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Electrostatic field may regulate proliferation and immune responses of macrophages induced by polyethylene wear particles

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ABSTRACT

Effects of electrostatic field on the macrophage responses induced by ultra-high molecular weight polyethylene (UHMWPE) wear particles have been investigated in this study. An inverted cell culture system was applied to study the interactions between UHMWPE wear particles and macrophage cells. The electrostatic field induced device (EFID) was installed on the cell culture system. The high voltage and low current stimulations generated from EFID were first applied to the UHMWPE particles/macrophage co-culture system. The proliferation and tumor necrosis factor-alpha, interleukin (IL)-6, and IL-1β cytokine expressions of J774A.1 macrophage cells were analyzed. The EFID applied voltage of 0.5 kV, 1.0 kV, 1.3 kV, and 1.6 kV were investigated. Our result indicated that the 0.5 kV and 1 kV voltages increased the proliferation of macrophage cells and activated the expression of related cytokines under the co-culture of UHMWPE wear particles. However, with the increasing applied voltage of 1.3 kV and 1.6 kV, the inhibition of the macrophage proliferation and expression of immunological cytokines were observed. There exists a critical applying EFID voltage to modulate the UHWMPE particle induced immune responses. The electrostatic field induced device presents a potential non-invasive therapy for particle induced bone resorption and osteolysis.

1. Introduction

Aseptic loosening from wear particles induced osteolysis has been recognized as the major reason causing the failure of artificial joints [1–3]. Wear particles are generated during articulation of the joint surfaces and remain in the joint capsule space as foreign substances. It is indicated that the foreign particles may further induce various responses from surrounding cells and tissues [4–7]. Macrophage phagocytosis of wear particles induces human biological/physiological responses that eventually lead to bone resorption and osteolysis. Ultra-high molecular weight polyethylene (UHMWPE) wear particles that is caused by articulation of the joint surfaces or by the changes in the material properties stimulate macrophages to release inflammatory associated substances which further enhance the activation of osteoclasts [8,9]. Activated osteoclasts with longer life-span appear around the joint results in osteolysis [10–13].

Physical stimulations, such as electrical field, electromagnetic field, and electrostatic field have been attempted to regulate the functions of tissues and cells, especially for their immune responses. Previous studies have shown that under electrical field stimulation, bone extracellular matrix such as collagen is increased and the growth factor synthesis is up-regulated [14–17]. Chang et al. stated that pulsed electromagnetic field stimulation could inhibit osteoclast formation and reduce cytokines release by bone marrow cells of rats [18]. A review by Johnson et al. summarizes that electromagnetic field is an effective, safe, and non-invasive therapeutic device to treat pain, cancer, epilepsy, and inflammation [19]. Several studies have used the electro-acupuncture on ulcerative colitis and tibial muscle inflammation of rats and found that electro-acupuncture could decrease the release of some inflammatory factors such as tumor necrosis factor-alpha (TNF-α) and interleukin-1 (IL-1) by macrophage, leading to the relief of pain and edema [20,21]. The influences of electricity on immune-related cells have been also investigated *in vitro* [22,23]. For example, Sontag has revealed that after exposure to interferential curve, cytokines release by human promyelocytes would be changed. In addition, Veronesi et al. have stated that negative static electricity carried by polystyrene would increase Ca^{2+} and IL-6 release of human tracheal epithelial cells [23]. Our previous study first applied an electrostatic field induced device (EFID) to the macrophage cell culturing process [24]. The results showed that the electrostatic

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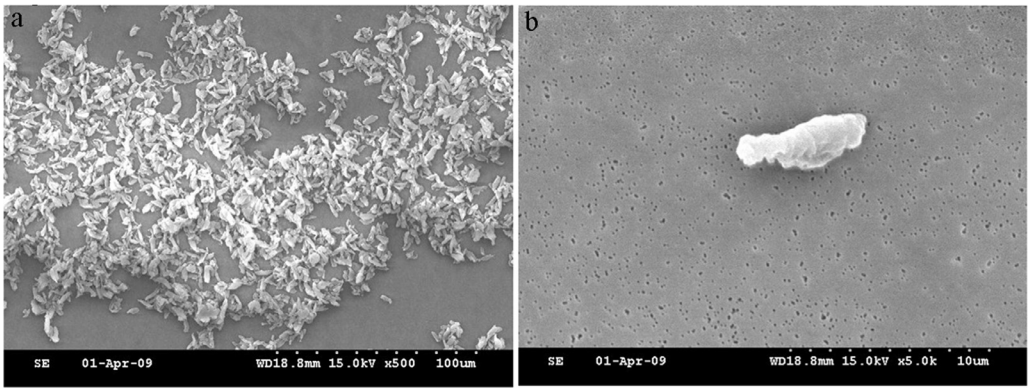

Fig. 1. Morphology of UHMWPE particles under scanning electron microscopy. Particles were generated by a linear reciprocating wear test of an UHMWPE pin on a silicon wafer with microfabrication of surface texture processed by photolithography patterning and etching of the bulk substrate. Magnification is 500× (a) and 5000× (b).

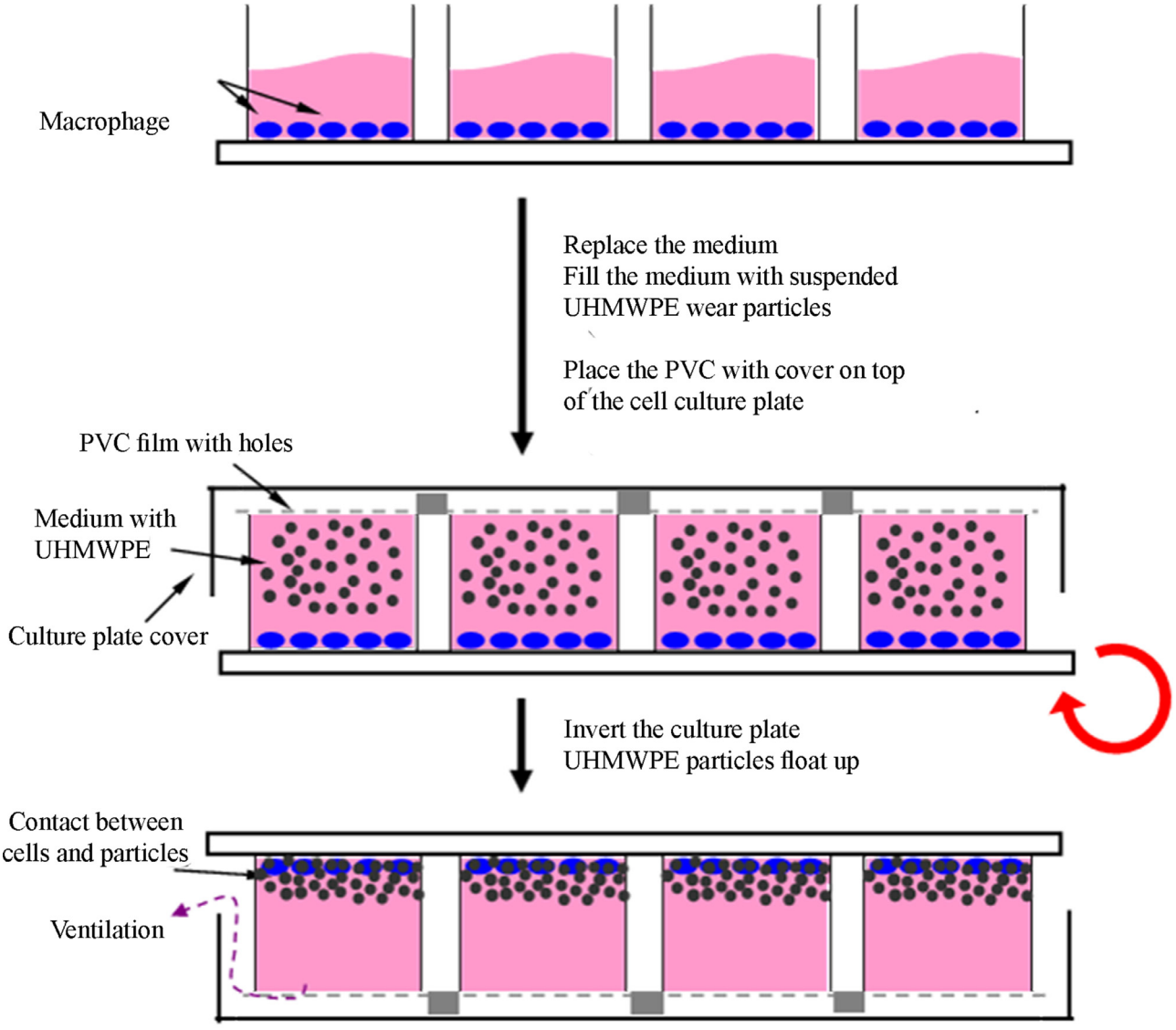

Fig. 2. Procedures of inverted culturing. Macrophages are shown as blue ovaries, and UHMWPE particles as black circles. After the culture plate was inverted, cells and particles would contact. The holes on the PVC film led to a better ventilation for cells. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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