A COMPARISON OF 5 DIFFERENT TYPES OF HIGHLY CROSSLINKED UHMWPES: PHYSICAL PROPERTIES AND WEAR BEHAVIOR

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Introduction

Recently, peroxide [1] and radiation [2] crosslinked ultra-high molecular weight polyethylenes (UHMWPE) have been suggested as alternative bearing materials for total hip arthroplasty. These highly crosslinked UHMWPEs exhibit markedly improved wear resistance. In addition though, some of the mechanical properties are adversely affected by crosslinking. These are a function of crosslink density and crosslinking method used. They could effect the device performance in vivo. In the present paper, we compare and contrast the mechanical, thermal, and wear properties, long-term stability, cross-link density, and morphology of UHMWPE crosslinked using five different methods, in an attempt to identify the method of choice for crosslinking UHMWPE for total joint arthroplasty.

Materials and Methods

The crosslinked UHMWPEs included in this study were as follows: (i) GUR 4150 ram extruded bar stock radiation cross-linked to 200 kGy (using e-beam) in its molten state (IMS); (ii) GUR 4150 ram extruded bar stock radiation crosslinked to 150 kGy (using e-beam) and subsequently melt-annealed (CISM); (iii) GUR 1050 ram extruded bar stock pre-heated to 125°C, e-beam irradiated to 150 kGy at a high dose rate, and subsequently melt-annealed (WIAM); (iv) peroxide crosslinked GUR 1050 (G-PRX) and (v) peroxide crosslinked Himont 1900 (H-PRX). The controls used were GUR 1050 gamma-sterilized (25 kGy) in air.

The physical properties of the crosslinked UHMWPEs were determined using the following methods: (i) tensile testing for mechanical properties; (ii) differential scanning calorimetry (DSC) for thermal properties; (iii) electron spin resonance (ESR) for the semi-quantitative assessment of residual free radicals; (iv) small angle x-ray scattering (SAXS) and transmission electron microscopy (TEM) for the morphology; (v) Izod impact testing for toughness; (vi) swelling in hot xylene for cross-link density; (vii) accelerated aging in air at 80°C to assess long-term oxidative stability; (viii) bi-directional POD and hip simulator testing for wear behavior. The following table summarizes the tests performed.

Tests	Samples tested
Tensile/DSC/POD	IMS, CISM, WIAM, G-PRX, H-PRX, control
ESR	IMS, CISM, WIAM, G-PRX, control
Izod/SAXS/TEM/aging	CISM, WIAM, control
Swelling	CISM, WIAM, G-PRX, H-PRX, control
Hip Simulator	IMS (5MC†); CISM (12MC); WIAM (20MC); control (20MC)

† MC: million cycles

Results

Table 1 summarizes the characteristics of the crosslinked UHMWPEs and the control test samples. Upon crosslinking, regardless of the method used, the wear resistance of UHWMPE increased sharply; there were no detectable free radicals by ESR; the mechanical properties and toughness declined along with a drop in crystallinity; the average lamellae thickness decreased; and there was no detectable oxidation of the polymer as a result of the crosslinking process.

Discussion

The most striking effect of increased crosslinking on UHMWPE is the marked improvement on the wear resistance of the polymer. Crosslinking also affects other material properties of UHMWPE. The full extent to which these changes effect the in vivo performance of acetabular liners is yet unknown. Nevertheless, based on the data presented in this abstract, the WIAM method of crosslinking appears to have the least effect on the material properties of UHMWPE while at the same time sharply decreasing the wear rate of the polymer.

Table 1. Characteristics of crosslinked UHMWPEs.

	IMS	CISM	WIAM	G-PRX	H-PRX	control
YS (MPa)	18	20	20±0	18	NA	24±0
UTS (MPa)	14	29	30±1	3	NA	55±4
e_b (%)	<100	150	330±25	NA	NA	410±9
T_m (°C)	126	137	137	126	17	137
X (%)	38	48	45±0.4	40	46	58±0.6
ESR frs	none	none	none	none	none	yes
Izod (kJ/m^2)	NA	NA	62±2.5	NA	NA	67±5.1
SAXS lt (Å)	NA	172	160	NA	NA	240
d_x (mol/dl)	NA	0.21 ±0.01	0.18 ±0.01	0.16	0.14	NA
M_c (g/mol)	NA	4800 ±250	5500 ±300	5132	6400	NA
max(OI)	0.030	0.020	0.025	NA	NA	0.079
HS-WR	-0.8	-1.3 ±0.3	-1.2 +0.3	NA	NA	64 ±16
POD-WR	0.2	0.2 ±0.01	0.9 ±0.2	0.8 ±0.0	2.8 ±0.0	10 ±1

YS: yield strength; **UTS:** ultimate tensile strength; **e_b:** elongation at break; **T_m:** melting point; **X:** crystallinity; **frs:** free radical signal; **lt:** lamellae thickness; **d_x:** crosslink density; **M_c:** molecular weight between crosslinks; **max(OI):** maximum oxidation index after aging; **HS-WR:** average hip simulator wear rate; **POD-WR:** average POD wear rate; **NA**: not available

References

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