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Cold atmospheric pressure gas plasma enhances the wear performance of ultra-high molecular weight polyethylene

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ABSTRACT

Ultra-high molecular weight polyethylene (UHMWPE) is frequently employed in joint replacements because of its high biocompatibility; however, this material does not exhibit particularly strong wear performance, thus potentially reducing the longevity of such devices. Numerous techniques have been investigated to increase the resistance to wear of UHMWPE, but they are all based on expensive machinery and require a high level of safety precautions. Cold atmospheric pressure gas plasma treatment is an inexpensive process that has been used as a surface modification method and as a sterilization technique. We demonstrate for the first time that a helium/oxygen cold atmospheric pressure gas plasma can be used to enhance the wear performance of UHMWPE without affecting the cytocompatibility of the material. The exposure to a cold atmospheric pressure gas plasma results in a greater level of crosslinking of the polyethylene chains. As a consequence of the higher crosslinking, the material stiffness of the treated surface is increased.

1. Introduction

Modern approaches to degenerative joints diseases are total joint replacement (TJR) and total disc replacement (TDR). These techniques have become increasingly popular due to the benefits of an enhanced life quality post operation and increasing life expectancy. The future will see a growing number of joint replacements because of the increasing average age of the population and the confidence in achieving high levels of activity [1,2].

The longevity of replacement joints and discs is a key factor in determining the success of such operations, which is mainly affected by the wear performance of the implant material [3,4]. Hence, the implants must be engineered to maximise wear performance, thus alleviating wear-related biological reactions [5,6]. To this end the choice and availability of implant materials is of central importance. Despite significant research effort and the application of new bearing materials such as carbon-fibre-reinforced and poly(ether ether ketone) [7,8], ultra-high molecular weight polyethylene (UHMWPE) remains the main bearing material of choice in knee and hip arthroplasty, because of the simplicity of the fabrication process, the biocompatibility and the low friction [9]. Nevertheless, UHMWPE is not wholly satisfactory. For example, present UHMWPE materials show high material loss due to relative motion between articulating surfaces. This leads to prosthesis failure due to adverse biological reactions to polyethylene debris particles, called osteolysis [6,10–14].

Therefore, there is a need to develop better-performing polymeric materials and/or improve the present UHMWPE materials to reduce wear and adverse reactions to wear particles whilst retaining bone and natural function. The traditional ways of improving wear performance of UHMWPE are by techniques such as gamma or electron beam irradiation followed by thermal stabilization (annealing or re-melting) [15]. The main disadvantages of these techniques are that wear resistance is accompanied by a decrease in bulk mechanical properties, such as toughness, tensile strength and fatigue performance [16]. This could be a serious problem for orthopaedic devices exposed to high stresses or large cyclic contact stresses as in the case of total knee replacement. Among other recent techniques of UHMWPE modification are the use of fibres [17], ion implantation [18,19] and argon plasma [20] and rapid heavy ion beam irradiation [21]. These techniques normally require a thermal stabilization step to eliminate the residual reactive species present in the materials, whose activity could result in reaction products with a detrimental effect on the overall performance of the treated material. In addition, such processes are expensive as they have to be carried out in complex machines.

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