High Oxidation- and Wear-resistance of PMPC-grafted Polyethylene Arisen by Extra Plasma Irradiation

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Statement of Purpose: We have recently developed a novel artificial joint system (Aquala®) with poly(2-methacryloyloxyethyl phosphorylcholine) (PMPC)-grafted onto the surface of CLPE (PMPC-grafted CLPE), aiming to reduce wear and avoid bone resorption [1]. The oxidation- and wear-resistances of the PMPC-grafted CLPE determined *in vitro* and *in vivo* are important indicators of the clinical performance of joint replacements. While discussing the durability of acetabular cups, it is an important factor to consider not only material of the bearing surface, but also sterilization method. The purpose of this study is to investigate the effects of extra energy irradiation by sterilization method on the oxidative and tribological stabilities of PMPC-grafted CLPE and to examine the possibility of controlling the longevity of artificial joints by utilizing this material.

Methods: Compression-molded polyethylene (GUR1020 resin; Quadrant PHS Deutschland GmbH) sheet stock was gamma-irradiated with 50/75 kGy and annealed at 120°C for 7.5 hours for cross-linking. The CLPE specimens were machined from this sheet stock. The CLPE specimens coated with benzophenone were immersed in the 0.5 mol/L aqueous MPC solution. The photo-induced graft polymerization on the CLPE surface was carried out with ultraviolet (350 nm wavelength) irradiation of 5 mW/cm^2 at 60°C for 90 min [2]. Then, the PMPC-grafted CLPE were extra energy (gamma-ray or H_2O_2 gas plasma irradiation) supplied by gamma-ray or gas plasma sterilization (STERRAD; ASP Ethicon Inc.). The surface chemical and physical properties of the PMPC-grafted CLPE with pre- and post-extra energy irradiation were examined by Fourier-transform infrared (FT-IR) spectroscopy and the static water-contact angle measurement. The oxidative property of accelerative aged PMPC-grafted CLPE (ASTM F2003) was evaluated by FT-IR according to ASTM F2102. The wear test was performed using a 12-stations hip joint simulator (MTS System Corp.). A mixture of 25% bovine serum, 20 mM/L of ethylene diamine tetraacetic acid, and 0.1% sodium azide was used as lubricant. Loads simulating a physiologic loading curve with double peaks of 1793 and 2744 N loads were applied with a frequency of 1 Hz.

Results: The static water-contact angle of the PMPC-grafted CLPE was approximately 30° before extra energy (gamma-ray or plasma) irradiation. Furthermore, that of PMPC-grafted CLPE decreased to 10° after extra energy irradiation. Oxidation index of gamma-ray irradiated PMPC-grafted CLPE increased gradually and reached approximately >2.0 (Fig. 1). Similarly, the oxidation index of the plasma irradiated PMPC-grafted CLPE increased gradually to 0.6. However, this index of the plasma irradiated PMPC-grafted CLPE was 70% reduction compared with that of gamma-ray irradiated one.

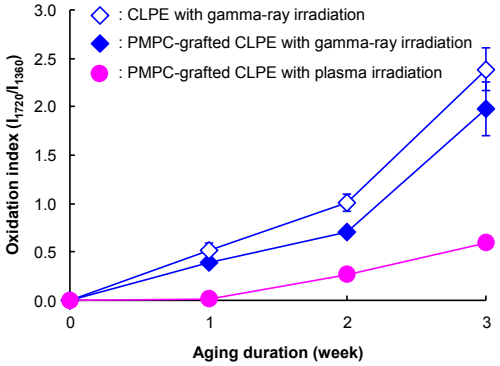

Fig. 1. Time course of oxidation index of PMPC-grafted CLPE during accelerative aging.

After 5.0 × 10^6 cycles of the simulator test, both the extra energy irradiated PMPC-grafted CLPE were found to show extremely low and stable wear (Fig. 2).

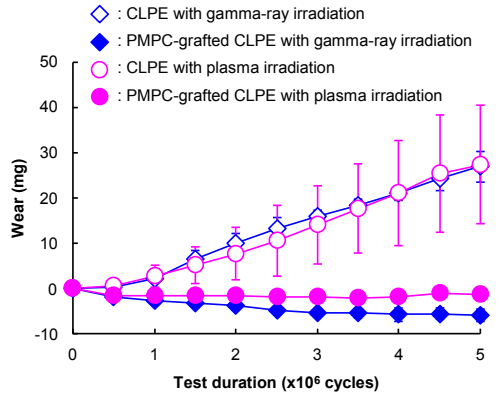

Fig. 2. Volumetric wear of PMPC-grafted CLPE in the hip joint simulation test.

Conclusions: In this study, we confirmed that the extra energy supplied by gamma-ray and H_2O_2 gas plasma irradiation brought high wear-resistance. When the CLPE surface is modified by PMPC grafting, the MPC graft polymer leads to a significant reduction in the sliding friction between the surfaces which are grafted because water thin films formed can act as extremely efficient lubricants. Extra plasma irradiated PMPC-grafted CLPE showed a higher oxidation-resistance than the gamma-ray irradiated one. These results suggest that the plasma irradiated PMPC-grafted CLPE makes not only high wear resistance not but also high oxidation-resistance.

References: [1] Moro T. Nature Mater. 2004;3:829-837, [2] Kyomoto M. J Biomed Mater Res A. 2007;82:10-17.