Optimization of Surgical Positioning in Total Hip Replacement

When joint pain and loss of mobility occur as a result of end-stage osteoarthritis or other severe hip pathologies, over 250,000 people choose to have total hip replacement (THR) surgery. Even though THRs are one of the most successful surgical inventions in medical history, they do fail. THR failures are often grouped as "early" or "late," with early failure usually due to dislocation of the head from the cup, and late failure frequently due to adverse biologic reaction to wear debris generated at the bearing surface. Despite nearly six decades of investigation, the ideal surgical orientation of THR components remains unclear. Positioning of total hip bearings involves significant tradeoffs, as cup orientations most favorable in terms of stability are not necessarily ideal in terms of reduction of contact stress and wear potential. Previous studies and models have not addressed these potentially competing considerations for optimal THA function. Additionally, it is currently unknown whether the ideal orientation varies on implant parameters, such as variations in femoral head size. We, therefore, investigated optimal surgical cup orientation with a previously generated and physically validated finite element (FE) model of metal-on-metal THR.

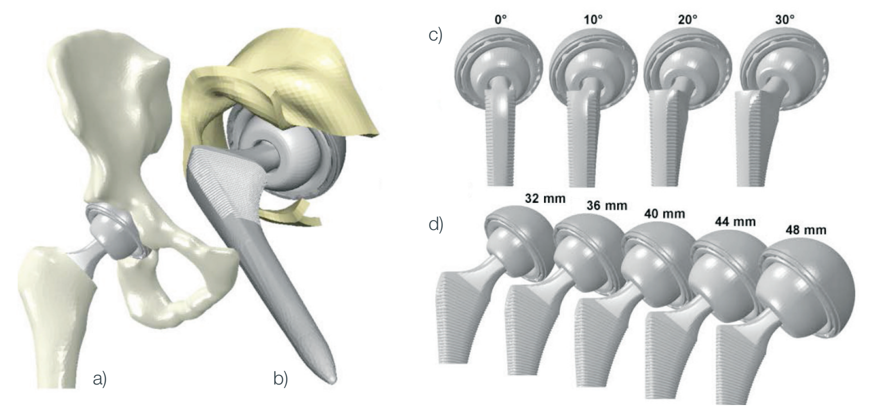

Figure 1. The FE model consisted of bony anatomy (a) and the hip soft tissues (b, anterior region of capsule rendered transparent for clarity). Four values of femoral anteversion were considered (c) as were five distinct femoral head sizes (d).

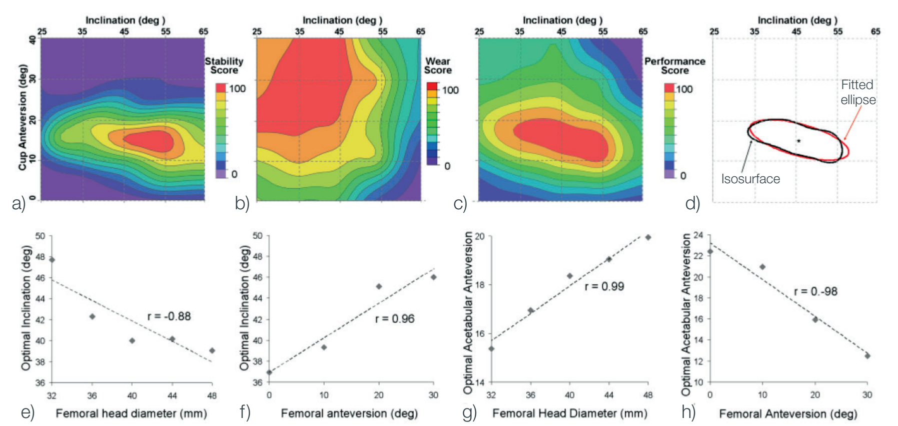

Figure 2. For every combination of femoral head size and femoral anteversion (20 such combinations total), the Stability Score (a) and Wear Score (b) are combined to determine the Performance Score (c). The optimal orientation is determined as the center of an ellipse fitted to an isosurface of scores > 90 (d). When considering all 20 combinations, regressions could be performed demonstrating optimal surgical orientation (e-h).

Method

The FE model consisted of bony anatomy and the hip soft tissues (see Figure 1). Five dislocation-prone motions as well as gait were considered, as were permutations of femoral anteversion (0° to 30°), femoral head diameter (32 mm to 48 mm), cup inclination (25° to 75°), and cup anteversion (0° to 50°), resulting in 4,320 distinct FE simulations. A novel metric ("Performance Score") was developed to delineate optimized cup orientation by considering both surface wear and component stability (see Figure 2 A-D).

All FE simulations were performed using Abaqus/Explicit.

Results

Ideal cup position was substantially more sensitive to cup anteversion than to inclination. Regressions demonstrated strong correlations between optimal cup inclination vs. head diameter (Pearson's r = -0.88), between optimal cup inclination vs. femoral anteversion (r = 0.96), between optimal cup anteversion vs. head diameter (r = 0.99) and between cup anteversion and femoral anteversion (r = -0.98) (see Figure 2 E-H).

Discussion

The "landing zone" of ideal cup orientation did not increase with increased head size, challenging the presumption that larger heads are more forgiving in terms of stability and durability. Additionally, ideal cup positioning was considerably more sensitive to cup anteversion than to inclination. Finally, the current investigation is the first to quantitatively suggest that ideal cup positioning varies with both femoral anteversion and femoral head size.

Positioning THR bearings involves significant tradeoffs with regard to stability and long-term bearing wear. The computational analysis identified optimal orientations to balance these considerations. These tradeoffs help explain the alarming rates of adverse local tissue response reported for large head metal-on-metal THR devices that have demonstrated an improvement in joint stability. The conclusions from this study can readily be translated to other hard bearing surfaces—including ceramics and highly cross-linked polyethylene—suggesting careful consideration of the choices and compromises in THA design are required for all bearing couples.

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