Introduction: Oxidation in ultra-high molecular weight polyethylene (UHMWPE) due to sterilization by gamma-radiation in air to a dose of 25-37 kGy is known to lead to embrittlement and delamination wear in tibial components of total knee replacement prostheses [1] and increased particulate wear in acetabular cups of total hip replacement prostheses [2]. It has been shown that incorporating antioxidants into UHMWPE, such as Vitamin E (α-tocopherol), imparts oxidation-resistance to UHMWPE, thereby decreasing delamination wear [3] as well as particulate wear [4] in irradiated, aged UHMWPE. In this study, we hypothesized that premixing Vitamin E would impart oxidation resistance to irradiated UHMWPE during shelf aging regardless of irradiation dose. Real-time shelf aging of UHMWPE containing various concentrations of Vitamin E, conducted over a 2-year period, showed that Vitamin E induced concentration-dependent oxidation resistance in UHMWPE and could thereby be a valuable additive for UHMWPE used in joint replacement prostheses.

Materials and Methods: Compression molded billets of GUR 1020 PE (Ticona, Bayport, TX) with Vitamin E content of 0%, 0.05%, 0.1%, and 0.5%, were obtained from MediTECH Medical Polymers (Fort Wayne, IN). Each billet was irradiated with 30kGy or 100kGy of gamma radiation and shelf-aged for a period of 2 years, along with unirradiated controls. Fourier Transform Infrared (FTIR) Spectroscopy was performed using a Nicolet Magna 860 spectrometer on thin (100-200μm) sections PE (n=6), prepared using a Leitz Wetzlar sledge microtome. The FTIR beam was directed at the subsurface region where oxidation is known to be high. The microtomed sections were polished with 360 grit followed by 600 grit emery papers to decrease the Fourier rippling effect. The transvinylene index, TVI, was defined as the ratio of the area under the 965 1/cm transvinylene and 1900 1/cm carbon absorbances. The oxidation index, OI, was defined as the ratio of the area under the 1740 1/cm carbonyl and 1900 1/cm carbon absorbances. Statistical analysis was conducted using ANOVA with Fisher's protected least significant difference post-hoc test in which a p-value less than 0.05 was used to define significance.

Results: The transvinylene index, TVI, for 0, 30 and 100kGy irradiated UHMWPE, both with and without Vitamin E showed an increase with radiation dose. Although there were small differences measured in the TVI between various samples irradiated to an identical dose, the average TVI for 30kGy and 100kGy was 0.067 +/- 0.004 and 0.242 +/- 0.009, and was negligibly low for unirradiated controls (see Figure 1). As expected, the oxidation index, OI, for UHMWPE without Vitamin E demonstrated a statistically significant (p=0.05, ANOVA) increase with irradiation dose (see Figure 2). There was measurable oxidation in the unirradiated control samples as well, probably due to thermal oxidation during processing. At all concentrations of Vitamin E, there was a statistically significant (p<0.05, ANOVA) decrease in oxidation compared to the pure UHMWPE components. As expected, the OI was higher in the 100kGy dose UHMWPEs compared to the 30kGy dose UHMWPEs for all concentrations of Vitamin E except for 0.5% Vitamin E dose, which showed no statistically significant increase in oxidation at the higher irradiation dose of 100kGy.

Discussion: In this study, UHMWPE components with various concentrations of Vitamin E, irradiated to a dose of 30kGy and 100kGy respectively and shelf-aged for a period of 2 years, demonstrated a Vitamin E concentration-dependent resistance to oxidation. Oxidation resistance, wear resistance and mechanical property preservation are the three most important factors for UHMWPE components used in total joint replacement prostheses. This study shows that the presence of Vitamin E in UHMWPE imparts oxidation resistance to UHMWPE even at the high irradiation dose of 100kGy often applied to induce a high degree of crosslinking, especially in acetabular cups of total hip replacement prostheses. In addition, the radical scavenging ability of Vitamin E prevents the need to remelt or anneal irradiated UHMWPE to decrease free radicals, thereby preserving mechanical properties of UHMWPE [4, 5]. A drawback of using high concentrations of Vitamin E in UHMWPE prior to irradiation is that there is a concentration-dependent decrease in the degree of crosslinking for the same irradiation dose since the Vitamin E scavenges some free radicals before they can recombine to form crosslinks, consequently inducing a lower resistance to particulate wear. However, this may be overcome by increasing the radiation dose to account for the suppression of crosslinks by Vitamin E. In summary, Vitamin E can impart oxidation resistance and prevent the need for post-irradiation thermal treatment in UHMWPE even at high-dose radiation necessary for high wear resistance. A limitation of this study is that it only focuses on shelf aging and does not measure the efficacy of Vitamin E in providing resistance to oxidation in vivo.


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