Plasma Surface Modification of PEEK to Improve Primary Human Osteoblast Cell Adhesion and Function

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Statement of Purpose: Polyetheretherketone (PEEK) has come to the forefront in the field of biomaterials as a radiolucent replacement for metals in devices such as spine cages and patient specific craniomaxillofacial (CMF) implants, due to its high strength and good wear properties compared to polymers such as UHMWPE[1]. Metal devices can obscure soft and hard tissue integration to implants during evaluation by X-ray or MRI. Many polymers such as PEEK have an intrinsic low surface energy which can restrict cellular adhesion, and this can in turn lead to implant loosening, as a result of fibrous encapsulation. Surfaces with higher energy are known to promote rapid cellular adhesion and spreading, in contrast to surfaces with lower energy[2,3]. To improve cellular adhesion the surface energy of PEEK can be increased by plasma surface treatment. The present study aims to investigate the effect of oxygen plasma treatment of PEEK on the adhesion and functionality of primary human osteoblast-like cells (HOB).

Methods: Injection moulded PEEK Optima™ discs (Invibio) were modified by plasma treatment and these were compared to Thermanox (THX) (Nunc) and standard medical grade micro-rough titanium (cpTi ISO 5832/2) (Synthes). Using an EMITECH RF plasma treater the PEEK samples were exposed to oxygen plasma for varying treatment times. Surface chemical compositions were characterised by XPS, wettability by contact angle and changes in topography by AFM and SEM. HOB cells isolated from human femoral heads removed during total joint replacement operations were grown to 70-80% confluence in DMEM (10% FCS in 5% CO_2 at 37°C), and plated at 10^3 cells/cm^2. Alpha-MEM (0.1µM dexamethasone and 10mM beta-glycerophosphate) was used as mineralisation media over the 28 day experiments. Cell functionality was assessed by alkaline phosphatase activity (ALP), phenotypic gene expression by qPCR, mineralisation by Alizarin red S (ARS) staining of calcium, cell attachment by SEM and cell density through the alamarBlue™ assay. Sampling was performed at 1, 7, 14, 21 and 28 days.

Results: Chemical surface characterisation by XPS of the untreated PEEK discs showed 14 atomic% surface oxygen, confirming that these surfaces are relatively hydrophobic in character[4]. Analysis of the plasma treated PEEK showed increasing surface oxygen concentrations with increasing treatment time, up to ~20 atomic% after 30min treatment. High resolution C1s spectra showed a greater increase in C-OR type functional groups than C=O and O-C=O with increasing treatment time. Experiments have to date shown the shelf-life of the surface treatment to be stable for up to 8 months.

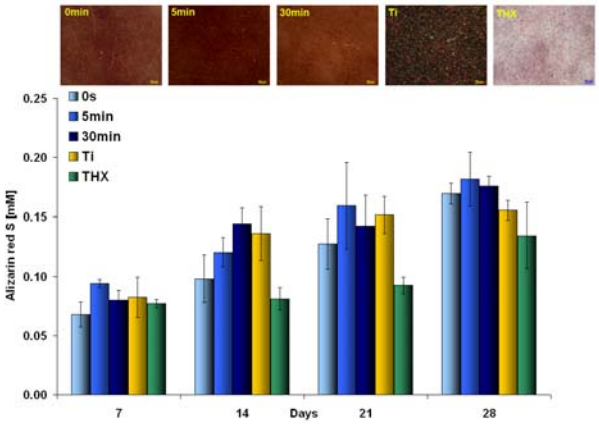

Figure 1. *In vitro* mineralisation determined by ARS staining of nodule formation produced by the HOB cells, staining shown at 28dys on untreated (0min) and treated surfaces (5min and 30min) compared to cpTi and THX.

Surface roughness was not affected by the surface treatment at the early treatment times, but after 20min changes in the surface micro- and nano- structure were observed. The effects of the surface treatment on cell attachment and functionality were examined after plating on the treated and untreated PEEK, THX and cpTi surfaces. Cell adhesion was observed by SEM and the HOB cells were found to attach more readily to the treated surfaces with higher concentrations of C-OR functional groups than the untreated PEEK surfaces, and higher densities were measured by day 3 with the alamarBlue™ assay. By day 21 the treated PEEK surfaces were shown to have similar cell densities to cpTi. Expression of ALP was observed to be more characteristic towards osteoblast phenotype on the treated PEEK surfaces, than untreated PEEK over the 28 day experiments. Nodule formation quantified by dissolving the ARS stain was found to be greater on the PEEK surfaces than on the THX surfaces from 7 days onward, and the treated PEEK surfaces had similar levels to the cpTi surfaces throughout the 28 day experiments (Fig 1).

Conclusions: Oxygen plasma treatment of PEEK can be used to increase the surface energy and thereby aid the adhesion of HOB cells. This surface modification has led to more characteristic osteoblast behaviour, indicating that these treated surfaces are likely to improve bony integration to PEEK implants.

References: [1]Kurtz, S.M. and Devine, J.N. Biom., 28, 4845, 2007. [2]Lopez, G.P., Ratner, B.D., et al. J Biom. Res, 26, 415, 1992. [3]Kasemo, B. Surf. Sci. 500, 656, 2002. [4]Comyn, J., Mascia, L., and Xiao, G. Int J Adhesion & Adhesives, 16, 97,1996. **Acknowledgments:** Financial contribution and PEEK discs from Invibio Ltd. Synthes Inc. provided Ti discs.