In vivo wear particles of remelted highly crosslinked polyethylene after total hip arthroplasty: report of four cases

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Abstract This is the first report of in vivo wear particles from four total hip arthroplasties using remelted highly crosslinked polyethylene. The number of particles was \((1.51 \pm 0.45) \times 10^7 \, \text{g}^{-1}\) (mean ± standard error); particle size (equivalent circle diameter), \(0.72 \pm 0.15 \, \mu\text{m}\); and roundness, \(1.45 \pm 0.05\). Remelted highly crosslinked polyethylene generates fewer, rounder, equivalently sized particles compared with corresponding reported values for particles generated from conventional polyethylene.

1 Case summary

We reported four patients with total hip arthroplasty (THA) using the cementless acetabular component (Trilogy; Zimmer, Warsaw, IN, US) and the remelted highly crosslinked polyethylene (Longevity; Zimmer, Warsaw, IN, US) who underwent revision THA. The remelted highly crosslinked polyethylene (Longevity) was machined from GUR 1050 UHMWPE bar cross-linked by subjection of 10-Mrad of electron beam with thermal treatment above melting point and were sterilized by gas plasma. The reason of the revision surgery was the loosening of the femoral component in two cases and the dislocation in two cases. We could not find osteolysis in any cases in the radiographs before revision surgeries (Fig. 1). The average age at the revision surgery was 64.5 years old. Two cases were male and two cases were female. The average duration before revision surgery was 2.8 years. The University of California Los Angeles (UCAL) activity score [1] before revision surgery was 5 in 1 case, 4 in 1 case, and 3 in 2 cases. Periprosthetic tissues were obtained at the time of revision THAs. Each patient was provided informed consent to participate in this study, which was approved by our Institutional Review Board.

2 Design and methods

The polyethylene wear particles in the periprosthetic tissue samples were isolated using the previously described technique [2–4]. The tissue sample was digested using 5 M sodium hydroxide at 65 °C for 1 h, applied to a sucrose density gradient (5, 10, 20 %) in a 14-mL tube (14PA tube, Hitachi Koki Co, Ltd, Tokyo, Japan), and ultracentrifuged at 28,000 rpm \((103,700 \times g)\) for 3 h (CP100x, P28S1014 rotor, Hitachi Koki Co, Ltd). The top layer was collected and applied to an isopropanol-water density gradient \((0.90 \text{ and } 0.96 \, \text{g/mL})\) in a 40-mL tube (40PA tube, Hitachi Koki Co, Ltd) and ultracentrifuged at 28,000 rpm \((103,200 \times g)\) for 1 h (CP100x, P28S1004 rotor, Hitachi Koki Co, Ltd). Polyethylene particles were collected from the interface between the two layers and filtered through 0.1-μm polycarbonate filters (VCTP 013-00, Millipore Corporation, Bedford, MA). The filters were dried, attached to an aluminum specimen mount (M4, Nisshin EM Co, Ltd, Tokyo, Japan), and coated with platinum (E-1030 ion
sputter, Hitachi Science Systems Ltd, Tokyo, Japan) for
scanning electron microscopic (SEM) examination (S-
4700SI, Hitachi Ltd, Tokyo, Japan). Images were ana-
yzed using a computerized image analyzer (Mac Scope,
Mitani Co, Tokyo, Japan). The number of polyethylene
wear particles (particles/g of wet tissue sample) in the
tissue sample was calculated. Particle size was expressed
using the equivalent circle diameter (ECD), which is the
diameter of a circle that has the same area as the particle.
Particle shape was determined on the basis of the aspect
ratio (length/breadth) and roundness (perimeter\(^2/\ 4\pi \times \text{area}\) [3, 4].

3 Results

SEM photographs of in vivo melted highly crosslinked poly-
ethylene wear particles are shown in Fig. 2. The number of
particles was \((1.21 \pm 0.30) \times 10^7/\text{g}\) (mean ± standard error).
Particle size (ECD) was \(0.85 \pm 0.07 \mu\text{m}\). Aspect ratio and
roundness were \(1.42 \pm 0.03\) and \(1.39 \pm 0.03\), respectively.

Fig. 1 A thirty-five-year-old male underwent THA using highly
crosslinked polyethylene, which failed 70 months after the operation
due to the failure of bone ingrowth of the cementless femoral
component. Although the femoral component loosened, there was no
osteolysis around the component in anterior-posterior and lateral
radiographs

Fig. 2 Scanning electron microscopy photographs of remelted highly
crosslinked polyethylene wear particles at high magnification
\((\times 10,000)\) were shown

Particle size distribution, expressed by ECD are shown in
Fig. 3. Ranges with the greatest frequency were 0.4–0.6 μm for
ECD.
4 Discussion

Polyethylene wear particles induce the release of cytokines by macrophages, leading to osteolysis and aseptic loosening in total joint arthroplasty [5–7]. Generation of polyethylene wear particles is one of the most important factors affecting mid-term and long-term results of THA [8, 9]. Number [3], size [10], and shape [11] of polyethylene wear particles have important effects on macrophage response and osteolysis prevalence. Increased numbers, submicron sizes, and elongated shapes of polyethylene wear particles induce stronger macrophage responses and are correlated to an increased likelihood of osteolysis [3, 10, 11]. To reduce polyethylene wear particle generation and achieve better long-term results of THA, highly crosslinked polyethylene has recently been introduced and is widely employed. Highly crosslinked polyethylene is classified into two groups according to the thermal treatment method performed after irradiation, namely, remelting and annealing. In former procedure, polyethylene was heated above its melting point (137 °C) after irradiation. In latter procedure, polyethylene was heated below its melting point after irradiation.

This is the first report of in vivo remelted highly crosslinked polyethylene wear particles. Previous in vitro simulator study showed that remelted highly crosslinked polyethylene acetabular component decreased volumetric wear but generated smaller particles than non-crosslinked polyethylene acetabular component [12, 13]. Smaller polyethylene wear particles induce stronger macrophage responses [10] and higher biological activity [14]. However, the size of in vivo remelted highly crosslinked polyethylene wear particles was much larger than that of in vitro previous report (0.23–0.27 μm) [13]. The difference of particle size between in vivo and in vitro studies might be due to the difference of tribological condition between the hip joint and hip simulator.

Previous in vivo study on noncrosslinked polyethylene after THA showed that the number of particles was (4.08 ± 1.35) × 10^7/g, ECD was 0.78 ± 0.06 μm, aspect ratio was 2.00 ± 0.09, and roundness was 2.61 ± 0.30 [3]. This study showed that remelted highly crosslinked polyethylene generated much fewer, rounder, and equivalently sized particles compared to non-crosslinked polyethylene in vivo. From the point of view of biological activity [14], remelted highly crosslinked polyethylene is advantageous, and is expected to reduce macrophage response and osteolysis compared to conventional non-crosslinked polyethylene.

A limitation of the current study is that the average in situ period of this study was about a sixth of that of previous report on non-crosslinked polyethylene. However the number of in vivo remelted highly crosslinked polyethylene wear particles was approximately 1/826 of the osteolysis threshold (10^{10} particles/g of tissue sample [3]), and 1/337 of non-crosslinked polyethylene [3]. We believe that the advantage of highly crosslinked polyethylene over non-crosslinked polyethylene was still evident.

This study suggested the advantage of a remelted highly crosslinked polyethylene in total hip arthroplasty. However, there were other types of highly crosslinked polyethylene, which were used not only in THA but also in total knee arthroplasty. Further in vivo evaluation on such new materials should be done.

5 Conclusions

This is the first report regarding in vivo remelted highly crosslinked polyethylene wear particles. Remelted highly crosslinked polyethylene generated much fewer, rounder, and equivalently sized particles compared with corresponding reported values for particles generated from conventional non-crosslinked polyethylene. These characteristics might affect macrophage response, osteolysis, and long-term results of THA.

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