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Enhanced bioactivity and osseointegration of PEEK with accelerated neutral atom beam technology

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Abstract: Polyetheretherketone (PEEK) is growing in popularity for orthopedic, spinal, and trauma applications but has potential significant limitations in use. PEEK is biocompatible, similar in elasticity to bone, and radiolucent, but is inert and therefore does not integrate well with bone. Current efforts are focusing on increasing the bioactivity of PEEK with surface modifications to improve the bone-implant interface. We used a novel Accelerated Neutral Atom Beam (ANAB) technology to enhance the bioactivity of PEEK. Human osteoblast-like cells seeded on ANAB-treated PEEK result in significantly enhanced proliferation compared with control PEEK. Cells grown on ANAB-treated PEEK increase osteogenic expression of ALPL (1.98-fold, $p < 0.002$), RUNX2 (3.20-fold, $p < 0.002$), COL1A (1.94-fold, $p < 0.015$), IBSP (2.78-fold, $p < 0.003$), and BMP2 (1.89-fold, $p < 0.004$). Cells grown on these treated surfaces also lead to an increased mineralization (6.4-fold at 21 days, $p < 0.0005$). In an ovine study, ANAB-treated PEEK implants resulted in enhanced bone-in-contact by 3.09-fold ($p < 0.014$), increased push-out strength (control 1959 ± 1445 kPa; ANAB 4068 ± 1197 kPa, $p < 0.05$), and evidence of bone ingrowth at both the early (4 weeks) and later (12 weeks) time points. Taken together, these data suggest that ANAB treatment of PEEK has the potential to enhance its bioactivity, leading to bone formation and significantly decreasing osseointegration time of orthopedic and spinal implants. ANAB treatment, therefore, may significantly enhance the performance of PEEK medical implants and lead to improved clinical outcomes. © 2015 Wiley Periodicals, Inc. J Biomed Mater Res Part B: Appl Biomater 00B: 000–000, 2015.

Key Words: bioactivity, in vivo, osseointegration, polyetheretherketone, surface modification

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INTRODUCTION

Several biomaterials have been developed and introduced over the past few decades with the aim of allowing reconstruction or repair of tissues to restore function. Traditional metallic orthopedic medical devices, including titanium (Ti), stainless steel, cobalt-chromium (Co-Cr), and others have been widely used due to their excellent corrosion resistance, high mechanical strength and load-bearing, cytocompatibility, and ability to promote bone integration.[1] However, growing concerns regarding release of metal ions, mismatched modulus of elasticity between metals and human bone, and radiopacity has led to the need to identify alternative biomaterials. Over the past 25 years, polyetheretherketone (PEEK), a key member of the polyaryletherketone (PAEK) family, has been gaining popularity for orthopedic, spinal, dental, and trauma applications.[2–4]

PEEK's radiolucency allows for improved imaging of bone fusion by X-ray, CT scan, or MRI compared with stainless steel or titanium; its chemical resistance makes it an ideal candidate for long-term use in the body without breakdown products.[5,6] The ability to manipulate the modulus of elasticity of PEEK to more closely match that of other materials, including bone, reduces the possibility of bone resorption.[7–10] By the addition of glass or carbon, the modulus can be augmented from 3 to 4 GPa to 18 GPa to mimic cortical bone or, if so desired for other applications, up to 150 GPa to mimic titanium.[3,11] Finally, PEEK can be easily fabricated by conventional equipment, repeatedly sterilized, and heat contoured to fit the desired bone shape.[12,13] Despite these benefits, the inert nature of PEEK means that it fails to promote an adequate bone apposition or integration.[2,14–16] Numerous groups are working to increase the bioactivity of PEEK by the addition of compounds such as hydroxyapatite,[13,17–19] calcium phosphate,[20] titanium,[17,21–24] and others.[15,25] A few researchers are attempting to use oxygen plasma to increase surface energy,[16,26] while others are using porous PEEK to allow for cellular ingrowth.[27–29] Most of these techniques have been met with limited

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