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Surface bioactivation of PEEK by neutral atom beam technology

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A B S T R A C T

Polyetheretherketone (PEEK) is an alternative to metallic implants and a material of choice in many applications, including orthopedic, spinal, trauma, and dental. While titanium (Ti) and Ti-alloys are widely used in many intraosseous implants due to its biocompatibility and ability to osseointegrate, negatives include stiffness which contributes to shear stress, radio-opacity, and Ti-sensitivity. Many surgeons prefer to use PEEK due to its biocompatibility, similar elasticity to bone, and radiolucency, however, due to its inert properties, it fails to fully integrate with bone. Accelerated Neutral Atom Beam (ANAB) technology has been successfully employed to demonstrate enhanced bioactivity of PEEK both *in vitro* and *in vivo*. In this study, we further characterize surfaces of PEEK modified by ANAB as well as elucidate attachment and genetic effects of dental pulp stem cells (DPSC) exposed to these surfaces. ANAB modification resulted in decreased contact angle at 72.9 ± 4.5° as compared to 92.4 ± 8.5° for control ($p < 0.01$) and a decreased average surface roughness, however with a nano-textured surface profile. ANAB treatment also increased the ability of DPSC attachment and proliferation with considerable genetic differences showing earlier progression towards osteogenic differentiation. This surface modification is achieved without adding a coating or changing the chemical composition of the PEEK material. Taken together, we show that ANAB processing of PEEK surface enhances the bioactivity of implantable medical devices without an additive or a coating.

1. Introduction

Over the past two decades, polyetheretherketone (PEEK) has been increasingly used as an alternative to metal implants in orthopedic and dental surgery because of its mechanical and biological properties as well as its radiolucency. One of the main reasons to use PEEK in place of metal alloys is to eliminate concerns regarding potential metal allergies [1,2]. The ability to manipulate the modulus of elasticity of PEEK to more closely match that of bone reduces the possibility of stress shielding and bone resorption. Despite the benefits of PEEK, its inert nature means that it fails to promote an adequate bone integration. Many studies have investigated surface modification methods to augment direct bone-implant contact. These methods include physical treatments (plasma) [3], chitosan film deposition [4–6], chemical treatment [7], calcium phosphate or titanium surface coatings [8–11], as well as the use of composites with hydroxyapatite (HA) [12,13]. However, the clinical success of these treatments may be limited because of reduced strength of the PEEK substrate and delamination of various coatings in physiological environments due to the stress concentration at the PEEK-coating interface [14]. While titanium implants have been the standard in dental and many orthopedic applications, they are increasingly being recognized to elicit either an immediate (type I, antigen/antibody based) or delayed (type IV, cell-mediated) allergen response in a subset of individuals, which may cause implant failure in these patients [15].

In continuation of previous studies, we have employed a relatively recent technology called Accelerated Neutral Atom Beam (ANAB) that can modify the surface of an implantable medical device to a shallow depth of no greater than 2–3 nm [16,17]. The ANAB technique, described earlier in detail [18], employs an intense directed beam of neutral gas atoms, which have average energies that can be controlled over a range from a few electron volts (eV) to over 100 eV per atom. These neutral atom beams are produced by dissociating energetic gas cluster ions produced by the Gas Cluster Ion Beam (GCIB) technique [19].

The first goal of this study was to further characterize the effects of ANAB treatment on the surface chemistry and bioactivation of PEEK. Secondly, we aim to establish a fundamental understanding of the genetic mechanism behind stem cell interactions with ANAB-modified PEEK surface. We accomplish that by assaying the ability of dental pulp stem cells (DPSC) to maintain their stemness, enhance their proliferative ability and differentiate towards bone on the modified

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