

Extraction Analysis of Vitamin E-Grafted Polyethylene

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Statement of Purpose: Radiation cross-linked ultrahigh molecular weight polyethylene (UHMWPE) is the dominant bearing material for joint arthroplasty. Researchers have long recognized that incorporation of antioxidants into polyethylene could improve oxidation resistance, and that these types of additives have the potential to migrate out of the polymer matrix [1]. The type of antioxidant used, and the processing method and conditions employed, can impact the long-term oxidation resistance and biocompatibility of the device fabricated from the stabilized UHMWPE. Manufacturers must determine if elution of the antioxidant could occur in order to assure the device's safety and long-term efficacy. A testing method was developed that investigates the elution products from an antioxidant-stabilized highly crosslinked polyethylene (HXPE). The general method developed is applicable to antioxidants typically used for polyolefin materials, including Vitamin E, which is the primary antioxidant being utilized to mitigate concerns with biocompatibility [2,3]. This investigation subjected a highly crosslinked Vitamin E-UHMWPE blend to this assay.

Methods: A blend of UHMWPE (GUR 1050) with approximately 0.3 wt.% Vitamin E (VE) was prepared, then irradiated at a dose > 100 kGy (VE-HXPE). Samples were microtomed into thin slices, and then extracted in both a polar solvent (isopropyl alcohol (IPA)) and an apolar solvent (hexane), with separate specimens for each solvent. The IPA samples were soaked at room temperature for 72 hours, while the hexane samples were refluxed for 72 hours. The solvent was decanted from the slices and evaporated for both sets of samples, and the extracted residue was weighed. A sample of neat Vitamin E was placed in each solvent and subjected to the same extraction procedure as a positive control. A sample of highly crosslinked UHMWPE with no antioxidant was included as a control (GUR 1050, 100 kGy, re-melted, Non-VE HXPE). The resultant residues were then analyzed by gas chromatography with mass spectroscopy (GC-MS) and liquid chromatography with mass spectroscopy (LC-MS). Negative controls were also run for each solvent. Infrared spectroscopy (FTIR) was also conducted on the residues.

Results: The mass of hexane-extractable material from the VE-HXPE was 0.03 wt.% (300 ppm) based on the starting mass of material, and is primarily composed of aliphatic hydrocarbons. Based on the detection limits of FTIR and GC-MS, the amount of VE in this extractable material is less than 0.003 ppm of the starting material, which had a starting VE concentration of 3000 ppm. The total extractable material from the VE-HXPE is comparable to the non-VE HXPE extraction (0.02 wt. % extractables), which was also composed of aliphatic hydrocarbons. The results show that little measurable VE is extractable from VE-HXPE under aggressive extraction conditions in either apolar or polar solvent conditions.

Sample	Solvent	Residue [%]
0.3% VE-HXPE	Hexane	0.03
	IPA	0.01
Non-VE HXPE	Hexane	0.02
	IPA	0.01

The FTIR spectrum for neat VE sample showed the characteristic peak at 1260 cm⁻¹; the residue from the 0.3 wt.% sample showed no peak at this location, and only alkane groups in the rest of the spectrum (Fig 1). The GC-MS data shows that a trace amount of VE is extractable with hexane from the 0.3 wt.% sample, although the bulk of the extractables were composed of saturated C16-C20 hydrocarbons, alcohols, and carbonyls, akin to fatty acids. The latter were also extractable from the non-VE HXPE sample. No compounds were observed in the samples that had undergone IPA extractions. This result suggests that the material is more soluble in an apolar solvent compared to a polar solvent.

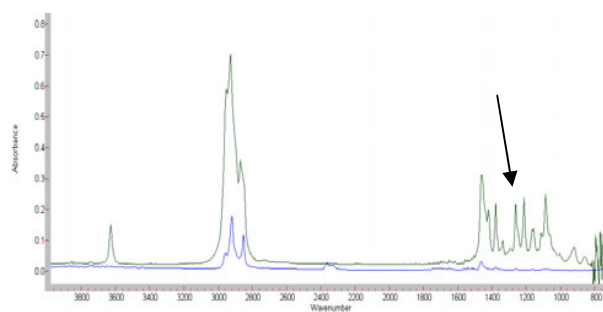


Figure 1: FTIR spectrum for hexane residue from neat Vitamin E (top) and 0.3 wt.% sample (bottom). The arrow indicates the characteristic Vitamin E peak.

The LC-MS showed comparable results for the 0.3 wt.% sample. The signal was small due to the low levels of residues extracted. The IPA residue showed some possible isomers of VE, whereas the hexane residue only showed a trace contaminant found in the LC line.

Conclusions: The polar and apolar extraction, coupled with chromatography and infrared spectroscopy allows quantification and identification of extractable residues that could possibly elute into joint space. The trace amounts of extractable material from the 0.3 wt.% blend after irradiation suggests that the VE is largely bound, i.e. grafted to the UHMWPE polymer chains, preventing elution in either polar or apolar solvents. Furthermore, the only extractable materials were simple alkanes with structures similar to fatty acids, naturally occurring species in the body, indicating that no by-products were produced from the VE.

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References:[1] Bair, Poly Eng Sci 13(6): 435-39 (1973). [2]Oral et al. JOA 21(4): 580-91 (2006); [3] Lerf et al. Biomaterials 31: 3643-48 (2010).