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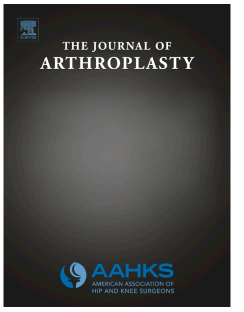

High Offset Stems are Protective of Dislocation in High Risk Total Hip Arthroplasty

Jonathan M. Vigdorchik, M.D., Abhinav K. Sharma, B.S., Ameer M. Elbuluk, M.D., Kaitlin M. Carroll, B.S., David J. Mayman, M.D., Jay R. Lieberman, M.D.

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Jonathan M. Vigdorchik, M.D.[†]

Abhinav K. Sharma, B.S.[†]

Ameer M. Elbuluk, M.D.[†]

Kaitlin M. Carroll, B.S.[†]

David J. Mayman, M.D. [†]

Jay R. Lieberman, M.D. [††]

Investigation performed at the Hospital for Special Surgery

[†] Hospital for Special Surgery

Department of Orthopedic Surgery

Adult Reconstruction and Joint Replacement Service

535 E 70th St

New York, NY 10021

[††] Keck School of Medicine of USC

Department of Orthopaedic Surgery

1520 San Pablo Street, Suite 2000

Los Angeles, CA 90033

Corresponding Author

Jonathan M. Vigdorchik, M.D.

Hospital for Special Surgery

535 E 70th St

New York, NY 10021

Email: vigdorchikj@hss.edu

Phone: 212.606.1992

Fax: 646.797.8603

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ABSTRACT

Background: Spinal stiffness has been shown to increase risk of dislocation due to impingement and instability. Increasing anteversion of the acetabular component has been suggested to prevent dislocation, but little has been discussed in terms of femoral or global offset restoration. The purpose of this study is to quantify dislocation rates after primary THA using standard versus high offset femoral components and to determine how differences in offset affect impingement-free range of motion in a stiff spine cohort using a novel impingement model.

Methods: 12,365 patients undergoing THA from 2016-2018 were retrospectively reviewed to determine dislocation rates and utilization of standard versus high offset stems. For 50 consecutive patients with spinal stiffness, a CT-based computer software impingement modeling system assessed bony or prosthetic impingement during simulated range of motion. The model was run 5 times for each patient with varying offsets. Range of motion was simulated in each scenario to determine the degree at which impingement occurred.

Results: There were 51 dislocations for a 0.41% dislocation rate. Total utilization of high offset stems in the entire cohort was 49%. Of those patients who sustained a dislocation, 49 (96%) utilized a standard offset stem. The impingement modeling demonstrated 5 degrees of added range of motion until impingement for every 1mm offset increase.

Conclusion: In the impingement model, high offset stems facilitated greater ROM before bony impingement and resulted in lower dislocation rates. In the setting of high-risk THA due to spinal stiffness, surgeons should consider the use of high-offset stems and pay attention to offset restoration.

Keywords: total hip arthroplasty; hip-spine; stiff spine; spinal deformity; impingement; offset; dislocation

INTRODUCTION

Total hip arthroplasty (THA) remains one of the most successful procedures in all of medicine[1-3]. Despite its success, modern dislocation rates after primary THA are between 1.5-2%, with dislocation rates after revision THA for instability up to 15-20%[4, 5]. Instability is also the most common postoperative complication within three months of surgery[6, 7].

Historically, instability has been the most common cause of THA failure[8, 9], and impingement is considered to be the final common pathway for instability[10]. Many factors contribute to the stability of the THA, including surgical factors such as soft tissue tension, component positioning, and femoral head size[11-13]. Component orientation and implant choice directly affect safe range of motion (ROM) of the hip arthroplasty, with impingement being a possible result of component malpositioning, suboptimal head diameter, head-neck ratio or geometry, or socket depth.

Impingement can be either due to prosthetic or bony contact. Component-on-component contact can occur at extremes of flexion or extension when the trunnion or neck of the femoral component contacts the acetabular cup or liner, and the risk of such impingement is a function of implant features such as head-neck ratio, liner rim thickness, center of rotation, as well as position and orientation of the components[10, 14, 15]. Bony impingement can occur between the greater trochanter and ilium, lesser trochanter and the ischium, femoral neck and supra-acetabular region, or the prosthetic stem and the anterior acetabular rim[14, 15]. Additionally, failure to remove osteophytes can result in component abutment against bone[14].

Offset is defined by the distance between the center of the femoral head and a perpendicular line drawn through the center of the stem[16]. The offset is selected to maximize joint stability by tensioning the soft tissues and increasing the strength of the abductor muscles, thereby helping balance the pelvis[17-19]. Matsushita et al. and McGrory et al. both reported that the use of high offset femoral components resulted in improved ROM and decreased bony impingement and thus, increasing offset increases ROM and presumably helps mitigate the risk of instability and dislocation[16, 18, 20].

It has previously been shown that patients with a stiff spine and spinal fusion have an increased risk of dislocation after THA[21, 22]. Presumably, when such patients transition from a standing to a seated position, the pelvis does not roll back as it typically would to accommodate the femurs and allow for them to move to a position parallel to the floor and as a result, impingement occurs[23] (Figure 1). Therefore, a protective mechanism to avoid instability in a stiff spine cohort of patients is to increase the offset of the femoral stem to move the trochanter away from the pelvis to prevent bony impingement (Figures 2 and 3).

The purpose of this study is two-fold: first, to determine the clinical impact of using high offset femoral components on dislocation rates after primary THA, and second, using a novel CT-based computer-generated impingement model, to determine how differences in offset affect rates of impingement-free range of motion in a high-risk stiff spine cohort.

MATERIAL AND METHODS

Retrospective Analysis

After Institutional Review Board approval, a series of 12,365 consecutive patients undergoing THA from 2016-2018 were retrospectively reviewed from a single-institutional database. Multiple surgeons participated, and all utilized the posterior approach with posterior soft tissue capsular repair. All THAs were performed with meticulous removal of anterosuperior and posteroinferior acetabular osteophytes, and careful attention to restoring leg-length and offset. Postoperatively, the only hip precautions maintained were no crossing of the legs past the midline for a period of six weeks. Implant information was evaluated for the utilization of high versus standard offset stems, and rates of subsequent dislocations recorded for each cohort. Postoperative follow up was conducted via the electronic medical record, and for those patients where follow-up was unclear, a telephone encounter was generated by the research assistant.

Impingement Model

A new group of fifty consecutive preoperative patients from January to March 2019 with a stiff lumbar spine were identified by examining standing and relaxed-sitting lateral spinopelvic radiographs[24], with a stiff lumbar spine defined as less than 10 degrees of posterior pelvic tilt as measured by changes in sacral slope[23, 25-28]. In all cases, there was no spinal deformity, defined as the mathematical formula of pelvic incidence minus lumbar lordosis of less than 10 degrees. These selections were made because they provide a clear, standardized situation that is high-risk given the mechanics of a stiff spine and hip replacement. If we chose patients without a stiff spine, the pelvis would tilt posteriorly, decrease impingement, and then change the results.

Utilizing a CT-based computer software (OPS Insight™, Corin Group, Cirencester, UK) running dynamic impingement analysis, we assessed bony or prosthetic impingement during simulated range of motion. The model recreates a patient-specific three-dimensional model of the pelvis and femur based on CT and radiographic images with virtually implanted components. The model can then move the bones in a specified range of motion and assess impingement (Figures 4a and 4b).

All acetabular cups (Trinity cups, Corin Group, Cirencester, UK) were templated in the position of 40 degrees inclination and 25 degrees anteversion to the supine anterior pelvic plane

(APP). These numbers were chosen based on available literature recommending more anteversion (~25 degrees) for patients with a stiff spine [29, 30]. 36mm heads were used in all patients. Cup sizes included 52mm x 23 patients, 54mm x 18 patients, 56mm x 8 patients, and 58mm x 1 patient. For each of the 50 patients, we ran the impingement model 5 times (Table 1). In Conditions 1 (Figure 5) and 2 (Figure 6), the acetabular cup was medialized to the teardrop and paired with either (1) a standard offset stem or with (2) a high offset stem (TriFit TS stems, Corin Group, Cirencester, UK). With this stem, changing from a standard to a high offset stem increases offset by 7mm, but does not change leg length. For Conditions 3 (Figure 7), 4 (Figure 8), and 5 (Figure 9), we compared these results separately (Table 2). In Condition 3, we created a scenario where the offset was exactly reproduced to the preoperative state, re-creating the exact native global offset for that particular patient depending on the patient's anatomy. Condition 4 started with Condition 3 but the global offset was reduced by 4mm. Condition 5 started with Condition 3 but the global offset was increased by 4mm (or 8mm more than Condition 4).

With the selected components in place, an impingement model was simulated according to the following ROM presets: for anterior impingement, flexion of 90 degrees, neutral abduction, and internal rotation until impingement, noting the degree at which impingement occurs. For posterior impingement, we selected extension of 10 degrees and external rotation until the point where impingement occurs.

Statistical Analysis

Statistical analysis was performed using SPSS software (version 26.0, Armonk, NY: IBM Corp.). Comparison of standard and high offset stems and dislocation rates was performed by using Pearson's Chi-square test. The test level was $\alpha = 0.05$ with significance set at $p < 0.05$.

Statistically significant difference between impingement model conditions was tested using Student's t-test, with significance set at $p < 0.05$ for all comparisons. We compared the results of Condition 1 to Condition 2 and the results of Conditions 3 versus 4 and 5.

RESULTS

Retrospective Analysis

There were 12,365 THAs performed via the posterior approach from 2016-2018. Of these, there were 51 dislocations for a 0.41% dislocation rate. Total utilization of high offset stems in the entire cohort was 49%. Of those patients who sustained a dislocation, 49 (96%) received a standard offset stem. There was a statistically significant difference in dislocation rates between the standard and high offset stems, with patients receiving standard offset stems being more likely than those receiving high offset stems to dislocate ($\chi2 = 41.64$, $p < 0.00001$).

Impingement Model

<u>Condition 1 (cup to teardrop, standard offset stem) versus Condition 2 (cup to teardrop, high offset stem):</u>

For flexion, the range of motion was simulated to 90 degrees of flexion, neutral abduction, and then internal rotation until impingement. In the standard offset group, range of motion until impingement occurred on average at 26 degrees of internal rotation (range 10-40) compared to an average 62 degrees of internal rotation (range 40-79 degrees) for the high offset stem group ($p < 0.001$).

For extension, the range of motion was simulated extension to 10 degrees and external rotation until impingement. In the standard offset group, range of motion until impingement occurred on average at 10 degrees of external rotation (range 5-35) compared to an average of 25 degrees of external rotation (range 15-63) degrees) for the high offset stem group ($p < 0.001$).

It is important to note that in these 50 cases, placing the cup at the teardrop and using a standard offset stem did not restore the preoperative offset (decreased the offset from the preoperative state) in 35 cases (70%).

Condition 3 (recreate preoperative offset) versus Condition 4 (decreased offset by 4mm):

For flexion, range of motion until impingement occurred at an average of 42 degrees of internal rotation (range 22-54) for the preoperative state compared to an average of 22 degrees of internal rotation (range 8-33 degrees) for the decreased offset group ($p < 0.001$). The average range of motion decreased by an average of 5 degrees for every 1 mm of offset loss.

For extension, range of motion until impingement occurred at an average of 24 degrees of external rotation (range 12-34) for the preoperative state compared to an average of 8 degrees of external rotation (range 3-16 degrees) for the decreased offset group ($p < 0.001$). The average range of motion decreased by an average of 4 degrees for every 1 mm of offset loss.

Condition 3 (recreate preoperative offset) versus Condition 5 (increased offset by 4mm):

For flexion, range of motion until impingement occurred at an average of 42 degrees of internal rotation (range 22-54) for the preoperative state compared to an average of 62 degrees of internal rotation (range 47-79 degrees) for the increased offset group ($p < 0.001$). The average range of motion increased by an average of 5 degrees for every 1 mm of offset gain.

For extension, range of motion until impingement occurred at an average of 24 degrees of external rotation (range 12-34) for the preoperative state compared to an average of 40 degrees of external rotation (range 25-50 degrees) for the increased offset group ($p < 0.001$). Range of motion increased by an average of 4 degrees for every 1 mm of offset gained.

<u>Condition 4 (decreased offset 4mm from preoperative state) versus Condition 5 (increased offset by 4mm from preop state OR 8mm increased from Condition 4):</u>

For flexion, range of motion until impingement occurred at an average of 22 degrees of internal rotation (range 8-33) for the 4mm decreased offset state compared to an average of 62 degrees of internal rotation (range 47-79 degrees) for the increased offset group ($p < 0.001$). Again, the average range of motion increased by an average of 5 degrees for every 1 mm of offset gain.

For extension, range of motion until impingement occurred at an average of 8 degrees of external rotation (range 3-16) for the decreased offset state compared to an average of 40 degrees of external rotation (range 25-50 degrees) for the increased offset group ($p < 0.001$). The average range of motion increased by an average of 4 degrees for every 1 mm of offset gained.

DISCUSSION

In this study, we aimed to evaluate the difference in rate of dislocation between standard and high offset stems, and the degrees within the extension-flexion cycle at which impingement occurs. Our retrospective analysis of the dislocation rates after primary THA determined that 96% of patients that suffered a THA dislocation had a standard offset component. Only 2 of the 51 dislocations had a high offset stem, while 49% of the entire cohort of THAs utilized high offset stems. Additionally, a novel computer software program was utilized to model ROM associated with standard versus high offset stems. Our analysis revealed that high offset stems facilitated greater ROM before bony impingement relative to standard offset stems. For flexion, each 1mm of offset gain/loss equated to 5 degrees increase/decrease in internal rotation until impingement. For extension, each 1mm of offset gain/loss equated to 4 degrees of external rotation gain/loss. In Condition 5, for which offset was increased, impingement free range of motion was increased relative to other conditions in which preoperative offset was recreated (Condition 3) and offset was decreased from the preoperative state (Condition 4). In comparing between Conditions 5 and 3 as well as Conditions 5 and 4, a similar result was appreciated: the average range of motion in flexion increased by 5 degrees for every 1mm of offset gain and the average range of motion in extension increased by 4 degrees for every 1mm of offset gained.

An important finding of our study that should not be overlooked is that when placing an acetabular cup medial all the way to the teardrop, native femoral offset was not restored in 35 cases (70%). Femoral offset is a parameter of stem design that should be decided on carefully by the arthroplasty surgeon during preoperative templating in order to maximize joint stability and reduce the incidence of impingement and implant dislocation. Increasing femoral offset has been shown to increase ROM, restore hip biomechanics, and reduce occurrence of impingement and implant failure by increasing the strength of the abductor muscles and decreasing the polyethylene wear rate[17-19, 31-33]. However, discretion should always be used to avoid increasing offset beyond necessary, because it may lead to postoperative complications such as trochanteric bursitis[34]. Additionally, with the use of smaller stems and in patients with high BMI, there can be a large bending stress at the neck in high offset stems that can predispose to fatigue failure and trunnionosis. Significantly increased offset can also lead to increased tension on the abductor muscles and trochanteric fractures, which may result in pain and diminished function.

Our retrospective review of 12,365 patients shows that patients who receive high offset stems have a lower rate of dislocation than those with standard offset stems. The results of our impingement model, which simulated patients with a high risk for instability, suggest that the use of high offset stems is protective of dislocation[35].

There are a number of limitations associated with this study. As this study was retrospective in nature with short-term follow-up, long-term rates of dislocation could not be evaluated. In addition, instability and subsequent dislocation can be due to a variety of factors, both patient and surgery-related, and not solely from impingement. In the impingement model, we did not take into account variations in trochanteric morphology which can directly contribute to impingement. Furthermore, we did not account for variations in acetabular or femoral version which directly influence both internal and external rotation until impingement. We also did not have the ability to remove osteophytes in the model to simulate a post-operative state, which can induce early bony impingement.

In conclusion, our clinical data showed a decreased rate of dislocation with high offset stems. The computer software program demonstrated increased range of motion until impingement with the high offset stems compared to standard offset stems. The results of this study suggest that surgeons should consider the use of high-offset stems in patients that are deemed at a higher risk for dislocation, such as those with adverse spinopelvic mobility. Further study of this issue is clearly needed to define parameters for the use of high offset stems in a population at high risk for dislocation after THA.

TABLES

Table 1. Conditions 1 and 2 were compared to each other to assess effects on anterior and posterior impingement during simulated range of motion, with the only change being the use of standard versus high offset stems, respectively.

Impingement Model Condition	Acetabular Cup Position	Stem Type	Range of Motion Until Impingement
Condition 1	Medialized to teardrop	Standard offset	Flexion: 26° of internal rotation (range 10-40°)
			Extension: 10° of external rotation (range 5-35°)
Condition 2	Medialized to teardrop	High offset	Flexion: 62° of internal rotation (range 40-79°)
			Extension: 25° of external rotation (range 15-63°)

Table 2. Conditions 3, 4, and 5 were compared to one another to assess effects on anterior and posterior impingement during simulated range of motion. Condition 3 was the basis for the designs of Conditions 4 and 5, for which the global offset was decreased and increased, respectively.

Impingement Model Condition	**Component Choice**	**Global Offset Change**	**Range of Motion Until Impingement**
Condition 3	Patient-dependent; recreated preoperative offset	No change	Flexion: 42° of internal rotation (range 22-54°)
			Extension: 24° of external rotation (range 12-34°)
Condition 4		-4mm global offset from preop	Flexion: 22° of internal rotation (range 8-33°)
			Extension: 8° of external rotation (range 3-16°)
Condition 5		+4mm global offset from preop	Flexion: 62° of internal rotation (range 47-79°)
			Extension: 40° of external rotation (range 25-50°)

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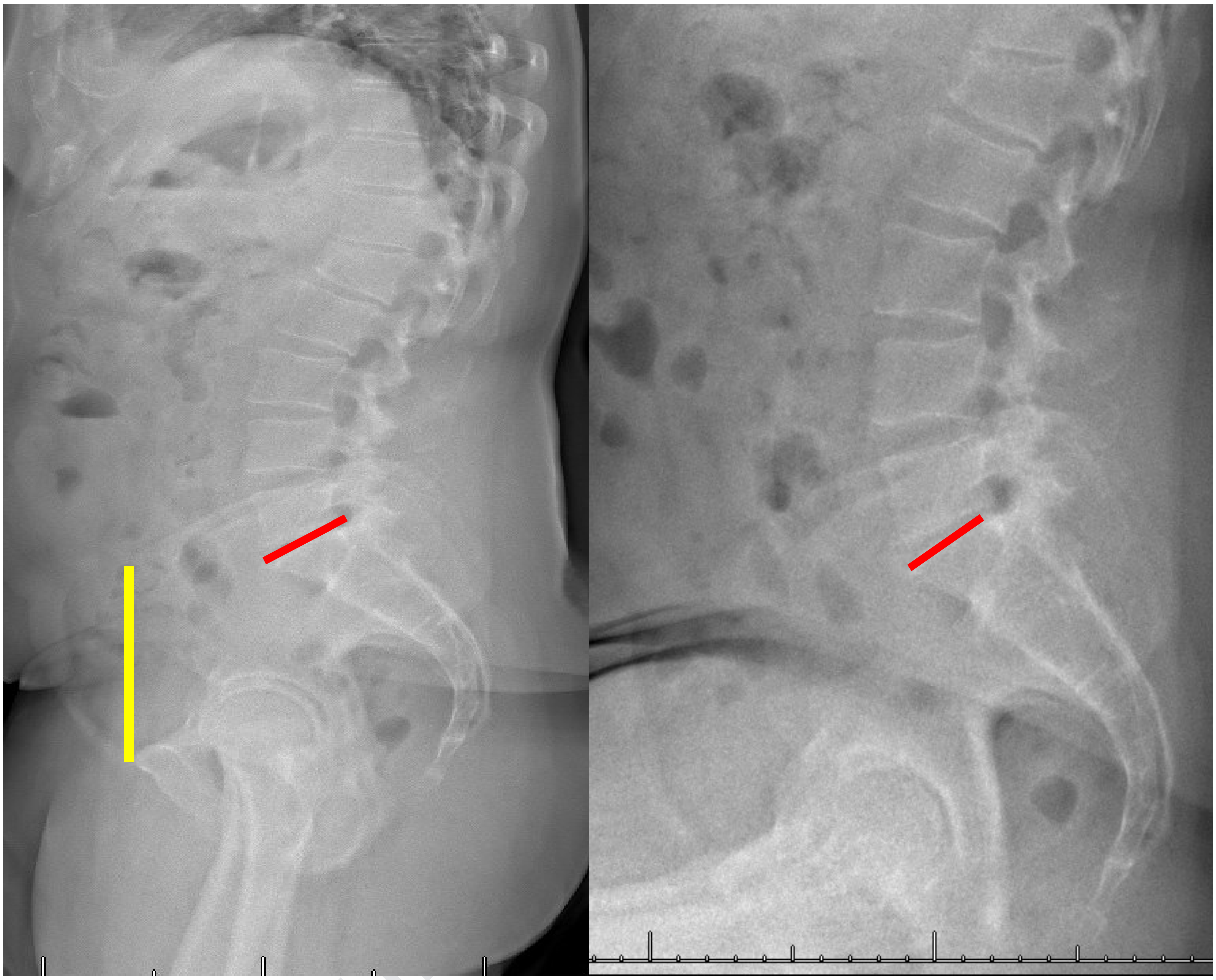

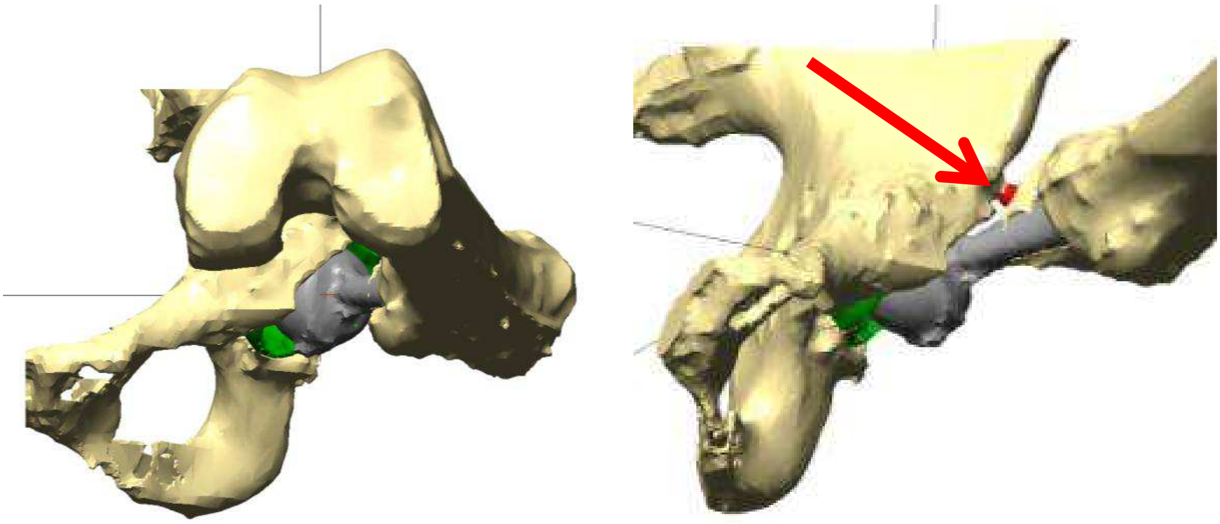

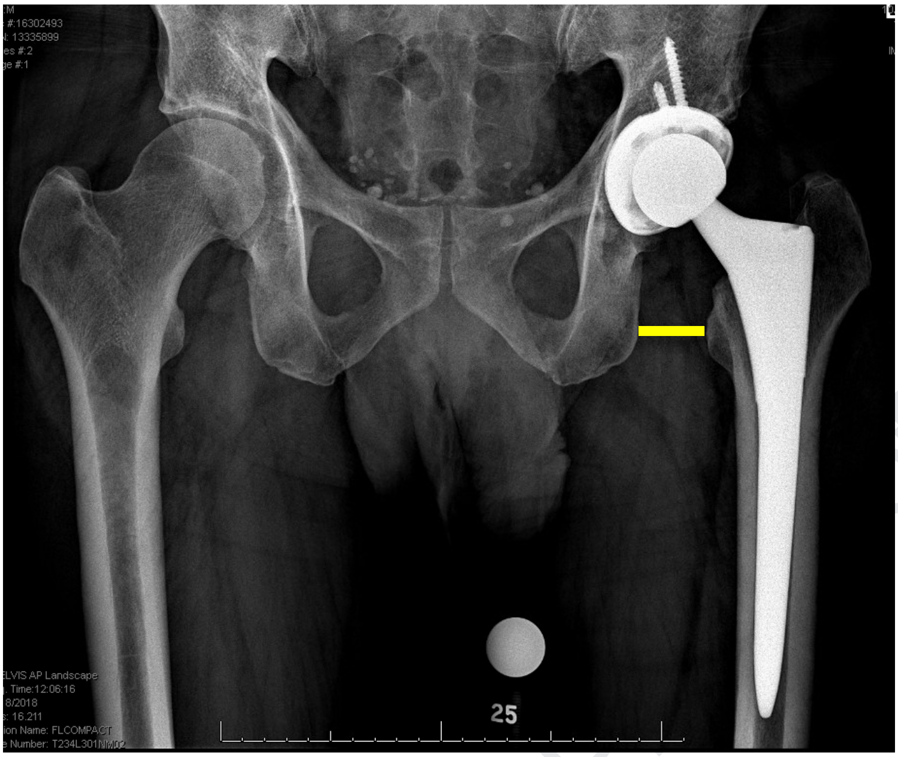
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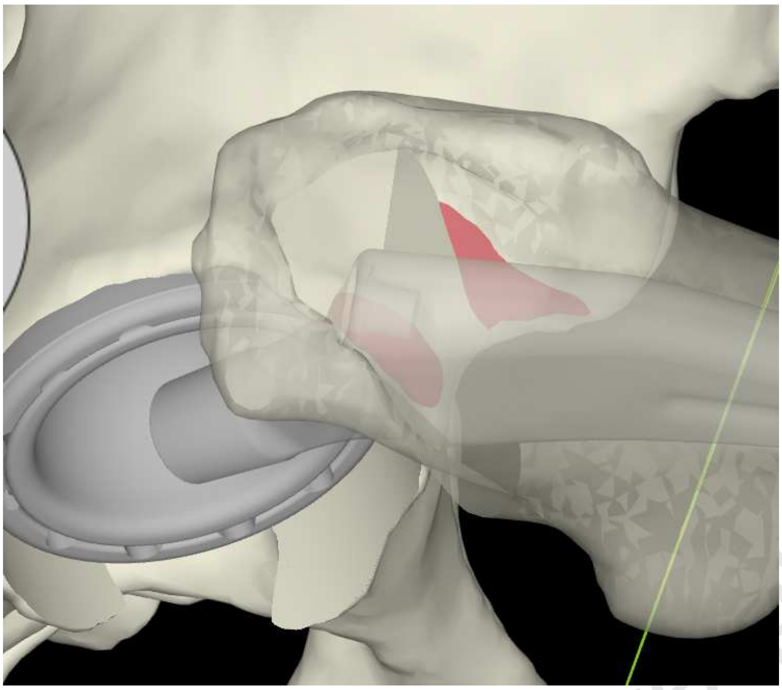

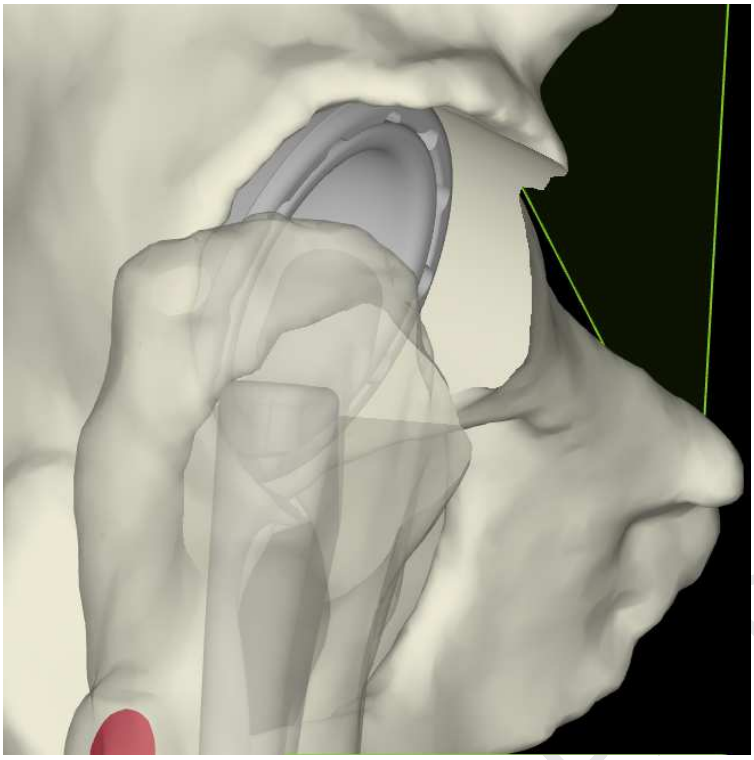

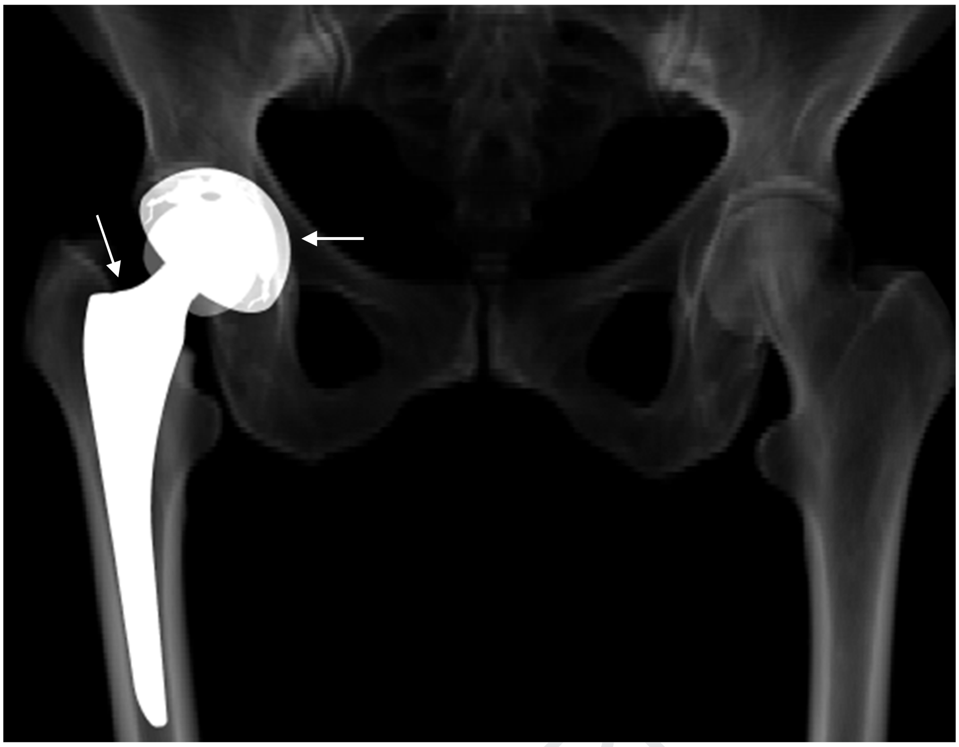

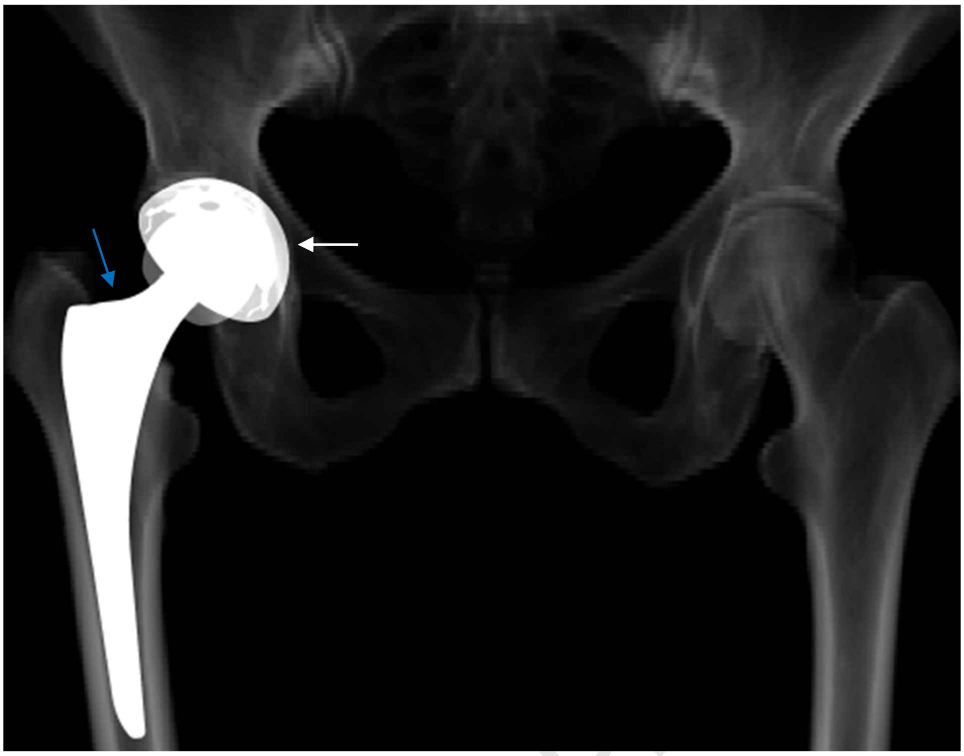

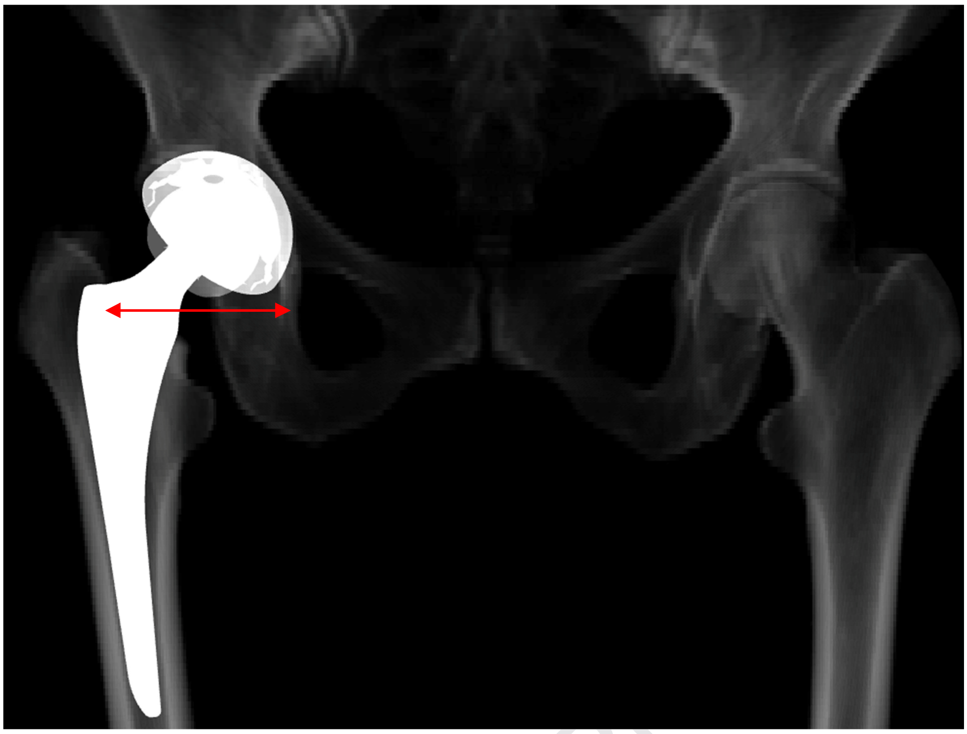

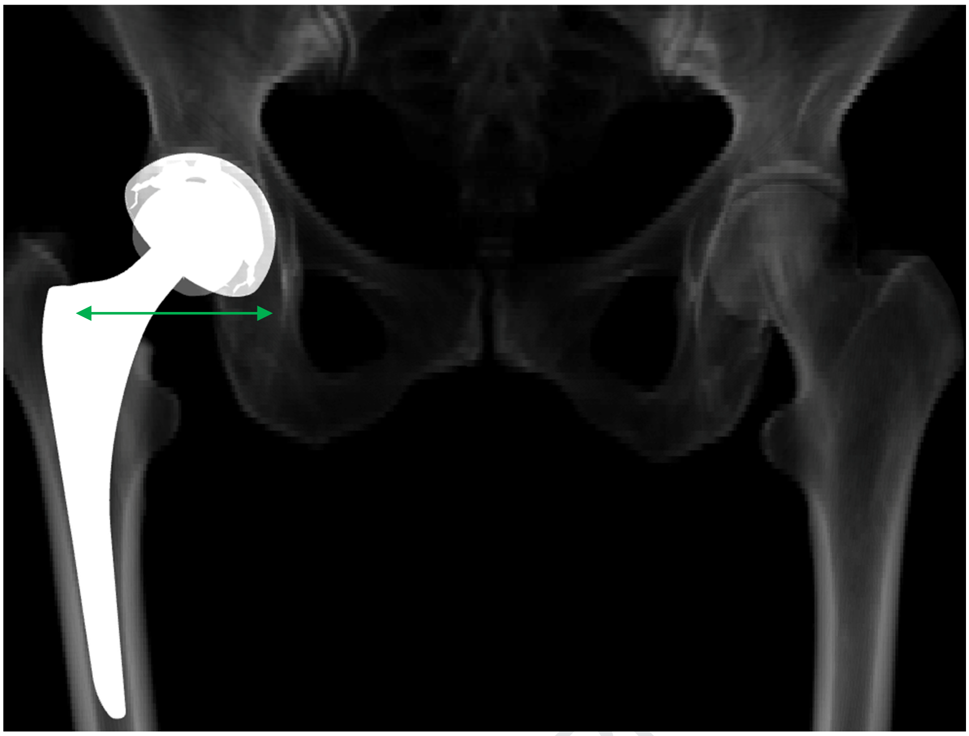

FIGURE CAPTIONS

Figure 1. Standing and seated lateral radiographs of the spine and pelvis illustrating the sacral slope (red line over superior plate of S1) and anterior pelvic plane (yellow line from the two anterior superior iliac spines and pubic symphysis). There is no change in the sacral slope (red line) between the two positions. This indicates failure of pelvic rollback and biological opening of the acetabulum during the transition from standing to sitting due to spinal stiffness and leads to increased risk of impingement.

Figure 2. Three-dimensional schematic depicting impingement above the cup. In order to increase impingement-free range of motion, lateralization of the trochanter is needed by increasing offset.

Figure 3. Postoperative, anteroposterior (AP) radiograph of the pelvis demonstrating increased offset of the femoral stem, moving the greater and lesser trochanter away from the pelvis and preventing bony impingement.

Figure 4. Three-dimensional schematic as seen in the software-based impingement model demonstrating **(a)** flexion and internal rotation; impingement in the supra-acetabular region and **(b)** extension and external rotation; lesser trochanter impingement on the ischium.

Figure 5. Condition 1 of the software-based implant modeling system demonstrating acetabular cup position medialized to the teardrop (white arrow) with a standard offset stem (white arrow).

Figure 6. Condition 2 of the software-based implant modeling system demonstrating acetabular cup position medialized to the teardrop (white arrow) with a high offset stem (blue arrow).

Figure 7. Condition 3 of the software-based implant modeling system demonstrating an offset that was patient-specific and designed to reproduce the preoperative offset.

Figure 8. Condition 4 of the software-based implant modeling system demonstrating a decrease in global offset (red arrow) by 4mm relative to Condition 3.

Figure 9. Condition 5 of the software-based implant modeling system demonstrating an increase in global offset (green arrow) by 4mm relative to Condition 3 (or an increase in offset of 8mm relative to Condition 4).