

Crystallinity Changes of UHMWPE Acetabular Liners in a Hip Simulator Study with Roughened Heads

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Statement of Purpose: Examinations of explanted femoral heads have shown that they are roughened in vivo [1]. Rougher surfaces suggest higher wear. The influence of surface roughness on wear of UHMWPE is not yet fully understood. Crystallinity effects wear debris production since shorter macromolecular chains have many weak physical links which makes abrasion easier. Sterilization by gamma irradiation can change the crystallinity. The purpose of this study was to study the influence of sterilization on wear of UHMWPE acetabular liners under rough conditions. Our hypothesis is that the wear mechanism of UHMWPE may be changed when the counter-surface is roughened. Raman-spectroscopy was used for crystallinity measurements, since it is a non-destructive method (as opposed to DSC) that enables further studies with the implants.

Methods: Gamma-sterilized (3 Mrad in nitrogen) and non-sterilized commercially available acetabular liners made of compression molded GUR1020 UHMWPE (Sulene™ PE, ISO 5834-2) were studied. Matching 28 mm CoCrMo (Protasul 20, ISO 5832-12) femoral heads were used as counter-surfaces, of which 7 were deliberately roughened (Ra = 400 nm) and 2 were used as new (Ra = 15 nm). The scratches were multidirectional as seen in vivo and roughness was measured with a white light interferometry profilometer. Wear testing was performed in inverted position (head on cup) in a 9 - station hip simulator (Shore Western Inc, USA) for 2 Mc at 1 Hz with a sinusoidal load curve (2 kN max) and lubricant was 25 % bovine calf serum (0.2% sodium azide and 20mM EDTA added). Polyethylene wear was determined by gravimetric measurements every 0.5 Mc and corrected for fluid absorption by non-loaded soak controls (3 sterilized, 3 non-sterilized liners). Crystallinity changes were investigated after wear test with Micro-Raman spectra Jasco NRS-2000C with a microscope of 20x magnification. Back-scattering conditions were used and detector was a 160 K frozen CCD (Princeton Instruments Inc.). 12 spectra of each cup in the inner surface near the center in the most worn area were recorded with 5 cm⁻¹ spectral resolution using 488 nm line (Innova Coherent 70) with a power of 10 mW. Crystallinity was correlated to Raman spectra using PLS regression, according to previous studies [2].

Results/Discussion: The results are summarized in Table 1. The raman spectra bands originating from the crystalline phase (1416, 1295, 1130 and 1060 cm⁻¹) were stronger for the soak gamma irradiated liners, whereas the amorphous bands (1440, 1305 and 1080 cm⁻¹) were stronger for the soak non-sterilized liners. This was also confirmed from a quantitative view by the PLS analysis. This higher crystallinity for the sterilized liners can be ascribed to the chain scission induced by gamma-irradiation [3]. Shorter chains can more easily arrange into more ordered (more

crystalline) arrangements. The gamma-irradiated liners worn with roughened heads had the highest wear and underwent an increase in crystallinity, whereas the non-sterilized liners showed the reverse effect, a decrease in crystallinity. The latter can be explained by a transformation from orthorhombic to monoclinic phase upon wear testing as previously reported only for EtO-sterilized liners after accelerated aging [4]. The gamma-irradiated liners tested with roughened heads had the highest wear, and abrasion has been reported to imply a decrease in molecular weight (and therefore increase in crystallinity) and removal of polymeric chains, that is debris production [5]. Raman spectroscopy showed that both sterilization method and head roughness influence morphology evolution of UHMWPE upon hip simulator wear testing. In fact, gravimetric measurements showed that both these parameters affect the wear performance. For the non-sterilized liners the couplings with higher surface roughness had a higher influence on UHMWPE morphology, than the couplings with new heads. This was also in agreement with gravimetric findings, Table 1.

Table 1. Crystallinity and total wear of UHMWPE acetabular liners

UHMWPE sterilization	Counterface surface	Mean % crystallinity ± standard deviation	Mean total wear (mg)
none	rough	61.3 ± 0.9	361 (N=2)
	new	62.1 ± 0.3	163 (N=2)
	none	62.0 ± 0.3	0 (N=3)
Gamma irradiation	rough	64.0 ± 0.6	409 (N=4)
	none	63.5 ± 0.3	0 (N=3)

Conclusions: Both sterilization method and head surface roughness play a role in UHMWPE morphology evolution. A crystallinity increase due to higher abrasion was observed for the gamma-irradiated cups worn with roughened heads, whereas the non-sterilized cups tested under same conditions underwent a crystallinity decrease. The decrease can be explained by the occurrence of an orthorhombic → monoclinic phase transformation.

References: [1]. Hall, RM et al, Med Eng Phys, 1997;19:711-719. [2]. Williams, KPJ, et al, J Raman Spectrosc, 1995;26:427-433. [3]. Rinnac, CM et al, J Bone Joint Surg Am, 1994;76:1052-1056. [4]. Taddei, P. et al, Biomacromolecules, 2006;7:1912-1920. [5]. Costa, L et al, Biomaterials, 1998;19:1371-1385.