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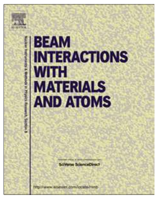

Neutral atom beam technique enhances bioactivity of PEEK

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ABSTRACT

Polyetheretherketone (PEEK) is currently gaining popularity in orthopedic and spinal applications but has potential drawbacks in use. PEEK is biocompatible, similar in elasticity to bone, and radiolucent; however, it has been shown to be inert and does not integrate well with bone. Recent efforts have focused on increasing the bioactivity of PEEK by modifying the surface to improve the bone-implant interface. We have employed a novel Accelerated Neutral Atom Beam technique (ANAB) to enhance the bioactivity of PEEK. ANAB employs an intense beam of cluster-like packets of accelerated unbonded neutral argon (Ar) gas atoms. These beams are created by first producing a highly energetic Gas Cluster Ion Beam (GCIB) comprised of van der Waals bonded Ar atoms, then transferring energy to the clusters so as to cause release of most of the interatomic bonds, and finally deflecting away the remaining electrically charged cluster cores of still bonded atoms. We identified that ANAB treatment of PEEK results in nanometer scale surface modifications as well as increased surface hydrophilicity. Human osteoblasts seeded onto the surface of ANAB-treated PEEK exhibited enhanced growth as compared to control PEEK as evidenced by cell proliferation assays and microscopy. This increase in bioactivity resulted in cell proliferation levels comparable to native titanium. An *in vivo* study using a rat calvarial critical size defect model revealed enhanced osseointegration where bone tissue formation was evident only on the ANAB treated PEEK. Taken together, these data suggest that ANAB treatment of PEEK has the potential to enhance its bioactivity, resulting in bone formation and significantly decreasing osseointegration time of orthopedic and spinal implants.

1. Introduction

Polyetheretherketone (PEEK), a dominant member of the Polyaryletherketone (PAEK) family, has been successfully used in the manufacturing and use of spinal, orthopedic, and trauma implants for over 25 years [1–4]. A key benefit for the use of PEEK in medical devices has been its radiolucency; its ability to be imaged by X-ray, CT scan, or MRI without distorting the visualization of the desired fusion as compared to the traditional titanium (Ti) and stainless steel materials used in these applications [5,6]. PEEK's chemical resistance and stability also make it a material of choice for long term use in the body without any breakdown products [5,6]. Another attractive property of PEEK is the ability to manipulate its elastic modulus to more closely match that of other materials [7,8]. The addition of carbon or glass can increase the modulus from 3–4 GPa to 18 GPa to mimic bone, or 150 GPa to mimic Ti [4,9]. A drawback of PEEK, on the other hand, is that due to its inert properties, PEEK fails to integrate well with bone [1,10–12]. Initially, this has been overcome with the addition of growth factors and proteins such as BMP-2 [13]; however as complications and issues are starting to arise surrounding the use of BMPs [14], there is an unmet need to create a more bioactive PEEK. Many groups are currently attempting to increase PEEK's bioactivity by adding bioactive compounds such as hydroxyapatite [15–19], calcium phosphate (CaP) [20], Ti [16,21], and others [11,22,23]. Various groups have attempted to use oxygen plasma to increase surface energy [12,24], and others are working on making porous PEEK to allow cellular ingrowth [25]. All these methods have had limited *in vitro* success.

We have developed a novel accelerated neutral atom beam technology (ANAB) that can modify the surface of implantable medical devices to a shallow depth of no more than 5 nm. The ANAB surface modification technique, which is described in detail elsewhere [26], employs intense directed beams of neutral gas atoms having average energies which can be controlled over a range from a few eV per atom to beyond 100 eV per atom. These neutral atom beams are created by dissociating energetic gas cluster ions produced by the Gas Cluster Ion Beam (GCIB) technique [27]. A beam of energetic gas cluster ions is created by expanding an appropriate gas, typically Ar, through a small nozzle into vacuum to form a stream of weakly-bonded gas clusters, then ionizing the clusters by electron impact and accelerating them

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