Bone-on-Bone vs. Implant Impingement in Large Diameter Total Hips

INTRODUCTION:
Dislocation remains a serious concern for total hip arthroplasty (THA). Due to the recent reduction in the incidence of wear-induced osteolysis, dislocation has surpassed aseptic loosening as the single most common reason for revision surgery. While dislocation is a highly dynamic and multi-faceted event, mechanical impingement leading to levering-out of the femoral head is undoubtedly the most common mechanism. Recent advances in THA bearings – specifically the use of highly crosslinked polyethylene, metal-on-metal and ceramic-on-ceramic – have allowed for substantial increases in allowable femoral head diameters. In addition to improved tribologic properties, larger head diameters afford substantial increases in range of motion prior to impingement. Ultimately, the upper limit of permissible head size is dictated by (pelvic) anatomy, and risk for intraoperative complications increases when component sizes approach this limit.

Cadaveric [1] and mathematical [2] studies have demonstrated that bone-to-bone impingement predominates for heads greater than 32mm or 36mm respectively. However, regarding variance in impingement mechanics, these investigations were limited by (1) only reporting range of motion, and (2) simplified joint motions. Therefore, a 3D dynamic finite element (FE) model of THA impingement was developed to investigate the role of femoral head size and impingement modality (i.e. bone-bone or component-component) on dislocation resistance and the generation of edge-loading stresses for metal-on-metal total hips.

METHODS:
A previously developed [3] FE model of a contemporary modular 36mm metal-on-metal THA implant was used in this investigation. Using manufacturer-provided specifications, additional implants with 32mm, 34mm, 38mm, 40mm, 42mm and 44mm were generated (Fig. 1). Mesh densities for each were determined from convergence studies. Bony anatomy of the pelvis and femur were determined by manual segmentation of the Visible Human (NLM, Bethesda, MD). The bony anatomy was registered to the pelvic reference frame of the FE model, and virtual femoral osteotomy and pelvic reaming were performed (Geomagic Studio 12).

Candidate impingement challenge motions were determined from five posterior-direction dislocation maneuvers (low sit-to-stand, stooping, squatting and leaning) [4]. Of these, only stooping resulted in bone-bone impingement for a neutrally-oriented cup (40° cup inclination, 15° anteversion) (Fig. 2).

In addition to these seven FE models of bone impingement (referred to here as “bone-40”), seven additional FE models were generated with a more horizontal cup orientation (approximately 30°, “cup-30”), resulting in neck-on-cup impingement. To eliminate cup orientation as a confounding factor, seven additional FE models were generated at the low cup position, but with numerical contact removed between the neck and cup, thus forcing contact instead to be bone-to-bone (“bone-30”).

RESULTS:
The component-on-component impingement events generated significantly higher contact and surface stresses compared to the two bone impingement scenarios (Fig. 3a). The two separate bone impingement models had similar stresses. Stresses for all three impingement situations decreased with increased head diameter, the effect being most pronounced for the cup impingement events. Peak resisting moment for the two bone impingement scenarios were, on average, 5.5- and 2.6-fold higher than for hardware impingement (Fig. 3b).

DISCUSSION:
To the authors’ knowledge, this study represents the first investigation of the variance in mechanisms and consequences between implant-on-implant vs. bone-on-bone impingement events. While all impingement events are bad, the present data clearly indicate that all impingement events are not equal. Bone-on-bone impingement, which has been postulated to occur with greater frequency in larger head THAs, was shown to generate substantially greater resistance to dislocation, and considerably less contact stress, than hardware impingement scenarios. For all but the largest implants investigated, surface stresses generated approached or exceeded the yield strength of cobalt-chrome alloy. Together, this suggests that, should impingement occur, impingement between the neck and cup are (1) more likely to dislocate, and (2) more prone to causing damage of the bearing surface.

Additionally, while it is often suggested that osseous impingement in large-diameter THAs is the limiting factor for joint range of motion, this investigation has shown that hardware-only impingement is still possible for multiple dislocation-prone motions.

SIGNIFICANCE:
Should impingement occur, contact between the bony femur and pelvis is substantially less detrimental than that between the implant neck and cup. Larger femoral heads, regardless of impingement location, result in less edge-stress and greater dislocation resistance.

REFERENCES:

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Figure 1: The THA FE models used in study. From left to right: 32, 34, 36, 38, 40, 42 and 44-mm.

Figure 2: Pure flexion (a) results in impingement between the femur and the anterior inferior iliac spine at approximately 100° of flexion. By contrast, even with 105° of flexion, squatting (b) does not result in impingement. Stooping, however results in impingement on the acetabular rim at 108° of flexion (c).