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The ‘Landing Zone’ for Wear and Stability in Total Hip Arthroplasty Is Smaller Than We Thought: A Computational Analysis

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Abstract

Background Positioning of total hip bearings involves tradeoffs, because 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 total hip arthroplasty (THA) function.

Questions/purposes We therefore asked if component positioning in total hips could be addressed in terms of

balancing bearing surface wear and stability. Specifically, we sought to identify acetabular component inclination and anteversion orientation, which simultaneously resulted in minimal wear while maximizing construct stability, for several permutations of femoral head diameter and femoral stem anteversion.

Methods A validated metal-on-metal THA finite element (FE) model was used in this investigation. Five dislocation-prone motions as well as gait were considered as were permutations of femoral anteversion (0°–30°), femoral head diameter (32–48 mm), cup inclination (25°–75°), and cup anteversion (0°–50°), resulting in 4320 distinct FE simulations. A novel metric was developed to identify a range of favorable cup orientations (so-called “landing zone”) by considering both surface wear and component stability.

Results When considering both wear and stability with equal weight, ideal cup position was more restrictive than the historically defined safe zone and was substantially more sensitive to cup anteversion than to inclination. Ideal acetabular positioning varied with both femoral head diameter and femoral version. In general, ideal cup inclination decreased with increased head diameter (approximately 0.5° per millimeter increase in head diameter). Additionally, ideal inclination increased with increased values of femoral anteversion (approximately 0.3° per degree increase in stem anteversion). Conversely, ideal cup anteversion increased with increased femoral head diameter (0.3° per millimeter increase) and decreased

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with increased femoral stem anteversion (approximately 0.3° per degree increase). Regressions demonstrated strong correlations between optimal cup inclination versus head diameter (Pearson's $r = -0.88$), between optimal cup inclination versus femoral anteversion ($r = 0.96$), between optimal cup anteversion versus head diameter ($r = 0.99$), and between optimal cup anteversion and femoral anteversion ($r = -0.98$). For a 36-mm cup with a 20° anteverted stem, the ideal cup orientation was $46^\circ \pm 12^\circ$ inclination and $15^\circ \pm 4^\circ$ anteversion.

Conclusions The range of cup orientations that maximized stability and minimized wear (so-called “landing zone”) was substantially smaller than historical guidelines and specifically did not increase with increased head size, challenging the presumption that larger heads are more forgiving. In particular, when the cup is oriented to improve not only stability, but also wear in the model, there was little or no added stability achieved by the use of larger femoral heads. Additionally, ideal cup positioning was more sensitive to cup anteversion than to inclination.

Clinical Relevance Positioning THA bearings involves tradeoffs regarding stability and long-term bearing wear. Cup positions most favorable to minimization of wear such as low inclination and elevated anteversion were detrimental in terms of construct stability. Orientations were identified that best balanced the competing considerations of wear and stability.

Introduction

THA has seen continual advances both in terms of surgical technique and implant design. Despite these steady improvements, however, the rates of THA failure, measured in terms of diagnoses requiring a revision surgery, have actually increased in recent years [37], underscoring the need to further our understanding of THA failure mechanisms.

Deleterious consequences of particulate wear generation at the bearing surface have long been recognized as being one of the most important sources of failure in THA [2, 39]. Despite advances in implant design, and the use of more wear-resistant bearing components, wear-associated failure continues to be a cause for revision THA [9]. Although it has historically been recognized that component orientation influences bearing surface wear [40], the exact biomechanical relationship between positioning and wear propensity remains poorly understood. For metal-on-polyethylene constructs, multiple studies [8, 26, 40] have associated increased wear with increased cup inclination; however, others [15] have not. Similarly, for metal-on-metal articulations, most [14, 29], but not all [11], investigations have demonstrated a relationship between elevated wear and increased cup inclination.

In addition to wear-associated failure, instability/dislocation continues to be a major clinical concern [9]. It is well established that component orientation plays an important role in stability and impingement avoidance. The historical guideline for the “safe zone” of component positioning for dislocation avoidance has been defined as a static target of $15^\circ \pm 10^\circ$ of cup anteversion with $40^\circ \pm 10^\circ$ of cup inclination [31]. More recent investigations [4, 7, 25, 33, 42] have more broadly defined the safe zone as 5° to 40° of acetabular anteversion and 30° to 55° of cup inclination. Despite extensive investigation, prior studies of implant positioning have evaluated only a limited number of all possible intraoperative surgical variables such as head size, cup inclination, cup anteversion, and femoral version. However, positioning of total hip bearings involves tradeoffs, because cup orientations that are most favorable in terms of implant stability are not necessarily optimal for minimizing bearing surface wear. It is presently unknown whether an analogous safe zone can be applied when considering bearing surface wear. Furthermore, to our knowledge, no quantitative guidelines are available that aid surgical component positioning that simultaneously address both bearing surface wear and implant stability. Therefore, developing a systematic basis for the simultaneous consideration of these two potentially competing factors is an important objective. The purpose of this investigation was to identify and analyze those factors directly within the surgeon's control, including femoral head diameter, cup orientation, and femoral stem version, which strike a balance between minimizing bearing surface wear and avoiding instability.

Materials and Methods

A physically [21, 23] and analytically [20] validated finite element (FE) model of metal-on-metal THA was used in this investigation (Fig. 1). This metal-on-metal model previously has been used and optimized to investigate impingement and dislocation [21, 22], edge-loading [20], and trunnion wear [19]. The FE model consisted of bony anatomy (National Library of Medicine Visible Male Project), the hip capsule, and THA hardware. Manufacturer-provided engineering CAD files of a widely used contemporary THA implant (Summit stem, Pinnacle cup; DePuy Orthopaedics, Inc, Warsaw, IN, USA) were pre-processed using TrueGrid (Version 2.3; XYZ Scientific Applications, Inc, Livermore, CA, USA) as the mesh generator. The femoral neck, head, and cup liner were modeled as linearly elastic cobalt-chromium (modulus = 210 GPa, Poisson's ratio = 0.3, density = 9.2 g/cm^3) using deformable eight-noded hexahedral elements. Radial clearance was 0.029 mm. The friction coefficient at the

Fig. 1A–B The FE model included bony anatomy (**A**) and the hip capsule (**B**). THA hardware consisted of the femoral head, femoral stem, cup liner, and shell backing. (The anterior region of the hip capsule was rendered transparent for clarity.)

bearing surface was set at 0.1 [10]. In the interest of computational economy, the shell backing and distal femoral stem were modeled with rigid elements. Joint contact forces and rotations, as determined from a 47-muscle inverse dynamics muscle optimization routine [36], were applied to a reference node located at the center of the femoral head. Given the highly nonlinear material behavior of the hip capsule and the multiple contact engagements, an explicit/dynamic solution scheme was required to avoid numerical instabilities. Further details regarding model development and inclusion of the hip capsule can be found elsewhere [20, 21, 23].

Orientation effects on stability and on bearing surface stress were addressed by considering 36 distinct cup orientations, varying the cup inclination (25° – 75° in 10° increments) and cup anteversion (0° – 50° in 10° increments) using the anatomic orientation definition [35]. Four variants of femoral anteversion were considered (0° , 10° , 20° , 30°) (Fig. 2A) as well as five variants of femoral head diameter (Fig. 2B). Six distinct motion challenges were

Fig. 2A–B (**A**) The effect of femoral anteversion on stability and bearing surface wear was investigated by considering four distinct values of femoral anteversion (0° , 10° , 20° , 30°). The average femoral anteversion used in this study was similar to that observed

radiographically for implanted stems (16.5°) [38, 43]. (**B**) The effect of head size on stability and bearing surface wear was investigated by considering five distinct values of femoral head diameter (32, 36, 40, 44, and 48 mm).

Table 1. Angular excursion during the six kinematic challenges

Kinematic challenges	(-) Extension/flexion (+)		(-) Abduction/adduction (+)		(-) Exorotation/endorotation (+)	
	Minimum (°)	Maximum (°)	Minimum (°)	Maximum (°)	Minimum (°)	Maximum (°)
SSL	-3	114	-12	2	-13	1
SSN	-2	110	-9	-1	2	12
Squat	9	108	-31	-1	-16	3
Stoop	43	107	-13	6	7	26
Pivot	-13	0	-4	6	-41	-11
Gait	-9	42	-5	5	3	14

SSL = sit to stand from a low chair; SSN = sit to stand from a normal-height chair.

used as kinematic and kinetic inputs for the simulations. These were level walking gait, four separate posterior dislocation-prone challenges (stooping, squatting, sit-to-stand from a low chair, and sit-to-stand from a normal height chair; Table 1), and one anterior dislocation-prone maneuver (lateral foot pivoting) [36]. This ratio of posterior:anterior dislocation challenges parallels the dislocation incidence observed clinically [17]. For each simulation, the location of the femoral head relative to the center of the acetabular cup was recorded. Subluxation was therefore taken as the magnitude of displacement of the head relative to the cup throughout the entire motion sequence. As measured, subluxation occurred during both femoral head micromotion as well as during impingement and slide-out [20]. To account for exaggerated subluxations for simulations that resulted in frank subluxation, subluxation distances exceeding the radius of the femoral head were truncated as the radius of the head. Stability (indexed in terms of femoral head center subluxation distance) and bearing surface volumetric wear (calculated using the Archard relationship [3]) were determined for each of the 4320 distinct FE simulations investigated. For each combination of femoral head diameter and femoral stem anteversion (20 such combinations total), the average femoral subluxation at each of the 36 distinct cup orientations was calculated. These data were processed to determine the stability score by (1) taking the numerical inverse of each value (in millimeters) of subluxation; and (2) linearly normalizing the resulting values such that a stability score of 100 represented the orientation that minimized instability, whereas a score of 0 represented the orientation for which instability was greatest. Intermediate scores represent a linear interpolation between these two situations. Using the inverse of the subluxation values allowed for greater distinction between orientations for which subluxation was relatively low versus those orientations that resulted in frank dislocation. Averaged bearing surface wear was similarly normalized to create a wear score at each cup orientation. A novel metric (termed the THA Performance Score) was developed to simultaneously

Fig. 3 The final metric used in the optimization procedure, the THA Performance Score, was determined from both joint stability and bearing surface wear using balanced weightings [12, 18]. Stability was determined from the five distinct dislocation challenges, whereas wear was determined from both the dislocation challenges and gait scaled in a 5%:95% ratio based on relative occurrence frequencies in activities of daily living in patients undergoing THA [34]. This THA Performance Score was computed for each combination of femoral head diameter and femoral anteversion (20 such combinations total). Using this methodology, final optimization determination was performed considering both femoral head diameter and femoral anteversion.

consider both stability and wear considerations (Fig. 3). Values for optimal positioning were determined by converting the THA Performance Score data to their corresponding radiographic definitions [35] and computing an isosurface (a computational tracing) of the resulting THA Performance Scores. To strike a balance between

Fig. 4A–F For each combination of head size and femoral anteversion, femoral head subluxation was assessed for each of the five dislocation challenges (A–E). The numerical average subluxation magnitude (F) was then computed by taking the arithmetic mean at each of the 36 cup orientations for all five motion challenges. In general, instability was greatest for cups positioned in decreased anteversion and decreased inclination when the posterior dislocation

challenges were assessed. In contradistinction, for pivot motion, instability was greatest for elevated anteversion and elevated inclination. The illustration shown is for a 36-mm femoral head with 20° femoral anteversion. (Cup orientations are reported in the anatomic reference frame.) STS-Low = sit-to-stand from a low-positioned chair; STS-Norm = sit-to-stand from a normal-height chair.

precisely identifying the highest performing orientations while maintaining a clinically realistic operative landing zone target, the landing zone was defined as a score above 90. An ellipse was fit to the landing zone isosurface, and the ideal cup orientation was determined as the center of this ellipse.

A total of 4320 FE simulations was run using Abaqus/Explicit 6.10.EF (SIMULIA, Providence, RI, USA) as the FE solver executed on a 64-bit Unix operating system with twin dual quad-core Intel® Xeon (Intel Corporation, Santa Clara, CA, USA) platforms configured with 24 GB of RAM. Each simulation required approximately 13 processor-hours of computer time with 16 models running simultaneously. Approximately 6 months of continuous computation was required, not counting postprocessing of the data provided. Statistical determination of variable correlation (Pearson product-moment correlation coefficient) was calculated using Mathcad (Version 14.1; Parametric Technology Corporation, Needham, MA, USA).

Results

Stability

Femoral head subluxation propensity was found to be strongly dependent on both cup orientation and femoral anteversion (Fig. 4). Subluxation was greatest at low values of cup inclination and low values of cup anteversion (for posterior instability challenges) and at high values of cup anteversion (for anterior instability challenges). Collectively (Fig. 5A), stability is greatest for cups positioned in approximately 45° to 55° of inclination and in 10° to 20° of acetabular anteversion.

Wear

In contrast to stability, wear was found to be reduced for cups positioned with increased acetabular anteversion and decreased inclination (Fig. 5B). Wear increased for cups oriented in > 45°. As opposed to stability, in which

Fig. 5A–D The stability metric (A) and the wear metric (B) were computed using the algorithm shown previously (Fig. 3). With equal weighting assigned to each component, the THA Performance score (C) was computed. For each instance of head diameter and femoral anteversion, a “landing zone” of optimal cup positioning was identified, which was chosen as Performance Scores > 90 (red contour in C). This

landing zone was found to be markedly more sensitive to cup anteversion than for cup inclination. Ideal cup orientation was then determined by fitting an ellipse to an isosurface of the identified landing zone (D). The optimal cup positioning was considered as the center of the ellipse (*). The instances shown are that for a 36-mm femoral head with 20° femoral anteversion. (Cup orientations are in the radiographic reference frame.)

subluxation appeared to be more sensitive to changes in cup anteversion, wear was roughly equally affected by both anteversion and inclination.

THA Performance Score

For each combination of femoral head diameter and femoral stem anteversion, the THA Performance Score (Fig. 5C) was calculated and the ideal cup orientation was determined (Fig. 5D). In general (varying with each distinct combination of head diameter and femoral stem anteversion), optimal cup inclination varied between approximately 37° and 48°, whereas optimal anteversion was generally between approximately 12° and 22°. For a 36-mm cup with a 20° anteverted stem, the optimal cup orientation was $46^\circ \pm 12^\circ$ inclination and $15^\circ \pm 4^\circ$ anteversion. When regression analyses were performed for all 20 combinations of head diameter and stem anteversion, high correlations were found between optimal

cup inclination (Fig. 6) and cup anteversion (Fig. 7) with femoral head diameter and femoral stem anteversion. Specifically, strong correlations were identified between optimal cup inclination versus head diameter (Pearson's $r = -0.88$), between optimal cup inclination versus femoral anteversion ($r = 0.96$), between optimal cup anteversion versus head diameter ($r = 0.99$), and between optimal cup anteversion and femoral anteversion ($r = -0.98$).

Inclination was optimized when the following equation was satisfied (diameter measured in millimeters, angles measured in degrees and in the radiographic reference frame):

$$-0.33 * \text{anteversion}_{\text{femoral}} + 0.48 * \text{diameter} + \text{inclination}_{\text{cup}} = 56$$

Similarly, the equation for optimal cup anteversion was:

$$0.35 * \text{anteversion}_{\text{femoral}} - 0.28 * \text{diameter} + \text{anteversion}_{\text{cup}} = 12$$

Fig. 6A–B Optimal cup inclination varies as a function of femoral head diameter and femoral stem anteversion. Regression analysis for optimal cup inclination with femoral head diameter (**A**) demonstrated a correlation coefficient of -0.88 . Regression with respect to femoral anteversion (**B**) yielded a correlation coefficient of 0.96 (where the

Pearson correlation coefficient, r , is a measure of linear correlation between two variables, giving a value between 1 and -1 , where 1 is total positive correlation, 0 represents no correlation, and -1 is total negative correlation).

Fig. 7A–B Optimal cup anteversion varies as a function of femoral head diameter and femoral stem anteversion. Regression analysis for optimal cup anteversion with head diameter (**A**) demonstrated a correlation coefficient of 0.99 . Regression with respect to femoral anteversion (**B**) yielded a correlation coefficient of -0.98 (where the

Pearson correlation coefficient, r , is a measure of linear correlation between two variables, giving a value between 1 and -1 , where 1 is total positive correlation, 0 represents no correlation, and -1 is total negative correlation).

The computed landing zones of optimal cup orientation, when analyzed for each of the head diameters investigated, were more restrictive than the historical safe zone with an area roughly one-third of the area circumscribed by the traditional safe zone (Fig. 8). Furthermore, it was shown that the area represented by the landing zone did not increase substantially with increased head size. Increasing the femoral head size by 50% (32 mm to 48 mm) only increased the area of the landing zone by 21%. Additionally, the landing zone was shown to be substantially more sensitive to cup anteversion than for cup inclination (Fig. 9).

Discussion

The importance of implant positioning in THA has been long recognized and extensively investigated, yet owing to inevitable study limitations, uncertain—and often directly contradictory—conclusions have emerged. For example, wear has been shown to be increased [29], decreased [32], or unaffected [6] with increased acetabular anteversion. Perhaps this is reflective of the smaller landing zone and/or higher sensitivity to cup anteversion identified with the present study. Therefore, this

Fig. 8A–E To gain a better appreciation regarding the effect of head size on the landing zone, data from each of the 864 distinct FE simulations (36 cup positions $\times$ six motions challenges $\times$ four femoral stem anteversions) for each of the five head diameters were combined and renormalized to a scale from 0 to 100. The resulting landing zones for the five different head diameters are shown (A–E). The previously described [31] “safe zone” for stability is superimposed over the THA Performance Scores. Note the small area (red) of

optimal Performance Scores compared with the previously reported safe zone for stability. On average, the numerical area of the landing zone was approximately one-third that circumscribed by the traditional landing zone and does not appreciably increase as the femoral head diameter increases. Additionally, a substantial portion of the Lewinnek safe zone is seen to overlap cup orientations that were determined to have poor THA Performance Scores.

investigation was undertaken to provide definitive quantitative conclusions regarding the influence of surgery-specific factors influencing wear and stability after THA.

Besides representing one of the most comprehensive computational analyses to date of positioning in THA constructs, this study is the first to our knowledge to

Fig. 9A–B Optimal cup orientations are more sensitive to changes in cup anteversion than cup inclination. **(A)** For each of the plots demonstrated in Fig. 8, the major and minor semiaxes that define the fitted ellipse used for determination of optimal cup orientation were determined. These axes roughly approximate the allowable range of cup inclination and cup anteversion, respectively, and allow for assessment of the relative sensitivity of each orientation angle on the

THA Performance Score. (The semiaxes for the 44-mm head are shown here.) **(B)** The allowable range of cup inclination and cup anteversion increased only modestly for larger diameter femoral heads. On average, the range determined for cup inclination was twice that determined for cup anteversion. Additionally, note that the computed THA Performance Scores are more forgiving when erring on the side of more—as opposed to less—acetabular anteversion.

balance combined and concurrent considerations for stability and for avoidance of bearing surface wear. We found that rather than a static target, the ideal positioning of the acetabular cup is strongly influenced by both femoral stem anteversion and femoral head diameter. Importantly, although femoral head diameter strongly influenced the location of the landing zone, it did not appreciably influence its size.

Although the present computational formulation represents a substantial step toward balancing wear and stability in THA, there are nevertheless a number of simplifications and limitations. The current study considered only an equally balanced weighting of bearing surface wear and joint stability. Although this 50:50 weighting was derived from clinical observations of failure modalities in contemporary metal-on-metal THA [12, 18], it is obviously only a single combination among a continuum of possible weightings. However, a major attraction of the present formulation is that this weighting can be straightforwardly adjusted to reflect the relative importance of stability, wear, or other considerations when new information becomes available. A second major limitation is the choice of bearing couple investigated. Although the contemporary use of metal-on-metal bearings has decreased precipitously, metal bearings were used in the present investigation because of the preponderance of recent literature on possible mechanisms responsible for adverse local tissue response associated with these bearings. Additionally, the FE model used in this investigation had been extensively used previously [19–21] to identify deleterious loading scenarios in metal bearings and was validated

specifically for these situations. Additionally, of all the available bearing couples for THA, metal-on-metal allows for the largest variation in allowable head diameter, which was a highly desirable variable for parametric analysis in the current study. However, the conclusions drawn from this investigation are not limited to metal-on-metal THA. The mechanisms for accelerated wear—namely microseparation and edge-loading—are not unique to metal bearings but arguably exist as well for other rigid-on-rigid bearing couples, including metal-on-highly crosslinked polyethylene [4]. However, from a mechanical perspective, the use of other bearing couples involves additional possible mechanisms that could plausibly affect the stability and wear computations. Examples include impingement-associated consequences such as plastic deformation in the case of metal-on-polyethylene and microfracture and third-debris wear for ceramics. Extension of the present computational formulation to other bearing couples is certainly an attractive and important avenue for further study. Third, the construction and use of the THA Performance Score merit further discussion. A numerical value of 90 was used to define the size of the landing zone and represented a balance between identifying the most favorable orientations while maintaining a realistic intraoperative target. The value of 90 was also used to identify the location of the single optimal cup orientation for any given combination of femoral head size and femoral anteversion. Although somewhat arbitrary, the use of a different numerical verge is not expected to have altered the results substantially. As illustrated (Fig. 5C), the centers of ellipses fitted to scores of 80, 70, 60, 50, etc., were

Table 2. Previously defined safe zones for acetabular cup orientation

Study	Ideal inclination*	Ideal anteversion*	Other orientations	Type
Lewinnek et al. [31]	$40^\circ \pm 10^\circ$	$15^\circ \pm 10^\circ$		Clinical
Dorr et al. [17]	$35^\circ \pm 15^\circ$	$15^\circ \pm 15^\circ$		Clinical
McCollum and Gray [33]	$40^\circ \pm 10^\circ$	$30^\circ \pm 10^\circ$		Clinical
Biedermann et al. [7]	$45^\circ \pm 10^\circ$	$15^\circ \pm 10^\circ$		Clinical
Barrack et al. [5]	$45^\circ \pm 10^\circ$	$20^\circ \pm 10^\circ$		Biomechanical
Widmer and Zurfluh [42]	$40^\circ\text{--}45^\circ$	$20^\circ\text{--}28^\circ$	$\beta + 0.7*\delta = 37^\circ$	Biomechanical
Yoshimine [44]			$\alpha + \beta + 0.77*\delta = 84.3^\circ$	Biomechanical
Jolles et al. [25]			$40^\circ < \beta + \delta < 60^\circ$	Clinical

* Values are mean $\pm$ range; α = cup inclination; β = cup anteversion; δ = femoral stem anteversion.

very nearly coincident and would therefore not likely affect the locations of the predicted optimal orientation. Additionally, the normalization scheme used in the present study was developed to be more sensitive with instances of microseparation and less sensitive to larger femoral head displacements. We felt that differences between dislocation and near dislocation should be weighted less heavily than the difference between no subluxation at all and the moment when subluxation begins. Obviously, there are several normalization schemes that are possible, the effect of which on the conclusions derived from this investigation are unknown. Fourth, given the scope of the present investigation, direct clinical correlation is certainly a daunting task. Although clinical corroboration with previous or future clinical series is possible in the short term, only a large clinical series that measures in vivo femoral head subluxation as well as frequent radiographic wear measurements would likely provide the fidelity required to truly validate the THA Performance Score metric and the notion of a landing zone. It is hoped, however, that the current study may engender such investigation. Finally, trunnion interface wear, a clinical concern that has recently emerged to the fore of clinical recognition [13, 19, 28], was not included in the present investigation, although the authors have recently investigated this variable with an adaptation of the current model [19].

Surgical component orientation is one of the most important intraoperative considerations for THA. Implantation of the cup in elevated inclination and high anteversion permits increased joint flexion and offers protection against posterior dislocation. However, cup verticality brings increased risk for posteriorly located impingement and associated anterior dislocation [7]. Conversely, total hips that dislocate posteriorly often have more horizontal anteversion and inclination angles. Historically, a “safe zone” of cup orientation was described by Lewinnek et al. [31] as being $40^\circ \pm 10^\circ$ of inclination and $15^\circ \pm 10^\circ$ of anteversion (radiographic definition). Various other definitions of component orientation safe zones have been emerged from both clinical and biomechanical

investigation (Table 2). The overwhelming majority of computational studies that have addressed cup orientation, femoral head size, or both used only impingement-free ROM as their only discriminant. However, instances of joint instability can involve complex kinematic and kinetic interactions. Using only impingement-free ROM severely limits the translation of these purely geometrical studies into the clinical realm. Additional variables such as dislocation resistance and nonconforming surface contact stresses are undoubtedly influenced by implant geometric design. Nonetheless, only a few computational studies [27, 41] have addressed these additional parameters. However, those studies have been limited in terms of the variation of independent variables considered, the absolute number of simulations run, and the lack of physiologic realism (ie, simplified kinetic and kinematic inputs and simple geometrical surfaces, lack of soft tissue representation, etc).

Additionally, there is currently little known about the effect of component positioning on bearing surface wear generation. Although it is generally assumed that increased cup inclination will lead to elevated wear generation for both metal-on-polyethylene and metal-on-metal constructs [8, 14, 26, 29, 40], multiple studies have failed to demonstrate such a correlation [11, 15]. It has been demonstrated that alterations in the cup geometry, namely the cup’s articular coverage, can result in increased apparent inclination even for well-positioned components. This has been shown to result in both accelerated wear [24] as well as increased risk of instability [20]. Additionally, owing to the difficulty of accurately and reliably measuring both cup [1] and femoral [16] anteversion, especially with standard radiographs, few studies have explicitly investigated the relationship between component anteversion and wear generation. The present study strongly suggests that construct outcome is more sensitive to variation in cup anteversion than to inclination (Fig. 9) with optimal anteversion being tightly restricted between 15° and approximately 20° , depending on stem version and head size. This finding is well corroborated clinically [30] with

the finding that blood ion levels were minimized for cups positioned between 15° and 20° of acetabular anteversion with precipitous increases in measured ions for cups positioned in greater or lesser values of anteversion. However, despite major clinical and experimental investigation, safe zone definitions for bearing surface wear, analogous to that for implant stability, have not yet been completely elucidated. The development of such a tool for surgical positioning of total hip constructs was the major impetus for the present investigation.

In summary, optimal positioning of THA bearings involves balancing the competing considerations of joint stability and implant-bearing surface wear. Optimal acetabular cup orientation was found to correlate strongly both to femoral anteversion and femoral head size, challenging the notion of a static “one-size-fits-all” safe zone to guide component positioning.

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