Comparison Between Surface Roughness and Wettability on Retrieved Metal and Ceramic Femoral Heads

Alex Wusylko[1]; Ryan Freed[1]; Jan-M Brandt, PhD[2]; Thomas Turgeon, MD[2]; Konstantin Kornev, PhD[3]; Melinda Harman, PhD[1]
[1] Dept. of Bioengineering, Clemson University, Clemson, SC USA
[2] Concordia Joint Replacement Group, Dept. of Surgery, University of Manitoba, Winnipeg, CANADA
[3] Dept. of Materials Science and Engineering, Clemson, SC USA

Statement of Purpose: High hardness and good wettability are considered essential characteristics contributing to fluid-film lubrication of articular bearing surfaces in total hip replacements (THR).[1] In the absence of low-friction polyethylene materials, as exists with hard-on-hard bearing couples such as ceramic-on-ceramic THR, the impact of wetting on fluid film behavior and lubrication is heightened. However, assessing wetting through accurate contact angle measurements of THR articular bearings is difficult due to the curved spherical geometry and variations in surface roughness accumulated during *in vivo* function.[2] The objective of this study is to quantify surface roughness and wettability of metal and ceramic femoral heads that have been retrieved from patients after *in vivo* function.

Methods: Two IRB-approved archives of retrieved hip prostheses were queried to identify a subset of modular ceramic (n=42) and metal (n=18) femoral heads that had functioned as ceramic-on-ceramic or metal-on-UHMWPE bearing couples, respectively. From these, a group of 12 Retrieved Heads were selected based on visual evidence of specific damage modes, including no damage, scratching, metal transfer, and stripe wear (grain pull-out). The Retrieved Heads were fabricated from metal cobalt-chrome alloy (Co-Cr), ceramic alumina oxide (Biolox Forte), and ceramic zirconia-toughened alumina (Biolox Delta). Three unused 28 mm diameter femoral heads fabricated from the same Co-Cr, Biolox Forte, Biolox Delta materials were acquired for use as Control Heads.

All heads were previously decontaminated following retrieval, with additional thorough cleaning using ethanol, deionized water and a jet of compressed nitrogen immediately prior to roughness and contact angle measurements. Measurement point locations on each head were predetermined using an optical microscope and circled with a fine-tipped marking pen for easy identification. Marked points were equally distributed around the Control Heads and selected within the previously identified damage zones for Retrieved Heads.

Surface roughness and contact angle were each measured in the marked point locations. Surface roughness parameters (Ra, Rpm, Rvm, etc.) were measured using a non-contact interferometer (NP-Flex, Bruker Corp.) at ~20X magnification and 316x237 micron field of view. Contact angle was measured using a drop shape analyzer (DO4010 Easy Drop, Krüss GmbH) and deionized water solvent applied consistently in 1 μl droplets. Air temperature and humidity during measurements were monitored and maintained at 80 °F and 50%, respectively. We have previously developed and verified a method for measuring contact angle on femoral head articular surfaces, including image analysis software and appropriate mathematical corrections for analyzing a curved (spherical) geometry.[3]

Table 1: Surface Roughness & Contact Angle for Control Heads
* For brevity, only Ra roughness values are presented in Table & Figure.

Material	Ra (nm)*	Angle (º)
CoCr	45.4±6.4	87.1±0.7
Biolox Forte	39.4±5.7	62.2±1.4
Biolox Delta	37.8±2.5	70.7±1.5

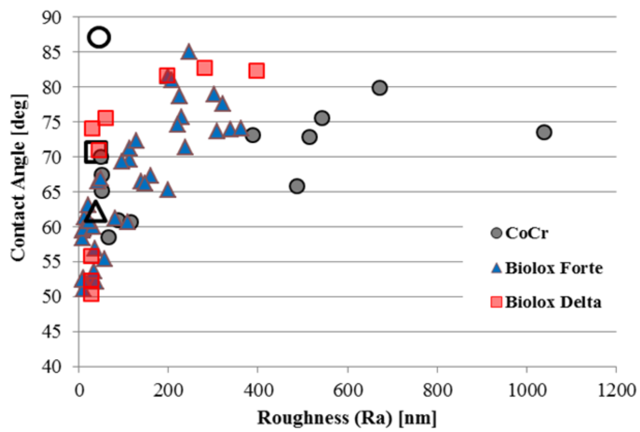

Figure 1: Contact angle and surface roughness were widely varied on Retrieved Heads (filled symbols) compared to the undamaged Control Heads (unfilled symbols are average values from Table 1).

Results: There were no significant differences in surface roughness among the different Control Head materials (Table 1). The Co-Cr had a significantly higher contact angle than either the Biolox Forte or Biolox Delta ceramic materials (ANOVA, $p<0.001$). The Biolox Forte had a significantly lower contact angle than either the Co-Cr or Delta materials (ANOVA, $p<0.05$), which corresponds to the highest wettability. Among Retrieved Heads, heads with metal transfer generally had the highest roughness due to material pile-up on the surface. Co-Cr Retrieved Heads had the largest range of surface roughness and consistently lower contact angles than Co-Cr Control Heads. Regions of stripe wear and metal transfer on the ceramic Retrieved Heads altered the magnitude of surface roughness and degree of wettability compared to the Control Heads.

Conclusions: The combined use of surface profilometry and optical contact angle methods was useful for characterizing relationships between roughness and wetting for different THR bearing materials. For all three femoral head bearing materials, function in a physiological environment prior to retrieval contributes to surface changes that alter the wetting behavior relative to the Control Heads, even in regions identified as "no damage".

References: 1) Rahaman. J Am Ceram Soc 2007. 2) Bormashenko. J Phys Chem 2009. 3) Freed. ORS 2014.

Acknowledgements: Technical input from Bryan Thurston & Gulya Korneva; funding from Bioengineering faculty start-up package; equipment from South Carolina COBRE Center of Biomaterials for Tissue Regeneration.