IDENTIFICATION AND QUANTIFICATION OF RADIATION IN UHMWPE

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Introduction

Ultra-high molecular weight polyethylene (UHMWPE) is treated with ionizing radiation for two purposes: (i) either sterilizing finished components or (ii) improving its wear behavior by increasing the crosslink density. Two important problems exist in identifying and quantifying the dose level of radiation used in the irradiation (either for sterilization or crosslinking) of UHMWPE. In retrieved components, it is impossible (usually) to know if radiation was used and if so at what dose level. Secondly, now that higher doses (>5Mrad) are being used to create more crosslinking in UHMPWE, there does not exist a dosimeter that could measure these high dose levels. The state of the art dosimeters saturate at a dose level of 5 Mrad; therefore, it is impossible to measure accurately higher dose levels. With gamma radiation, it is possible to use multiple dosimeters and measure a cumulative dose level. However, this is not possible when electrons are used as the irradiation source. UHMWPE undergoes chain scission and crosslinking upon irradiation. Along with these chemical reactions, trans-vinyl units are also formed by the recombination of secondary free radicals that reside on the same chain. The concentration of the trans-vinyl units (TVU) can be readily measured by infra-red spectroscopy. The concentration of TVU has been shown to be linear with the absorbed radiation dose at low dose levels (<40 Mrad)[1]. The trans-vinyl vibration appears at a wavenumber of 965 cm^{-1} on the ir-spectrum of irradiated UHMWPE. The trans-vinyl peak height increases with increasing radiation dose level. Here we present the development of a dose/trans-vinyl calibration curve that can be used as an internal dosimeter for the radiation-crosslinking or radiation-sterilization of UHMWPE.

Materials and Methods

The material used in the present study was GUR 1050 ram extruded UHMWPE bar stock machined into puck shaped cylinders (3 cm in diameter, 4 cm in height). An Impela 10/50 linear electron beam accelerator (E-Beam Services, NJ) was calibrated to administer 25 kGy per pass. Using these calibration parameters, UHMWPE was irradiated to 25, 50, 75, 100, and 125 kGy by passing under the beam multiple times. Thin films (200 µm) were microtomed parallel to and 5 mm below the e-beam incidence surface. IR spectra was collected on these thin sections using a BioRad UMA500 ir-microscope with a an aperture size of 100x50 μm^2. The trans-vinyl index (TVI) was calculated by normalizing the area under the trans-vinyl vibration at 965 cm^{-1} to that under the 1900 cm^{-1} vibration after subtracting the respective baselines. The normalized values were then used to generate a calibration curve.

To check the validity of this method we cross-analyzed the well defined cascade penetration of e-beam in polyethylene using dosimetry and TVI method. For the dosimetry, we irradiated a stack of 16 thin sections (3 mm) of UHMWPE sandwiched with 3 Far West technology dosimeters between each section. The dosimeters were then used to calculate an average dose level as a function of e-beam penetration depth. We also irradiated a 120 mm thick puck which was then microtomed (200 µm section) in the direction of the e-beam penetration. We collected ir-spectra from this thin section, calculated the TVI and used the calibration curve to determine the dose level as a function of depth away from the e-beam incidence surface. This latter profile was then compared to one obtained from the dosimeter study.

Results

The TVI increased linearly with increasing radiation dose level (see Figure 1) with the following functionality between dose (D) and TVI: $D = 0.23(TVI) - 11$. The R^2 value of the linear regression was 0.995. Figure 2 compares the dosimeter measurement of the cascade effect with that of the TVI method. Both sets of data are in good agreement which shows strong evidence for the validity of the TVI method in determining the dose variation as a result of the cascade effect.

Discussion

The TVI method described herein is a valuable tool in several important ways: First, it can be used to quantify the effect of radiation. This allows the validation of the crosslinking process in terms of the uniformity of the dose throughout the irradiated polymer. It can also be used in determining the absolute dose level used in the newer processes of crosslinking which uses doses of radiation that exceed the capacity of the currently used radiochromic dye based dosimeters. Secondly and most importantly, the TVI method can be used in determining the actual dose level which was used in the gamma-sterilization of retrieved or shelf-stored UHMWPE components. For instance, an acetabular component implanted 20 years ago with no sterilization information can be analyzed using the TVI method to determine first if the component was sterilized using an ionizing radiation (gamma or e-beam) or EtO by checking for the presence or absence of the trans-vinyl vibration. Second, if it was sterilized by ionizing radiation, the TVI can be used to estimate the absolute dose level used in the sterilization process. The latter use of the TVI may help understand why certain components age more than others (e.g. UHMWPE components implanted prior to 1980 age much less than those implanted after 1980) both in vivo and in vitro.

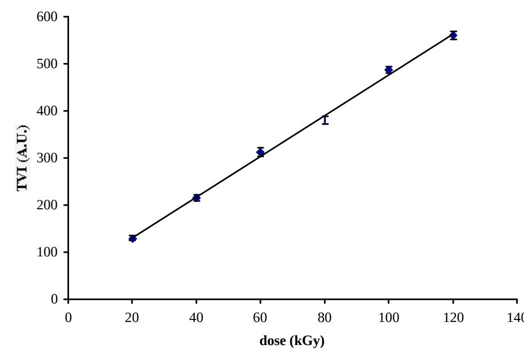

Figure 1.

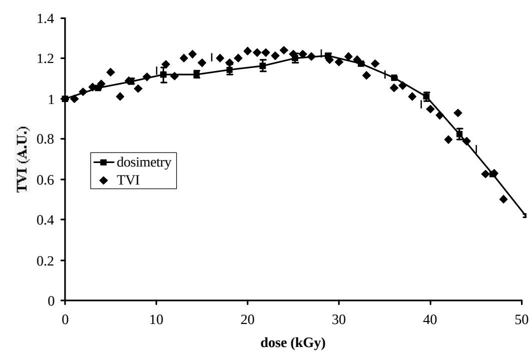

Figure 2.

References

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