

THERMAL CONDUCTIVITY OF FEMORAL BALL STRONGLY INFLUENCED
UHMWPE WEAR IN A HIP SIMULATOR STUDY

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Introduction

Although on average ceramic-on-polyethylene systems out-perform metal-on-polyethylene systems by 2-fold in patients [1,2], this superior performance of ceramic balls over Co-Cr is not consistently demonstrated in hip simulator studies [2]. For example, a UHMWPE study by Saikko et al [3] correctly ranked alumina balls lower than Co-Cr balls, while studies by McKellop et al, Polineni et al and Clarke et al reported the opposite [2,4,5]. Also note that simulator studies with zirconia balls have reported ultra-low UHMWPE wear [6] while zirconia balls in patients have frequently shown higher wear compared to Co-Cr [1,7]. Factors like serum concentration, simulator type and sterilisation may explain some differences [2,5]. However, the thermal conductivity of the femoral ball may be a strong factor in the in-vitro wear of UHMWPE [4].

Alumina has a higher thermal conductivity than the other materials, (Figure 1). This may create a high wear condition due to less protein precipitates [2,4], i.e. in a manner that does not occur in-vivo. Thus, the relationship between femoral ball thermal conductivity and UHMWPE wear has yet to be established.

Our aim was to explore the relationship between ball thermal conductivity and UHMWPE wear in a head-to-head study. The hypothesis was that balls with high thermal conductivity would create higher UHMWPE wear compared to balls with lower thermal conductivity.

Materials and Methods

Ten 28 mm ID isostatically moulded UHMWPE liners were investigated: GUR 1050 resin, gamma-sterilized with 25–40 kGy in argon (ArCom™, Biomet Inc, Warsaw, IN). The liners were coupled with zirconia (Y-ZrO₂: Prozyr®), cobalt-chrome (Biomet, Inc), silicon nitride (Si₃N₄: Amedica-Inc, UT) and alumina femoral balls (Al₂O₃: BioloX-forte®) (Figure 1). All balls had similar initial surface finish (Ra: 4–12 nm).

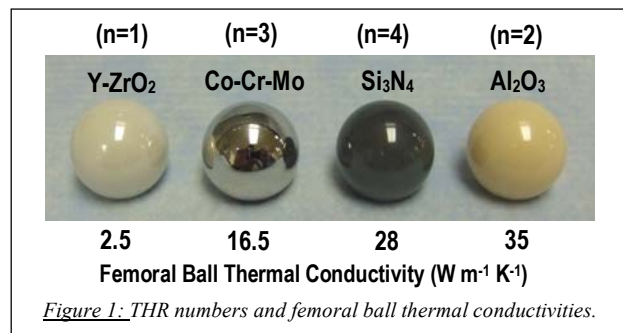


Figure 1: THR numbers and femoral ball thermal conductivities.

Liners were positioned inverted in an orbital hip simulator (Shore-Western, Monrovia, CA). Diluted alpha-calf serum (HyClone, UT) was used as a lubricant (protein 20 mg/ml; volume 150 ml). Test duration in this report was 3.0 million cycles (Mc) (Paul Curve, 2.2 kN max, 1.0 Hz). Any contamination by bio-films were removed every 0.5 Mc. Polyethylene wear was measured gravimetrically every 0.5 Mc and adjusted using identical loaded soak controls (N=6). Bulk serum temperatures were measured using a thermometer.

Results

The wear trends appeared linear for all UHMWPE liners. The average wear slopes were 5.8, 16.5, 20.0 and 20.0 mm³/Mc for the Y-ZrO₂, Co-Cr-Mo, Si₃N₄, and Al₂O₃ hips, respectively. Average wear versus femoral ball thermal conductivity demonstrated a strong logarithmic relationship [y=5.6Ln(x), r²=0.99, Figure 2].

Bulk serum temperatures for Y-ZrO₂ and Co-Cr-Mo stations averaged 33 °C, while Si₃N₄, and Al₂O₃ stations averaged 29 °C, i.e. a 4.0 °C difference. After 0.5 Mc, the used serum from the Y-ZrO₂ and Co-Cr-Mo stations appeared more viscous and lighter in colour

compared to the Si₃N₄, and Al₂O₃ stations. This was indicative of greater protein precipitations.

Discussion and Conclusions

Our study showed that UHMWPE wear increased logarithmically with increasing thermal conductivity of the femoral ball (R²=0.99), thereby proving our hypothesis. This may be the first laboratory study to demonstrate this relationship.

The ranking of UHMWPE wear versus femoral ball material in our study was not consistent with clinical data, and confirmed previous work [2,4,5]. Alumina as a known good clinical wear performer had identical results in our laboratory study as silicone nitride. As Si₃N₄ and Al₂O₃ are both good conductors of heat, the serum proteins were less compromised, thereby promoting higher UHMWPE wear. Zirconia, as a thermal insulator, promoted lower UHMWPE wear as a result of the higher protein precipitation [4].

As the wear of UHMWPE is so influenced by protein precipitation, it is likely that current hip simulation protocols are unable to correctly rank the performance of ball materials with markedly different thermal conductivities. The simulator study by Saikko et al [3] reported the correct ranking of femoral balls. However, their data showed 50% variability and their specimen groups were not evaluated simultaneously.

Liao et al [8] suggested that circulating coolant could avoid serum overheating with zirconia balls and give the correct ranking of alumina/PE lower than Co-Cr/PE. However, such active cooling also created non-physiological wear features. Although some degree of cooling may help, there is obviously a limit to what can be performed. Thus, it is likely that that modern hip simulation cannot provide correct ranking of varied femoral ball materials with calf-serum lubrication.

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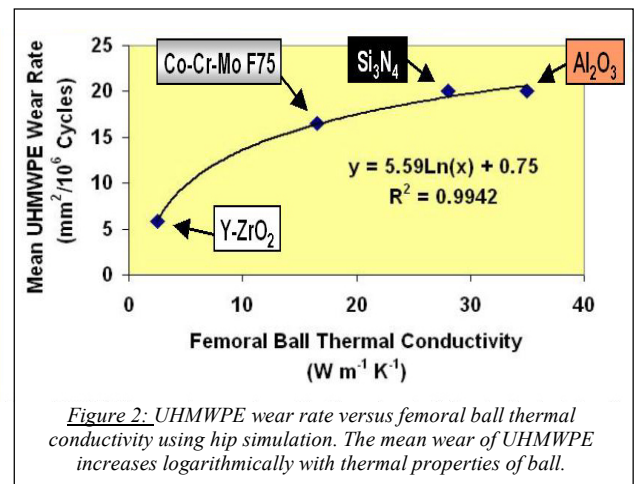


Figure 2: UHMWPE wear rate versus femoral ball thermal conductivity using hip simulation. The mean wear of UHMWPE increases logarithmically with thermal properties of ball.

