Comparing the oxidation index between first and second generation highly crosslinked polyethylene retrievals used in total joint arthroplasty

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INTRODUCTION: Highly crosslinked polyethylene (HXLPE) was clinically introduced in the late 1990s to reduce wear and the incidence of revision caused by osteolysis. [1]. However, the process of radiation cross-linking in the polymer could generate free radicals, which have long been implicated in oxidative degradation of the material [2]. Therefore, second generation HXLPE with antioxidants such as vitamin E has been used for total joint arthroplasty recently to prevent oxidative degradation [3]. Early in vitro studies of HXLPE with antioxidants have shown promising results in terms of oxidative stability, wear resistance, and fatigue strength [4, 5]. However, there are few reports showing high oxidative stability of second generation HXLPE in vivo. Therefore, we hypothesized that second generation HXLPE has high oxidative stability compared to first generation HXLPE even in vivo environment. The purpose of this study was to compare the oxidative degradation between retrieved first and second generation HXLPE using Fourier transform infrared spectroscopy (FT-IR).

METHODS: Forty-three samples of first and second generation HXLPE retrievals with average implantation time of 57.9 months were included in this study. The first generation HXLPEs were divided into 10 samples of annealed HXLPE and 11 samples of remelted HXLPE. 22 samples of second generation HXLPE were from three materials: 9 samples of vitamin E infused HXLPE, 10 samples of vitamin E blended HXLPE, 3 samples of pentaerythritol tetrakis [3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate] (PBHP)-stabilized HXLPE. A patient demographics of three groups were shown in Table 1. There was no significant difference among three groups for a patient demographics. Retrievals were vacuum-sealed and stored at −80 °C while not undergoing analysis to inhibit ex vivo changes that occur on the shelf at room temperature in air [6]. Slices with a thickness of 200 μm were microtomed from main load zone and rim zone of acetabular liners and medial load zone of tibial inserts. Each slice was used to extract the absorbed esterified fatty acids and other lipids in boiling hexane (70℃) with a reflux for 16 h. After hexane extraction, each slice was analyzed by performing three-line scans from the articular surface to the backside using FT-IR. Each spectrum was recorded as an average of 32 individual infrared scans. Maximum oxidation index was calculated dividing the carbonyl absorption area at 1720 cm^{-1} (1680-1760 cm^{-1} or 1660-1800 cm^{-1}) and the C-H absorption area at 1360 cm^{-1} (1330-1390 cm^{-1}) in accordance with the ASTM standard [7]. We compared maximum oxidation index in the main load among three groups using Mann Whitney U test. In addition, spearman's rank correlation coefficients were used for correlation analysis between the maximum oxidation index and implantation time for three groups.

RESULTS SECTION: The maximum oxidation index of annealed HXLPE was 0.59 ± 0.29 in the main load zone, 2.32 ± 2.10 in the rim zone. The maximum oxidation index of remelted HXLPE was 0.62 ± 0.74 in the main load zone, 0.05 ± 0.09 in the rim zone. The maximum oxidation index of second generation HXLPE was 0.09 ± 0.07 in the main load zone, 0.04 ± 0.02 in the rim zone. The maximum oxidation index of second generation HXLPE was significantly lower than that of annealed HXLPE and that of remelted HXLPE in the main load zone (Figure. 1). The maximum oxidation index of second generation and remelted HXLPEs were significantly lower than that of annealed HXLPE. There was no significant difference between the maximum oxidation index between second generation and remelted HXLPEs in the rim zone. There was no significant difference between the maximum oxidation index and implantation time for annealed and remelted HXLPEs. The maximum oxidation index of second generation HXLPE was positively correlated with implantation time (Figure. 2). Second generation HXLPE with an implantation time of 99 months was observed a maximum oxidation index of 0.34.

DISCUSSION: The main finding of this study was that the maximum oxidation index of second generation HXLPE was significantly lower than that of annealed HXLPE and that of remelted HXLPE in the main load zone. Namely, high oxidative stability of second generation HXLPE was observed in the early and mid-term results in vivo. However, the maximum oxidation index of second generation HXLPE was positively correlated with implantation time. These results indicate that oxidative degradation may occur second generation HXLPE in the long-term results. HXLPEs with antioxidant were reported to prevent oxidation in retrieval analysis. Currier et al have reported low amounts of oxidation index for antioxidant polyethylene within 3 years in vivo [8]. Space et al have reported that the mean oxidation index was 0.09 ± 0.05 for the articulating surface in short term retrievals of vitamin E doped HXLPE [9]. In the present study, the low amounts of oxidation index for second generation HXLPE was observed in the main road and rim zones as compared to the same vitamin E doped HXLPE investigated in previous studies. However, no clinical studies have clarified whether second generation HXLPE has long-term oxidative stability. Therefore, long term results of the second generation HXLPE should be investigated for oxidative stability. The present study has three limitations. First, our sample size was small. Second, this result included both acetabular liners and tibial inserts. Third, the difference of mean in vivo time was observed by materials.

SIGNIFICANCE/CLINICAL RELEVANCE: High oxidation stability was observed for second generation HXLPE, as compared to annealed and remelted HXLPEs in the load and rim zone. However, concerns persist regarding the long-term oxidative stability of second generation HXLPE in the load zone.

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Table 1. Patient demographics of three groups

	Annealed HXLPE (n = 10)	Remelted HXLPE (n = 11)	Second generation HXLPE (n = 22)	p value
Male/Female	3/7	5/6	6/16	ns
Age (year; mean ± SD)	64.5 ± 13.3	73.5 ± 11.6	72.8 ± 10.0	ns
Body mass index (kg/m^2; mean ± SD)	23.7 ± 4.7	25.5 ± 4.3	25.3 ± 3.8	ns
Implantation time (months; mean ± SD)	106.7 ± 90.6	76.3 ± 55.7	26.5 ± 28.9	ns
Acetabular liner/Tibial insert	10/0	5/6	11/10	<0.05

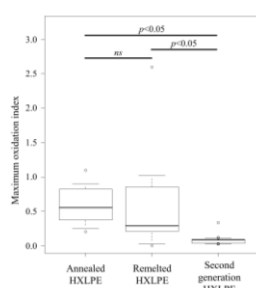

Figure 1. Comparison of maximum oxidation index in the main load zone

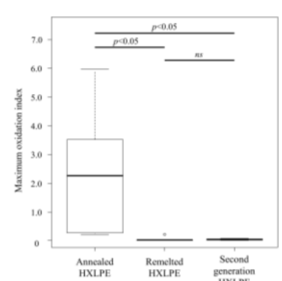

Figure 2. Comparison of maximum oxidation index in the rim zone