EFFECT OF HEAD MATERIAL AND SIZE; SERUM CONCENTRATION, RECIRCULATION, AND TEMPERATURE; CYCLIC FREQUENCY; AND LOAD MAGNITUDE ON HEAD/LINER TEMPERATURES IN AN ANATOMICAL HIP WEAR SIMULATOR

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Relevance to Musculoskeletal Conditions: UHMWPE wear can contribute to clinical failure in total hip arthroplasty (THA). Accurate in vitro assessment of the wear behavior of THA materials and designs requires careful development and validation of hip simulator test procedures.

Introduction: One test condition which has a potentially significant effect on UHMWPE wear during hip simulator testing is head/liner interface temperature (i.e., frictional heating).[1] Lu et al.,[2] using a biaxial rocking hip simulator, have measured 32 mm CoCr head / UHMWPE liner interface temperatures to increase from 43°C to 96°C by increasing cyclic frequency from 1 Hz to 2 Hz. Based on such results they cautioned investigators about the potential for thermal artifacts. Bragdon et al.,[3] however, using a fundamentally different simulator, have measured this increase to be from 41°C to only 45°C. It is suspected that machine- and method-related variables explain this disparity. In this study, a simulator similar to that used by Bragdon et al.[3] was used to further the understanding of the many factors which affect thermal conditions at the head/liner interface. In addition to the effect of head material and cyclic frequency investigated by Lu et al.,[2] this study also investigated the effects of serum concentration, recirculation, serum temperature, load magnitude, and head size.

Methods: CoCr, Al_2O_3, and ZrO_2 femoral heads of various sizes were matched with commercially available UHMWPE liners and Ti-6Al-4V shells (S&N Reflection). All stations of a 12-station anatomically oriented hip simulator (AMTI, Watertown, MA) were used. With a "cold" start, it took 4-6 hours for the system to reach thermal equilibrium. Thermocouples were placed in each lubricant reservoir, in the lubricant a few millimeters adjacent to the base of each femoral head, and 0.13 mm below each femoral head surface ("interface"). A one-peak load curve[4] and three independent motion waveforms (flex-ext, IE, ab-ad)[5,6] were applied to each test assembly. Hyclone® bovine calf serum (Logan, UT) with sodium azide and EDTA was used as the lubricant. Constant conditions included: 1) lab temp. 22°C, 2) max. hydraulic oil temp. 43°C, 3) load/motion waveforms, 4) specimen orientation, and 5) lubricant volume (500 ml). Variable conditions included: 1) serum concentration (100%, 50%, and 0%, diluted with deionized water), 2) serum recirculation (on vs. off), 3) serum coolant temperature (37°C vs. 20°C), 4) cyclic frequency (0.5, 1.0, 1.5, and 2.0 Hz), 5) load magnitude (peak load: 1111 N, 2223 N, 3335 N, and 4446 N), 6) head material (CoCr, Al_2O_3, and ZrO_2), and 7) head size (22 mm, 28 mm, and 32 mm).

Results: Peak interface temperatures with Al_2O_3 heads were lower than for CoCr and CoCr heads were lower than ZrO_2 as shown in Figure 1. Also shown is the trend for decreasing temperatures with increasing head size. Interface temperatures increased only slightly with increasing load, as shown in Figure 2. There was a modest increase in interface temperature from water to 50% serum to 100% serum. The increase in interface temperature from 1 Hz to 2 Hz was slight, especially for CoCr heads, similar to the AMTI simulator results of Bragdon et al.[3] These temperatures increased when temperature control and serum recirculation were turned off (Fig. 3) which could partially explain the results of Lu et al.[2] When the serum was cooled (bulk serum temperature from 37.5°C to 29°C) and recirculated, interface temperatures decreased notably.

Discussion: Bergmann et al.[7] have used in vitro data[8] to estimate that in vivo peak interface temperatures during walking with a 32 mm CoCr head are roughly 44.5°C. This extrapolation assumed that the interface temperature was only 1°C higher than at the neck location. For comparable conditions, the present study measured peak interface temperatures to be 7°C higher than at the neck location which extrapolates to 50.5°C at the interface. Relevant baseline conditions in this study (Fig. 1) resulted in a peak interface temperature of 41.22°C, well below this maximum value. This approach may be used to establish target temperatures which should not be exceeded during simulator wear testing. The material dependent temperature effects result from combined thermal and frictional parameters. Specifically, Lu, et al.,[9] has noted that the thermal conductivity of ZrO_2 is 7% of Al_2O_3 and 16% of CoCr. In addition the friction coefficients for Al_2O_3 and CoCr are 35% and 63%, respectively, greater than ZrO_2,[9]. This suggests that the effect of a lower thermal conductivity is partially offset by a reduced friction coefficient for ZrO_2. This study indicated that numerous machine- and method-dependent test parameters have significant interacting effects on the thermal conditions present during simulator wear testing. For this reason, we recommend that hip simulator investigators conduct their own measurements and not rely on the results of others, even if test conditions appear similar.

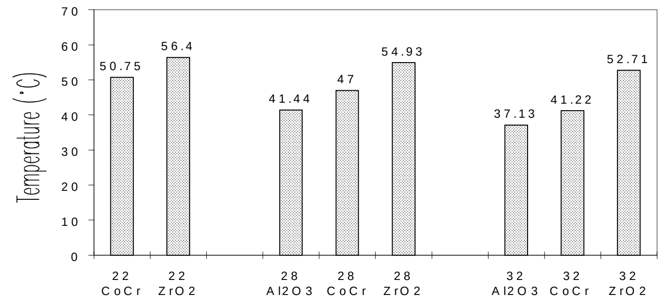

Fig. 1: Peak interface temperatures as a function of head material and size (at 2 Hz, 2223 N peak load, 100% serum, with serum recirculation)

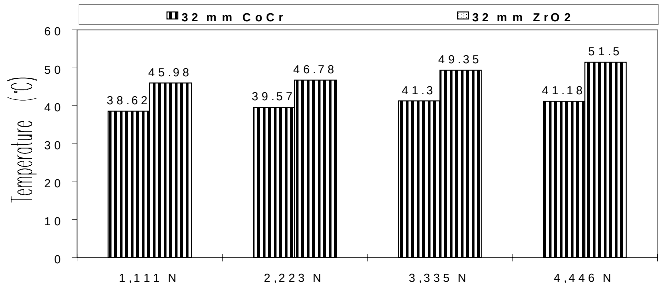

Fig. 2: Peak interface temperatures as a function of load magnitude (at 1 Hz, 100% serum, with serum recirculation)

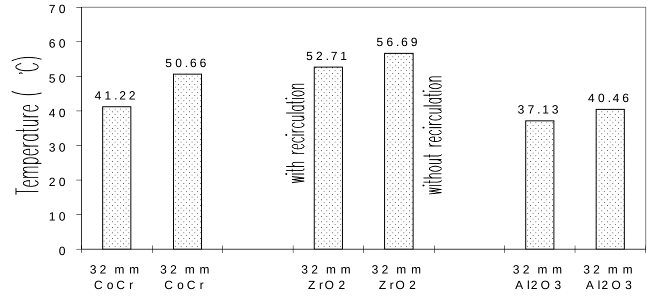

Fig. 3: Peak interface temperatures as a function of serum recirculation (at 2 Hz, 2223 N peak load,100% serum)

References: [1] McKellop, Eng.in Med., 10, 123-136, 1981, [2] Lu et al., Trans.44th ORS, 358 (1998), [3] Bragdon et al., Trans.24th SFB, 361 (1998), [4] Bergmann et al., J.Biomechanics, 26 (8) (1993), [5] Murray, Am.J.Phys.Med., 46 (1967), [6] Johnston et al., JBJS, 51A (1969), [7] Bergmann et al., Trans. 37th ORS, 223 (1991), [8] Davidson et al., JBMR, 22 (A1) (1988), Lu, et al., IMechE, 106, (211), 1997

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