A Comparison of Titanium Particulate Implant Debris with Titanium Particulate in Select Food Products

Nadim J Hallab[1,2], Salem R Hallab[2], Lauryn Samelko[1]
[1]Rush University Medical Center, Chicago, IL; [2]Bioengineering Solutions Inc, Chicago, IL
nhallab@rush.edu
Disclosures: Nadim J Hallab (4-BioEng. Solutions Inc), Salem R Hallab (3A- BioEng. Solutions Inc), Lauryn Samelko (3A- BioEng. Solutions Inc)

INTRODUCTION: Orthopedic implant debris remains a clinical concern. Although newer implants must pass standards associated with debris generation and residual particulate, food items currently face no such scrutiny when it comes to titanium-based particulate/powder. Further, very little is known of how titanium-based powder in some food items compares to titanium implant debris (ie, size, dose, and shape characteristics). Currently ASTM and ISO guidelines for implant wear require analysis of particulate debris into the submicron and nanometer range with no universally applicable acceptance criteria; yet justification based on predicate implant data is required. We hypothesized that the amount of titanium particulate debris generated from orthopedic implants will be similar to the amount of titanium powder people ingest on yearly basis from common daily food products. Thus, the objective of the current study was to compare titanium particulate isolated from common food items with the following: 1) predicate titanium implant debris, 2) titanium debris of a low wear (non-articulating) spinal fusion implant simulator study, and 3) with previously determined acceptable levels of residual (pre-op) titanium implant debris reported for historically well-performing total hip arthroplasty (THA) components.

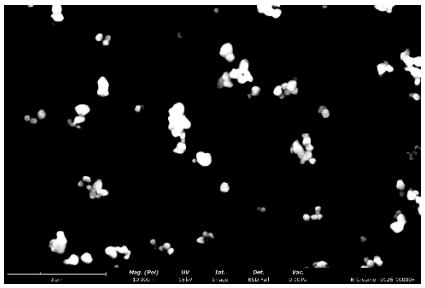
METHODS: Titanium-based particulate was isolated and characterized from 4 common food items: 1) Kroger coffee creamer, 2) Kroger lite ranch dressing, 3) Muscle Milk protein drink, and 4) Kroger mushroom soup. The titanium found in these food items was compared with 4 measures of implant derived titanium particulate exposure: 1) reported THA data[1], 2) reported total disc arthroplasty (TDA) data[2], 3) analyzed simulator debris of a titanium spinal fusion cage, and 4) residual particulate from large THA stem components (femoral stems, size 15, fiber metal midcoat titanium 6-4-alloy, with a 12/14 taper). Residual implant debris of well-performing THA stems were previously reported.[3] Simulator debris from 4 specimens of titanium based spinal fusion cages were assessed after 5 million cycles of loading according to ASTM 2077 and simulator solutions were processed and analyzed according to ASTM1877-24 and ISO 17853:2011 guidelines. Briefly, particle analysis involved enzyme/acid digestion for sample preparation, followed by Laser Diffraction (LALLS) analysis providing number and volume-based size distributions for particles from 0.01 to 700um. Extensive Scanning Electron Microscopy (SEM) with elemental x-ray analysis (EDAX) covered particles ranging from 0.02 to 2000um, including morphological quantification and high-resolution imaging using low-, med- and high-power fields (150x, 1000x and 10-50,000x) of particles collected on 0.1um and 0.015um polycarbonate filters, with over 400 particles counted per specimen and nanometer-sized particles confirmed via LALLS. Post digestion, particulate in the food items were assessed for size and shape characteristics (ie, ECD, aspect ratio, roundness form factor and perimeter) generating number and volume-based distributions for size and other characteristics. To determine mass of titanium in foods 300-600uL of sample digest was dried on 0.1um polycarbonate membranes and weighed and scaled to original food mg/mL and product-denoted serving size.

RESULTS: All particulate analyzed in this study were >95% titanium-based by composition (on a total number or total volume analysis). Titanium oxide particulate in food items ranged from 20nm to 2um in size, with an averaged median size of 0.21±0.09um ECD, which is approximately what was found in food grade titanium oxide powder (available on Amazon) at 0.25um in size, where over 99% of the particles were less than 1um. **Fig 1-a** shows an example SEM micrograph of titanium particulate in the tested coffee creamer. The associated number-based size distribution (**Fig 1-b**) demonstrates 99% of all particulate was less than 1um in size. The relative sizes of titanium-based particles are shown in **Fig 1-c**. The volume associated with a single serving of the food (following individual product labeling) compared with a year (or 1 million cycles) of implant use is shown in **Fig 1-d**, where a single serving of any of the food items was approximately 120-220mm^3 (or 480-925mg) and was over 2 orders of magnitude more than any implant total or yearly exposure measure, ie, 0.0006-1mm^3 (0.003-4.6mg). The resulting number of particles associated with this volume loss at each items respective size is reported in **Fig 1-e**.

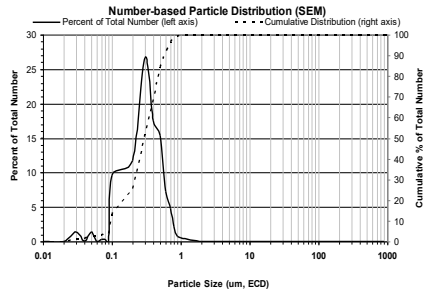
DISCUSSION: Our hypothesis that exposure to titanium-based particulate from food items and implants would be similar on a yearly basis was dramatically refuted. Even limiting the comparison to a single serving of the food item to that of a year of implant exposure demonstrated two orders of magnitude more titanium volume exposure in the single serving compared to a year of implant use (≈1 million cycles of use). Titanium particle data from previous implant studies demonstrated an order of magnitude smaller sized particles (ie, 0.050um ECD) compared with our spine implant analysis and residual particle analysis (0.2-0.4um ECD). The smaller 50nm sized particles previously reported for titanium-based implants result in similar total numbers of titanium particles as single servings of the food items despite 2 orders of magnitude less volume (or mass) exposure. This is the first study to show the several orders of magnitude greater exposure of titanium particulate in some foods in a single serving even compared to a whole year of implant use. This highlights that all sources of metal-based particulate should be incorporated into any assessment of pathology or deleterious outcomes attributed to systemic distribution of implant metals including ions and particles.

SIGNIFICANCE/CLINICAL RELEVANCE: Of clinical concern is that particulate debris within the size range of <10um are readily phagocytosed by immune and epithelial cells etc., and are well established as pathogenic regardless of the chemical reactivity of the particle. Our findings indicate that the large amount of food/ingested titanium particulate compared to the relatively small amount of implant debris highlights the relative likelihood of phagocytosis induced inflammation and systemic dissemination in vivo.

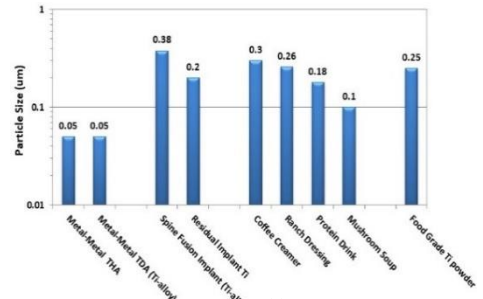
REFERENCES: [1] Catelas I, et al. *JBMR Applied*. 2004; 70(2)167-178 [2] Hellier, et al. *Spine.* 1992;17:S86-S96. [3] Hallab NJ, et al. *JBMR B*. 2024;112(2):e35387.



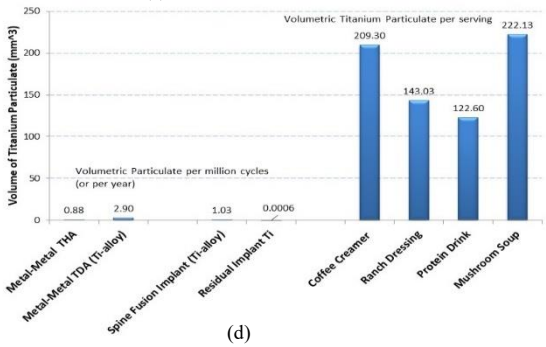
(a)



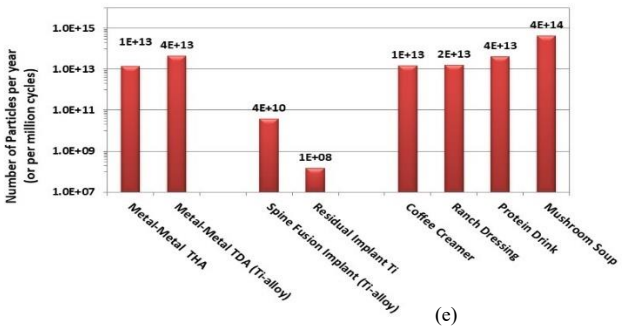
(b)



(c)



(d)



(e)

Figure 1. (a) Example micrograph of titanium oxide particles in coffee creamer; (b) Number-based size distribution of coffee creamer titanium particles; (c) Number-based median sizes of titanium particle; (d) total volume in mm^3 of particles per million cycles for implants compared with per serving in food items; (e) total number of particles calculated from size and volume per million cycles for implants and per serving for food items.