Institute of Medical & Biological Engineering

Total Wear Particle Burden in Total Joint Replacement: A Novel Method for the Isolation of High and Low Density Wear Particles from the Periprosthetic Tissue of THR, TKR and TAR.

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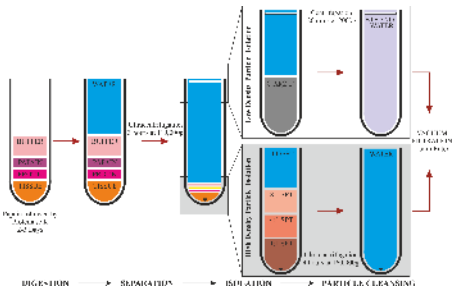
Introduction

- Total ankle replacement (TAR) is less successful than total hip and knee replacement (THR, TKR) with ~77% survivorship at 10 years.
- Differences in wear particle characteristics between THR, TKR and TAR may explain, in part, the inequality of survivorship for TAR.
- In the England, Wales and Northern Ireland, 98% of TARs are uncemented, whereas only 39% of THR and 3% of TKR are uncemented [1].
- Fixation surface integrity for TAR has been previously scrutinised [2] and fixation surface wear debris has been identified histologically [3].
- A method was developed to isolate and characterise high (>2g/cm^3) and low density (<1g/cm^3) wear particles from the same sample of periprosthetic tissue.
- The aim was to identify and compare the wear particle types within periprosthetic tissue surrounding failed THR, TKR and TAR using ultra-high resolution imaging.

Materials and Methods

- 20 mobile-bearing uncemented TAR tissue samples (15 TARs), 10 cemented THR and 8 cemented TKR tissue samples were retrieved (NHS HRA ethics: 09/H1307/60).
- Time in-vivo ranges were as follows:
  TAR: 5.9 to 15 yrs;
  THR: 6.0 to 20.8 yrs;
  TKR: 7.2 to 18.7 yrs
- Pain, infection, dislocation and/or loosening were the primary indications for revision.
- Two published protocols [4, 5] were combined to separate high (>2.0g/cm^3) and low (<1.0g/cm^3) density wear particles from the same tissue sample. The key steps were:
- **DIGESTION** of 0.5g periprosthetic tissue with 1mg/ml of papain and 1mg/ml of proteinase K over 2-3 days.



- **SEPARATION** of low and high density materials: Ultracentrifugation at 110,000g for 3 hours.
- **ISOLATION of low density particles.** Purified with chloroform:methanol (C:M) (2:1) and 2000g centrifugation.
- **ISOLATION of high density particles**. Sodium polytungstate (SPT) density gradient, centrifuged for 4 hours at 160,000g, followed by several washing steps.
- **CHARACTERISATION.** High and low density particles were filtered onto separate 15nm filters and imaged using SEM at magnifications between 200 and 100k times. Particles were characterised using ImageJ [6].
- **ELEMENTAL COMPOSITION** Identified using energy-dispersal X-ray analysis.

Results

- Similar UHMWPE particles (e.g. fibrils, granules) were identified in all joints (Fig. 1A-C). UHMWPE particles were significantly different in size between joints (Kruskal-Wallis test; p<0.001). However, there were no significant differences between individual histogram bins.
- All HA-coated TARs produced calcium phosphate particles (Fig. 1D,E), cobalt chromium and titanium particles (Fig. 1F,G).

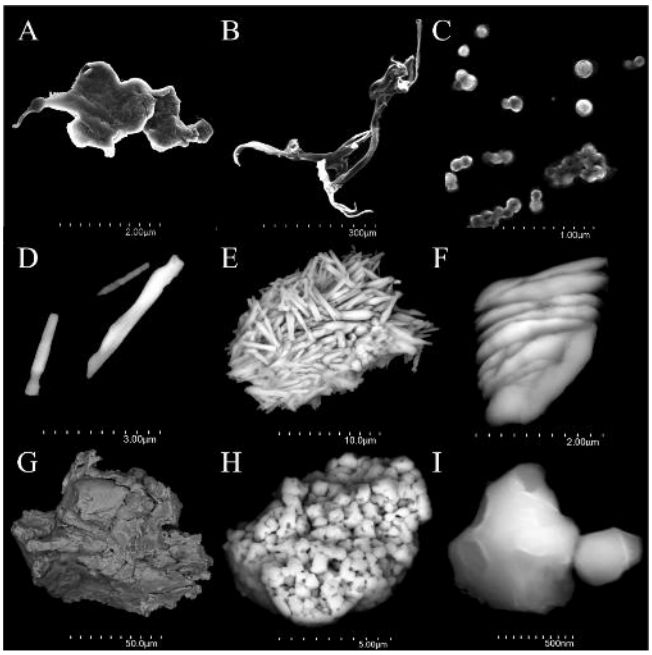
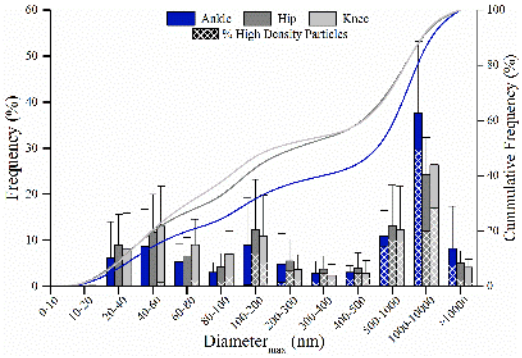


Figure 1. Example SEM images of isolated particle types. A) UHMWPE, B) UHMWPE Fibril, C) UHMWPE Granule, D) Calcium phosphate shard, E) Calcium phosphate urchin, F) Cobalt chromium alloy, G) Titanium, H) Zirconia bulk, I) Zirconia grain.

- TARs produced significantly more high-density particles between 1um and 10um (37.6±15.6% 1SD) compared to THRs (23.8±8.4%) and TKRs (26.6±11.0%) (ANOVA (arcsine transform); p=0.03) (Fig. 2).
- Zirconia grains were prevalent in THR (n=4) and TKR (n=7), and had a low aspect ratio.
- Shard-like calcium phosphate particles had the greatest mean aspect ratio (3.7±1.9). Cobalt chromium and titanium alloy particles also had high aspect ratios (Figure 3).



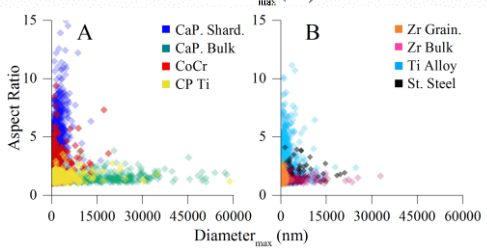


Figure 2 [Top]. Size distribution of the total wear particle burden for TAR, THR and TKR.
Figure 3 [Bottom]. Aspect ratio for the most common particle types in (A) TAR and, (B) THR and TKR. CaP. Shard, Shard-like Calcium phosphate; CaP. Bulk, Urchin-type calcium phosphate; CoCr, Cobalt chromium; CP Ti, Commercially pure Titanium; Zr Grain, Zirconia grain; Zr Bulk, Zirconia agglomerate; Ti Alloy, Titanium alloy; St. Steel, Stainless Steel.

Discussion

- UHMWPE particle types were similar between tissue isolated from all joint replacements.
- Micron-sized high density particles (i.e. calcium phosphate, cobalt chromium and titanium) caused a disparity in overall size distribution for TAR compared to THR and TKR.
- Radiopaque zirconia grains from bone cement were present in several THR and TKR tissues.
- HA-coated THR or TKR tissue samples had not been retrieved at the time of this study, therefore comparisons between uncemented devices could not be made. However, calcium phosphate particles surrounding HA-coated TARs were predominantly <10um in size with a high aspect ratio and may contribute to the risk of osteolysis.

[1] National Joint Registry for England, Wales, Northern Ireland and the Isle of Man: 13th Annual Report (2016) http://www.njrcentre.org.uk/ [2] Dalat, Frédéric, et al. OTSR 99.6 (2013): S285-S295. [3] van Wijngaarden, Redmer, et al. Foot and Ankle Surgery 21.2 (2015): 132-136. [4] Richards, L, et al. Journal of Bone & Joint Surgery, British Volume (2008). 90(8): p. 1106-1113. [5] Lal, S., R. M. Hall, and J. L. Tipper. Acta Biomaterialia 42 (2016): 420-428. [6] Schneider, Johannes, et al. Nature methods 9.7 (2012): 676-682.
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