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Comparison of Simulator Wear Measured by Gravimetric vs Optical Surface Methods for Two Million Cycles

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ABSTRACT INTRODUCTION

Understanding wear mechanisms are key for better implants

- Critical to the success of the simulation
- Small amount of metal wear can have catastrophic effects in the patient such as heavy metal poisoning or deterioration of the bone/implant interface leading to implant failure
- Difficult to measure in heavy hard-on-hard implants (metal-on-metal or ceramic-on-ceramic)
  - May have only fractions of a milligram of wear on a 200 g component
  - At the limit of detection of even high-end balances when the component is 200 g and the change in weight is on the order of 0.000 1 grams
- Here we compare the standard gravimetric wear estimate with
  - ***A non-contact 3D optical profiling method at each weighing stop***
  - ***A coordinate measuring machine (CMM) at the beginning and end of the run***

METHODS

Hip Wear Simulator

- Ten CoCr Adept resurfacing hips, 50 mm diameter (MatOrtho, UK, Figure 1)
  - Nine hips tracked after lubricant failure in one station after 0.66 MC
  - Cups retained beaded surface design to promote bony ingrowth
- ProSim hip wear simulator
- Lubricating fluid, 25% calf serum, 20 mM EDTA and 0.2% NaN_3
- Dual peak loads of ~3,000 N at 1.0 Hz and at 37 ± 2°C
- Stopped at 0.33, 0 .66, 1.0, 1.33 and 2.00 MC for gravimetric and optical measurements

Gravimetric Method of Wear Measurement

- Five-decimal Genius balance (Sartorius AG, Germany) to 0.01 mg
- Three measurements for each head or cup within 0.1 mg
- Followed ASTM F1714 standard weighing procedure

Optical Measurement of Wear Scar

- Done at each weight measurement
- RedLux Artificial Hip profiler (RedLux, UK)
  - Used chromatic aberration to measure distance to surface (Tuke et al, 2010)
  - Depth resolution of ~ 20 nm in a spiral pattern (Figure 2)
  - Data fit to a sphere
  - Compared to initial base measurement (0 MC)
  - Found volume of wear, total wear area and maximum depth of wear

CMM Measurements

- Before and after 2 MC (University of Huddersfield, UK; Bills et al, 2012)

Scanning Electron Microscopy (SEM)

- Bearing surface & backside
- Energy dispersive X-ray Spectroscopy

Statistics

- Paired Student's t-tests, Considered statistically significant at $p < 0.05$
- Pearson's correlation coefficient

Figure 1. Ten Adept heads and cups with their holding fixtures.

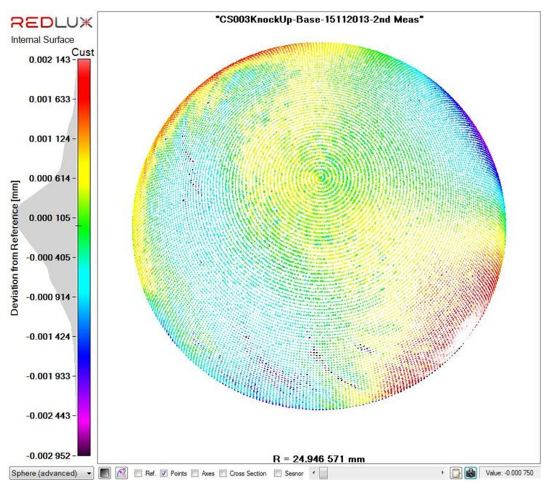

Figure 2. Spiral point pattern of the 3-D non-contact optical method on a head.

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Brian G. Mellor, Univ. of Southampton, burnishing analysis.

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Tuke et al, *Precision Engineering 34*:777–783, 2010.
Bills et al, *Wear 274*: 212-219, 2012.
McKellop et al, *J Orthop Res 32*:1221–33, 2014.
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RESULTS

Optical measurements done at all weighing intervals (n = 47)

- High degree of linearity between optical and gravimetric methods (R^2 = 0.997 for heads and R^2 = 0.96 for cups, Figures 3 & 4)
- Progressive growth of wear scars observed at each measurement over the course of the test (Figure 5)
- Tribofilm formation (Haskert et al, 2014) seen visibly and identifiable on the optical scans on most bearing surfaces
- Optical method revealed more material loss then gravimetric at a statistically high level for both heads ($p < 10^{-8}$)and cups ($p < 10^{-5}$)

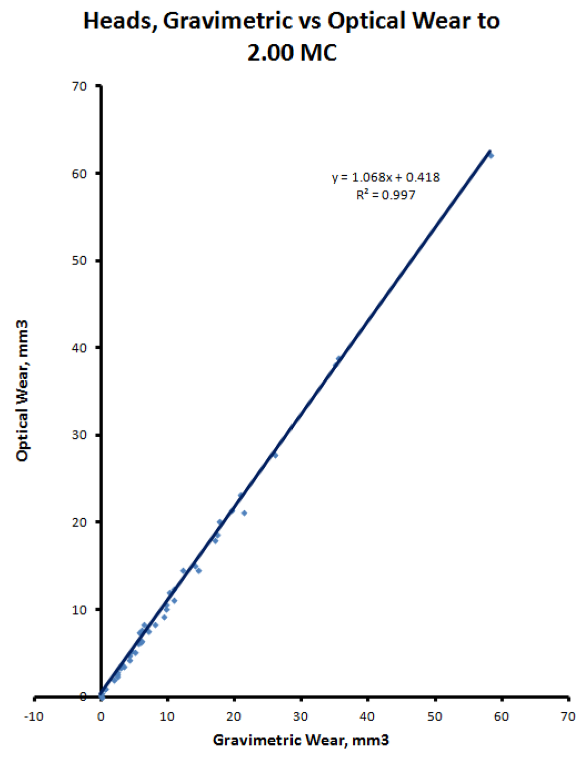

Figure 3. Volume loss measured optically versus gravimetrically for the heads.

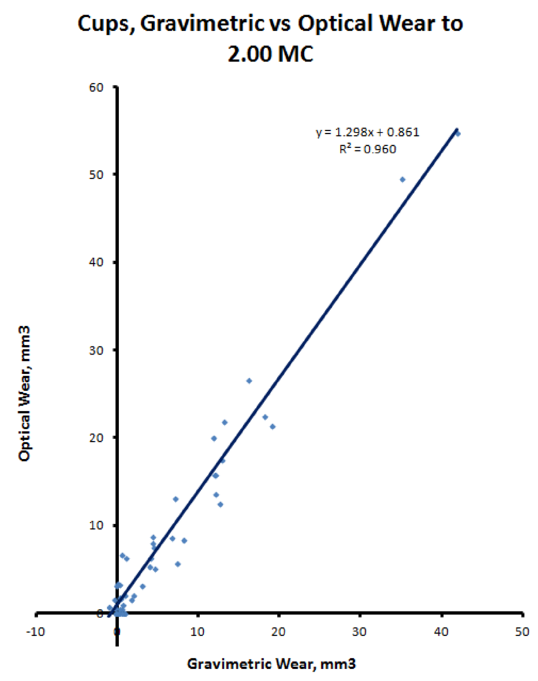

Figure 4. Volume loss measured optically versus gravimetrically for the cups.

CMM and Optical at 2 MC (n = 9 each)

Heads (Figure 6)

- Both geometric methods (optical and CMM) measured more volume loss than the gravimetric method (Optical, p = 0.004; CMM, p = 0.08)
- No statistically significant difference between the two methods in volume loss measured (p = 0.6)

Cups (Figure 7)

- Both methods measured significantly more volume loss than the gravimetric method (Optical, p = 0.01; CMM, p = 0.003)
- CMM measured more wear loss than the optical method (p = 0.04)
- Two cups recorded negative wear at 2 MC by the gravimetric method but none by either the optical method or by CMM

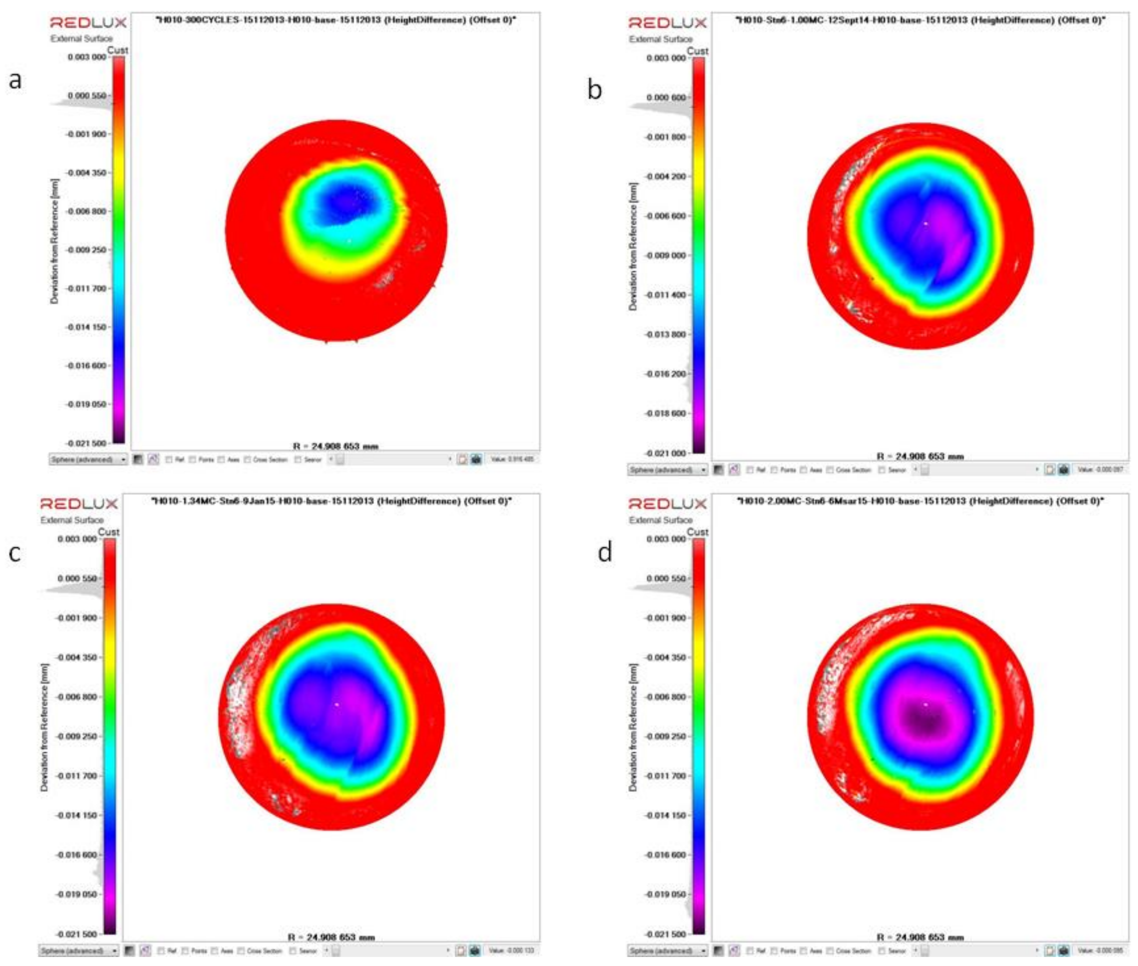

Figure 5. Progression of the wear scar and its depth from one head at a) 0.34 MC, b) 1.00 MC, c) 1.34 MC and d) 2.00 MC. White regions outside of the wear scar correspond to areas where tribofilm was observed.

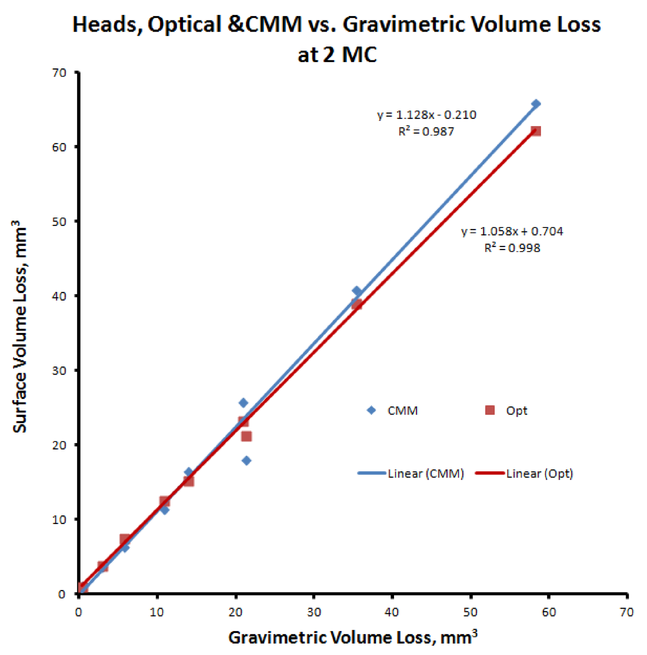

Figure 6. Volume loss in the heads measured by the optical method and CMM at 2 MC.

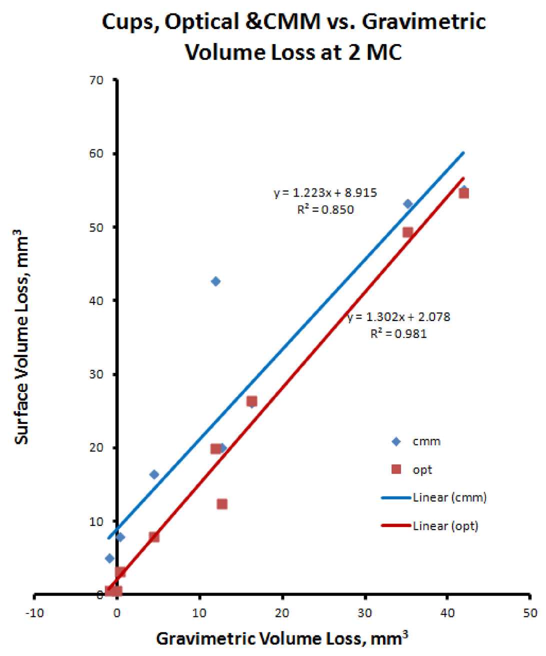

Figure 7. Volume loss of the cups measured by the optical method and CMM at 2 MC.

Confounding Factors Observed

- **Plastic Deformation, Burnishing.** Both the optical and CMM methods agree that there was more deformational change than is accounted for by the gravimetric method. The parallel scratches and polishing (Figure 8) we observed in high wear areas on the cups may have been indicative of burnishing, a type of plastic deformation.
- ***Backside absorption.*** Beaded backside surface on all the cups attracted proteinaceous debris (Figure 9) from the lubricant solution that could not be removed by the standard cleaning protocol.

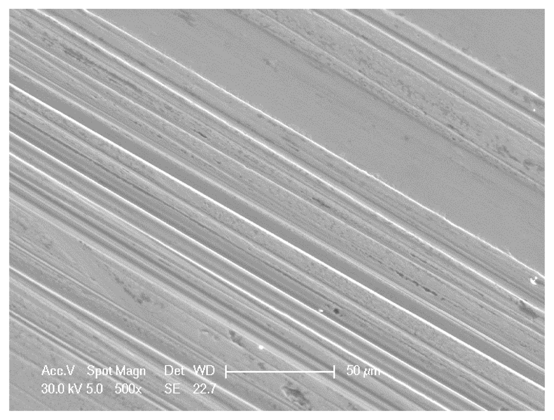

Figure 8. Burnishing on the bearing surface of a cup.

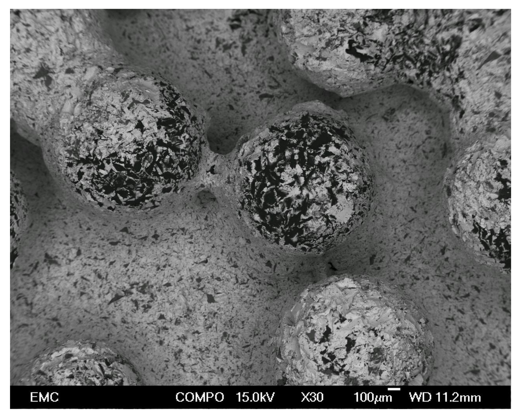

Figure 9. SEM backscatter image of proteinacious absorption on the beaded surface of the backside of a cup.

DISCUSSION

In high wear areas, particularly in the cups, we observed parallel scratches and polishing similar to that described by McKellop, et al (2014). Its appearance and our data suggests that some of this may be burnishing, a type of plastic deformation that could account for the enhanced geometric loss data not explained by the gravimetric measurement. In some situations burnishing is applied as a form or work hardening in low wear situations. We have not observed this type of wear in our retrievals suggesting that burnishing may not affect them.

In the cups, the higher deviations between the geometric and gravimetric data we believe are due to a couple of confounding factors; the above mentioned surface deformation and protein absorption on the beaded back. Burnishing would tend to bias the geometric methods to measure more wear whereas protein absorption would bias the gravimetric method to underestimate wear. The use of a combination of geometric measurement and gravimetric measurements may help distinguish between material removal and surface deformation.

There was a tendency for the CMM method to record significantly more material loss than both optical and gravimetric methods in some very low wear cups. In one cup, it measured over 8 mm^3 of loss when gravimetrically it was near zero and 3 mm^3 optically. In another, it recorded 5 mm^3 as opposed to negative wear gravimetrically and 0.7 mm^3 material optically. On the other hand, the optical method was not able to measure the excluded hip components where the serum was lost and burned unless it was changed to a 'ceramic' setting instead of a 'polished' setting.

SIGNIFICANCE

The optical and CMM geometric measurement methods provide valuable informative that cannot be obtained by the gravimetric method alone; the total wear area, its location, its depth profile and isolation of bearing surface changes from the backside wear. With automation, the optical method allowed each surface scan to be performed in minutes making it possible to monitor the progression of the wear scar with each weighing procedure. Such tracking may be used to estimate the direction and amount of wear beyond the test duration and provide more reliable values for extremely low wear allowing for improved patient outcomes through longer lasting implants.

Disclosures: L. Russell Alberts (N), Vanesa Martinez Nogues (N), Richard B. Cook (5-Biomet), Christian Maul (N), Paul Bills (3-DePuy Synthes, Johnson & Johnson, 3C-Stryker, Corin, 6-DePuy Synthes), Radu Racasan (3B-DePuy Synthes), Martin Stolz (N), Robert J. K. Wood (N)

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