube diameters and nanotube-layer thickness.

1. Introduction

1.1. Bone: structure, composition and properties

Like other parts of the body, bone becomes damaged or weakened by age, accidents or disease. This damage, which includes bone fractures, low back pain, osteoporosis, scoliosis and other musculoskeletal problems, usually occurs in elderly people, though not exclusively. Biomaterials such as implants are used to repair injured bones, cartilage or ligaments and tendons [1].

Weiner and Wagner [2] described basic bone composition as consisting of mostly fibrous protein collagen, carbonated apatite ($Ca_5(PO_4, CO_3)_3(OH)$) and water. The crystal size and the proportions of these components change over time. As a result, younger bones replace older bones. Uddin et al. [3] emphasized that bones are tissues that are alive and growing. Bone-forming cells, such as osteoblasts, are responsible for generating the synthesis and deposition of the calcium phosphate crystals that are required to confer hardness and strength in biomineralization. A schematic illustration of the hierarchical structure of cortical bone is shown in Fig. 1. It can be seen that cortical bone contains many different structures, which exist on several levels of scale starting from sub-nanostructures. Mour et al. [4] described bone as a solid material that is highly porous on the micrometre scale. Bone is a viscoelastic material due to these pores, which are filled with fluid and cells: osteoblasts, osteoclasts, osteocytes and bone-lining cells that are regenerative. Bone, moreover, has values of compression strength several times higher than, for example, concrete, but its low density is in the range of aluminium.

1.2. Bone implant materials

Different materials are used for implants, including polymers, ceramics, metals, composites and natural products. Metal implants can bear loads for several decades and are consequently used as endoprostheses. However, they need to be inserted into the human architecture and become fixed and stable in the surrounding natural tissue. Furthermore, these implants need to be bioinert within the highly corrosive and demanding environment of the human body. Polymers, in comparison to metals, give rise to inflammation because of monomers that are intrinsic to their structure or that become available through infection, thereby increasing the likelihood of degradation. However, polymers demonstrate excellent primary fixation [1].

Ceramics and bioglass exhibit lower fracture toughness and higher elastic modulus than bone, and also demonstrate property variations with respect to their formulation [5]. Their mechanical and biological properties depend on many factors during synthesis, such as maximum temperature, duration of the thermal steps, purity of the powder, and size and distribution of the grains and porosity, many of which cannot be accurately controlled [1].

* Corresponding author. Tel.: +61 3 9214 5651; fax: +61 3 9214 5050.
E-mail address: cwen@swin.edu.au (C. Wen).

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