Surface Cross-linking of Vitamin E Blended UHMWPE by Low Energy Irradiation

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Statement of Purpose Crosslinked polyethylene (UHMWPE) is used for joint implants. Crosslinking decreases wear, addressing wear-debris induced osteolysis but also decreases the strength of the polymer [1, 2]. Limiting the crosslinking to the surface is desirable to obtain wear resistance with improved strength.

Surface cross-linking was achieved by irradiating UHMWPE containing low surface concentrations of the antioxidant vitamin E, which can also act as an anticross-linking agent [3]. This approach uses high concentrations of vitamin E in the bulk of the material to decrease cross-linking. An alternative is using low energy electron beam irradiation to limit the penetration of the beam. Thus, we hypothesized that a surface cross-linked UHMWPE with high wear resistance could be obtained by using low energy irradiation of vitamin E-blended UHMWPE.

Methods Medical grade UHMWPE (GUR1050) was blended with 0.1wt% vitamin E and compression molded. Cuboids (n=3, 1×3×3 cm) were machined and irradiated using an electron beam (Van de Graf generator) at 0.8, 1.2, 1.6 and 2.4 MeV to 150 kGy (dose rates ranged from 5 to 25 kGy/pass).

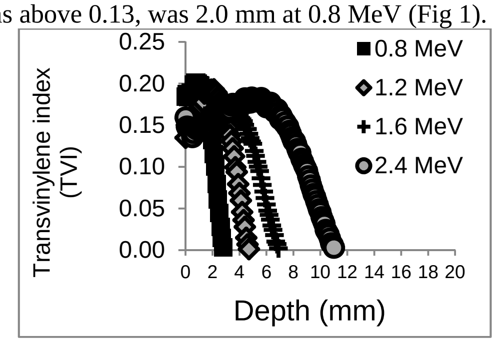
Thin sections (150 µm-thick) were microtomed and Fourier Transform Infrared Spectroscopy (FTIR) was used every 100µm from the surface along the depth. A transvinylene index was calculated by normalizing the absorbance at 965 cm^{-1} (950-980cm^{-1}) against 1895 cm^{-1} (1850 – 1985 cm^{-1}). The number of trans-vinylene groups have been linearly correlated with the radiation received [4].

Pucks blended with 0.1wt% vitamin E were irradiated to 150 kGy at 0.8, 3 and 10 MeV. Pin-on-disc (POD) wear testing was done on cylindrical pins (9 mm dia., 13 mm length, n=3) at 2 Hz [5] for 1.2 million cycles (MC). Wear rate was measured as the linear regression of weight change vs. number of cycles from 0.5 to 1.2 MC. Impact testing was performed according to ASTM F648.

Cubes (1 cm) were machined from 0.1wt% uniformly blended and 150 kGy irradiated pucks (0.8 MeV). These cubes were soaked in vitamin E at 110°C for 1 hour and homogenized at 130°C for 48 hours. Vitamin E indices were calculated by FTIR as a function of depth away from the surface as the ratio of the area under 1265 cm^{-1} (1245-1275 cm^{-1}) normalized by 1895 cm^{-1} (1850 – 1985 cm^{-1}).

Results Antioxidant stabilization of irradiated UHMWPE is used to increase its oxidation resistance [6]. New clinical formulations of UHMWPEs contain natural and synthetic antioxidants because the active stabilization of the polymer *in vivo* is desirable. We combined antioxidant blending of UHMWPE with low energy irradiation to create a surface cross-linked, vitamin E-blended UHMWPE.

The penetration depth of radiation, as measured by the maximum depth where the TVI was above 0.02, increased with beam energy (Fig 1). The surface, which was defined as the depth at which TVI was above 0.13, was 2.0 mm at 0.8 MeV (Fig 1).



Our hypothesis that the surface could be cross-linked for high wear resistance using low energy irradiation of uniformly vitamin E-blended UHMWPE proved positive. The wear rate of the surface cross-linked UHMWPE (1.12±0.15 mg/MC) was comparable to uniformly cross-linked UHMWPEs irradiated at 3 MeV (0.98±0.11) and 10 MeV (1.02±0.17 mg/MC; p>0.5). The impact strength of 0.1wt% vitamin E blended UHMWPE irradiated at 0.8 MeV was 73 kJ/m^2 compared to 54.2 kJ/m^2 for that irradiated at 3 MeV (p=0.001).

Some of the vitamin E on the surface is consumed during irradiation. It can be replenished by additional doping after cross-linking. Doping and homogenization increased the surface vitamin E of 0.1 wt% vitamin E blended UHMWPE irradiated at 0.8 MeV from undetectable levels to 0.11±0.01 (~0.7 wt%). An advantage of this method may be the shorter doping and homogenization time compared to that required for penetrating throughout an entire component [7] for increased oxidation resistance.

Conclusions Low energy irradiation of vitamin E blends of UHMWPE is a feasible method which may be used to fabricate total joint implants with high wear resistance and impact strength.

References 1. Baker et al. JBMR 66A:146-54 (2003); 2. Oral et al. Biomaterials 27: 917-25 (2006); 3. Oral et al. Biomaterials 31: 7051-60 (2010); 4. Muratoglu et al. JBMR 56: 584-92 (2001); 5. Bragdon et al. J Arthroplasty 16: 658-65 (2001); 6. Oral et al. Biomaterials 25: 5515-22 (2004); 7. Oral et al. Biomaterials 28: 5225-37 (2007).