THE COMPARISON OF THE WEAR BEHAVIOR OF FOUR DIFFERENT TYPES OF CROSSLINKED ACETABULAR COMPONENTS

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Introduction:
Crosslinking of polyethylene has been known for decades to improve the abrasion resistance of the polymer for industrial applications. However, only three applications of this technology have been reported in use in total hip replacements in the orthopaedics literature by Grobbelaar et. al. [1], Oonishi et. al. [2], and Wroblewski et. al. [3]. Recently, the interest in highly crosslinked UHMWPEs increased, due largely to the demonstration by several investigators that crosslinking can markedly improve the wear resistance of UHMWPE in hip simulators [4-5]. Today there are four different types of low wear UHMWPE acetabular components available or in process to become available to the orthopaedic surgeon, namely Crossfire™ from Osteonics/Howmedica, Marathon™ from DePuy/J&J, Longevity™ from Zimmer, and Durasul™ from Sulzer. These components are all crosslinked using different techniques and different radiation dose level, which lead to different degrees of improvement in wear resistance. In this study, we have evaluated the wear behavior of the four types of low wear, crosslinked UHMWPEs prepared for use in total hip replacements, before and after artificial aging

Materials and Methods:
The crosslinked UHMWPEs studied were either the commercial product or a replica of the described technique to produce: (i) Crossfire™, (ii) Marathon™, (iii) Longevity™, and (iv) Durasul™. The following descriptions for the manufacturing details of each crosslinked UHMWPE are according to their corresponding manufacturer: (i) Crossfire™ (Osteonics) is UHMWPE irradiated with gamma rays to 7.5 Mrad, annealed below the melt temperature, machined, packaged, and sterilized with gamma radiation (2.5 Mrad) in an inert gas; (ii) Marathon™ (DePuy) is UHMWPE irradiated with gamma rays to 5 Mrad, annealed above the melting temperature (150°C), machined, packaged, and sterilized with gas plasma; (iii) Longevity™ (Zimmer) is UHMWPE irradiated with 10 MeV electron-beam to 9.5 Mrad, machined, packaged, and sterilized with ethylene oxide. Except Marathon™, all the other crosslinked UHMWPEs were obtained from the manufacturers. The Marathon type material was manufactured by us, following the descriptions reported by the manufacturer (6). As control samples, we used conventional UHMWPE sterilized with 2.5 Mrad of gamma radiation in nitrogen.

All samples were machined into pins (diameter=9mm and height=13mm). Some of the pins of each material were artificially aged in an air convection oven at 80°C for three weeks. Three aged and three unaged pins from each series were wear tested. The wear tests were carried out in a bi-directional pin-on-disk machine by rubbing the pins against an implant finish Co-Cr disk through a rectangular path with a peak contact stress of 5MPa at a frequency of 2 Hz. The lubricant was 100% bovine serum. The tests were carried out to at least 2 and at most 5 million cycles (MC) with a gravimetric assessment of wear at every 0.5 million cycles. Some of the aged pins were sacrificed to determine the oxidation levels using a BioRad UMA 500 infra-red microscope as a function of depth away from the articulating surfaces. The oxidation index values were calculated by using the preferred method described by the ASTM F04.15.12 Task Force by normalizing the area under the carbonyl peak with the area under the 1370 cm⁻¹ methylene vibration. The infra-red analyses were performed before any aging and every week during the artificial aging process up to three weeks.

Results:
Figure 1 shows the wear rate comparison of the series studied here. The wear rate of the unaged pins showed significant improvement in wear rate compared to conventional polyethylene (Control). The wear rate of unaged Crossfire™, Longevity™, and Durasul™ were about 1.4 mg/MC compared to the wear rate of unaged Marathon type material at 4.5±0.2 mg/MC and control pins at 9.4±1 mg/MC. After the artificial aging, the wear behavior of the Longevity™, Durasul™, and Marathon type material were unchanged. On the other hand, the wear rate of the control increased from 9.4±1 to 14±1 mg/MC. To our surprise, the wear rate of the aged Crossfire™ pins (28±6mg/MC) was higher than that observed in aged control pins. Figure 2 depicts the oxidation profile in each series after the third week of aging, which represents the oxidation state of the pins right before the POD wear testing. The Marathon type material, Longevity™, and Durasul™ pins did not oxidize following the artificial aging cycle. The control pins showed a subsurface oxidation index of 0.4. The Crossfire™ pins displayed the highest level of subsurface oxidation at 1.7.

Discussion:
The wear rate of unaged Marathon type material was higher than that of unaged Durasul™, Longevity™, and Crossfire™ due to the lower radiation dose level used in the manufacture of Marathon type material. Reported data by the originators of Marathon material on hip simulator tests also show detectable wear [5]. The radiation dose levels in Longevity™, Durasul™, and Crossfire™ are around 10 Mrad; therefore they displayed equivalent wear rates in their aged forms.

Upon artificial aging the Marathon type material, Durasul™, and Longevity™ did not show any appreciable oxidation and hence no change in their wear behavior because the ethylene oxide and gas plasma sterilization techniques used with these polymers have no long-term deleterious effects on the properties of UHMWPE. On the other hand, Crossfire™ showed significant oxidation subsequent to the artificial aging, which was also reflected on its wear behavior. In fact, wear rate and oxidation level of aged Crossfire™ were even higher than those of the aged control polyethylene. This observation raises significant concerns on the long-term stability of the gamma sterilized highly crosslinked UHMWPEs.

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