HIP

Abnormal spinopelvic mobility as a risk factor for acetabular placement error in total hip arthroplasty using optical computer-assisted surgical navigation system

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Aims
Navigation devices are designed to improve a surgeon’s accuracy in positioning the acetabular and femoral components in total hip arthroplasty (THA). The purpose of this study was to both evaluate the accuracy of an optical computer-assisted surgery (CAS) navigation system and determine whether preoperative spinopelvic mobility (categorized as hypermobile, normal, or stiff) increased the risk of acetabular component placement error.

Methods
A total of 356 patients undergoing primary THA were prospectively enrolled from November 2016 to March 2018. Clinically relevant error using the CAS system was defined as a difference of > 5° between CAS and 3D radiological reconstruction measurements for acetabular component inclination and anteverision. Univariate and multiple logistic regression analyses were conducted to determine whether hypermobile ($\Delta$ sacral slope (SS) $\text{stand-sit} > 30°$), or stiff ($\Delta$ SS $\text{stand-sit} < 10°$) spinopelvic mobility contributed to increased error rates.

Results
The paired absolute difference between CAS and postoperative imaging measurements was 2.3° (standard deviation (SD) 2.6°) for inclination and 3.1° (SD 4.2°) for anteverision. Using a target zone of 40° (± 10°) (inclination) and 20° (± 10°) (anteversion), postoperative standing radiographs measured 96% of acetabular components within the target zone for both inclination and anteverision. Multiple logistic regression analysis controlling for BMI and sex revealed that hypermobile spinopelvic mobility significantly increased error rates for anteverision (odds ratio (OR) 2.48, $p = 0.009$) and inclination (OR 2.44, $p = 0.016$), whereas stiff spinopelvic mobility increased error rates for anteverision (OR 1.97, $p = 0.028$). There were no dislocations at a minimum three-year follow-up.

Conclusion
Despite high reliability in acetabular positioning for inclination in a large patient cohort using an optical CAS system, hypermobile and stiff spinopelvic mobility significantly increased the risk of clinically relevant errors. In patients with abnormal spinopelvic mobility, CAS systems should be adjusted for use to avoid acetabular component misalignment and subsequent risk for long-term dislocation.

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Keywords: Total hip arthroplasty, Computer assisted navigation, Acetabular cup position, Accuracy, Spinopelvic mobility

Introduction
Total hip arthroplasty (THA) is considered one of the most successful surgeries for end-stage arthritis, resulting in excellent long-term survivorship and significant improvement of pain and overall quality of life.\textsuperscript{1,2} Accurate positioning of the acetabular or femoral components is crucial for THA success,
as malpositioning can lead to multiple early and late complications including dislocation, aseptic loosening, accelerated wear, and hip impingement.\(^3\,^4\) However, appropriate placement of the acetabular component to a target zone using freehand conventional techniques remains difficult irrespective of surgeon experience.\(^5\)

The use of computer-assisted surgery (CAS) navigation systems has improved the accuracy and reliability of patient-specific component positioning by providing intraoperative feedback.\(^6\,^9\) These systems have high accuracy and positive predictive values for determining cup inclination and anteversion inside a target zone.\(^6\) Consequently, CAS systems can significantly reduce the number of acetabular components placed outside target cup positions.\(^7\,^{10}\) Despite this improvement, numerous patient-specific and CAS-dependent factors are still reported to increase acetabular component placement error when using CAS navigation systems.\(^7\,^{11-13}\)

Although studies have investigated BMI and soft-tissue thickness as patient-specific factors contributing to increased error in CAS systems,\(^11-13\) studies have not investigated whether abnormal spinopelvic mobility can also contribute to increased error. Specifically, spinopelvic hypermobility, as defined by a change in sacral slope (SS) greater than 30° or 35° between sitting and standing, can influence acetabular component target and placement during THA.\(^14\,^{16}\) Likewise, spinopelvic hypermobility has been correlated with worse outcomes following THA.\(^17\)

This study had two specific aims. We aimed to first evaluate the accuracy of an optical intraoperative CAS navigation system in a large patient cohort with both standing and sitting radiographs. Then we aimed to determine whether abnormal spinopelvic mobility was associated with higher rates of clinically relevant error using the CAS navigation system. Given that spinopelvic mobility can potentially alter the registration of CAS navigation systems, we hypothesized abnormal spinopelvic mobility would significantly increase the risk of clinically relevant error in component acetabular placement during THA.
from the CAS system. Sacral slope was measured using Murray’s radiological definition in order to match outputs. All measurements were converted and transformed to fit the pelvic plane (APP), which is defined by the two anterior superior iliac spines and the pubic symphysis, was used.

Changes that can occur with pelvic tilt or femoral rotation and femoral component position to avoid angular differences were defined as absolute differences greater than 5°. Differences in SS were calculated between standing and sitting radiographs, and patients were categorized as either having hypermobile (ΔSSstand-sit > 30°), normal (10° ≤ ΔSSstand-sit ≤ 30°), or stiff (ΔSSstand-sit < 10°) spinopelvic mobility. Clinically relevant errors between intraoperative and postoperative inclination and anteversion measurements were defined as absolute differences greater than 5°. Chi-squared test analyses were performed to determine the interaction between patient-specific factors, including obesity, sex, and spinopelvic mobility, with rates of clinically relevant acetabular component placement error in anteversion, inclination, anteversion or inclination, and anteversion and inclination. Obesity was defined as a BMI > 30 kg/m². Multiple logistic regression analysis was performed to determine the odds of acetabular component placement error based on patient-specific factors. A power analysis using an α of 0.05 demonstrated that 698 patients were required for an 80% power to show a significant increase in the clinically relevant error rate by 10% based on preliminary analysis of the data with a 21% error rate in anteversion in

### Table I. Summary of computer-assisted surgery Intellijoint and radiological 3D SterEOS measurements.

| Measurement | CAS intraop, ° | Six wks postop, ° | Paired differences, ° |
|-------------|---------------|------------------|----------------------|
| Inclination |               |                  |                      |
| Mean (SD)   | 39.3 (4.3)    | 40.2 (4.7)       | 2.3 (2.6)            |
| Range       | 23 to 52      | 30 to 55         | 0 to 14              |
| Anteversion |               |                  |                      |
| Mean (SD)   | 20.7 (4.7)    | 19.7 (4.1)       | 3.1 (4.2)            |
| Range       | 8 to 33       | 10 to 32         | 0 to 18              |

CAS, computer-assisted surgery; SD, standard deviation.
patients with normal spinopelvic mobility. In the analysis, BMI was categorized as obese and non-obese, whereas spinopelvic mobility was categorized into hypermobile, normal, and stiff. A p-value under 0.05 was deemed statistically significant. All analysis were conducted with R software (R Foundation for Statistical Computing, Austria).

**Results**

In total, 354 hips were used in this study with two patients excluded due to failure to collect intraoperative values. The mean BMI was 28 kg/m² (18 to 51). Of the hips included, 178 were from female patients and 176 were from male patients. Preoperative standing radiographs were unavailable for 16 patients, leading to a total of 338 patients for analysis regarding spinopelvic mobility (169 male and 169 female). No hips in this study resulted in dislocations at a minimum three-year follow-up.

The mean inclination and anteversion for intraoperative and postoperative measurements are depicted in Figure 1. The absolute paired difference between intraoperative and 3D sterEOS imaging postoperative measurements was 2.3° (standard deviation (SD) 2.6°) for inclination and 3.1° (SD 4.2°) for anteversion (Table I). Linear correlation analysis revealed there was a significant, strong correlation ($r = 0.734$) for inclination between intraoperative CAS and postoperative radiological measurements (Figure 2). There was also a significant, but weaker, correlation between intraoperative and postoperative measurements for anteversion ($r = 0.335$) (Figure 3). Anteversion and inclination were significantly different between the intraoperative and postoperative measurements, and the means were different by 1.0° and 0.9°, respectively ($p < 0.001$, paired t-test).

Figures 4 and 5 depict the anteversion and inclination of each hip and their placement relative to a target range.
of 40° ± 10° for inclination and 20° ± 10° for anteversion. For the intraoperative CAS measurements, 330 hips (93%) were placed within this target range whereas for the postoperative measurements, radiographs revealed that 341 hips (96%) were placed within the target range. Accordingly, the sensitivity of the intraoperative CAS was 0.94 and specificity was 0.23 for placement within the target range. Using the radiological measurements as the reference for correct placement, and an assumed prevalence of 90% of hips correctly within the range, the PPV was calculated as 0.92 and NPV as 0.29. Further analysis using the traditional Lewinnek safe zone of 40° ± 10° for inclination and 15° ± 10° as the target range, revealed a sensitivity, specificity, PPV, and NPV of 0.86, 0.45, 0.93, and 0.27, respectively.

On univariate analysis, there was a significant interaction between spinopelvic mobility and clinically relevant errors (> 5°) using the CAS navigation system (Table II). This interaction was evident in anteversion (p < 0.001), inclination (p = 0.042), and inclination or anteversion (p = 0.005). Notably, 40.0% (18/45) of patients who had hypermobile spinopelvic mobility had clinically relevant errors in anteversion compared to 21.3% (48/225) of patients who had normal spinopelvic mobility and 33.8% (23/68) patients who had stiff spinopelvic mobility. For inclination, 31.1% (14/45) of patients who had hypermobile spinopelvic mobility had clinically relevant errors compared to 15.6% (35/225) of patients who had normal spinopelvic mobility. Furthermore, 51.1% (23/45) patients who had hypermobile spinopelvic mobility had clinically relevant errors for either inclination or anteversion compared to 27.6% (62/225) patients who had normal spinopelvic mobility. Obesity and sex did not have a significant interaction with clinically relevant errors for either inclination or anteversion.

Controlling for BMI and sex through multiple logistic regression, hypermobile spinopelvic mobility significantly increased the odds of having an error > 5° in anteversion.
(odds ratio (OR) 2.48; 95% confidence interval (CI) 1.24 to 4.87; p = 0.009), inclination (OR 2.44; 95% CI 1.15 to 4.99, p = 0.016), in either anteversion or inclination (OR 2.76; 95% CI 1.43 to 5.35, p = 0.002), and in both anteversion and inclination (OR 2.42, 95% CI 0.99 to 5.58, p = 0.044). Stiff spinopelvic mobility significantly increased the odds of having an error > 5° in anteversion only (OR 1.97, 95% CI 1.07 to 3.59, p = 0.028). BMI and sex, however, did not significantly increase the odds of acquiring an error > 5° (Table III).

**Discussion**

The mean paired absolute difference between intraoperative and postoperative measurements was 2.3° (SD 2.6°) for inclination and 3.1° (SD 4.2°) for anteversion. Our results are consistent with those found in previous studies using radiological analysis for the validation of other CAS systems, as well as a cadaver study using the same CAS system. Studies with other systems also had mean differences from 1.8° to 9.0° for anteversion and 2.0° to 6.5° for inclination with postoperative measurements with similar SDs. However, these studies had fewer than 100 patients in evaluating the accuracy of intraoperative CAS systems. In this study, we used a large patient cohort and compared CAS measurements against 3D radiological measurements. Consistent with previous work, the small deviation between intraoperative and postoperative values in our study validates the use of this optical CAS navigation system.

Furthermore, there was a strong correlation for inclination (r = 0.734; p < 0.001) and a lower correlation for anteversion (r = 0.335; p < 0.001). Likewise, Hohmann et al reported that in 32 subjects who underwent imageless navigation THA with postoperative CT scans, there was a strong correlation (r = 0.68; p < 0.01) for cup inclination in intraoperative and postoperative measurements.
However, there was a non-significant correlation for cup anteversion, which was later attributed to systematic error associated with anatomical landmark acquisition. Despite this reduced correlation for anteversion, we still demonstrate a high accuracy rate in placing the acetabular component in a defined target zone. Furthermore, this study compared anteversion measurements against the use of 3D stereEOS, which has been shown to measure anteversion with less accuracy when compared to CT measurements. Thus, the error comparing anteversion from this CAS system to the 3D radiological measurements may be due to either the CAS system, the 3D radiological measurements, or a combination of both. Comparison of the CAS system against CT scans would provide the most accurate analysis in future studies.

We assessed the accuracy of the navigation system for its sensitivity, specificity, PPV, and NPV in placing the acetabular component in a specified target range. Using a range of $40^\circ \pm 10^\circ$ for inclination and $20^\circ \pm 10^\circ$ for anteversion based on the surgeon’s targets, we found the sensitivity in placing the cup was 0.94, indicating that 94% of hips within the target acetabular positioning will be correctly placed by the CAS system. We also calculated a PPV of 92%, indicating that 92% of hips intraoperatively placed within this target range will be correctly positioned according to postoperative radiographs. These values are similar to that of Snyder et al’s study, which found a PPV of 94% and a specificity of 90% for a different CAS system using a target zone of $45^\circ \pm 10^\circ$ for inclination and $20^\circ \pm 10^\circ$ for anteversion. Of note, they defined specificity as correctly placing a hip within the target zone, which is how we defined the sensitivity of the CAS system used in this study. Our NPV was calculated as 0.29, indicating that the CAS system was not as effective in reliably placing a hip outside the target zone. Given that the target zone in both this study and Snyder
et al’s study is not the traditional Lewinnek safe zone, we also assessed the accuracy of the navigation system using a target zone of 40° ± 10° for inclination and in 15° ± 10° for anteversion, finding a similar sensitivity of 0.86 and PPV of 0.93. These results suggest this CAS system is a highly reliable tool in placing the acetabular hip within the defined target zones. This can provide advantages to the surgeon by potentially increasing accuracy of cup placement, decreasing operating time in position targeting, and mitigate learning curves for trainees. Furthermore, these potential benefits are of interest for future investigations for this CAS system.

A clinically relevant error was defined as an error greater than 5° based on studies assessing the accuracy and precision of CAS navigation systems. Despite the relatively high accuracy of this CAS system, for 338 patients included in the analysis for spinopelvic mobility, 89 (26%) patients had a clinically relevant error for anteversion, 60 (18%) patients for inclination, 101 (30%) patients for either anteversion or inclination, and 38 (11.2%) patients for both anteversion and inclination. In a study of 30 THAs, Hohman et al found a similar pattern where more cases had an error greater than 5° in anteversion (63%) compared to inclination (23%), and the error was attributed to a higher BMI (> 30 kg/m²) in their patient cohort and difficulty palpating the pubic symphysis. Similar studies suggest truncal obesity may play a critical role in correct acetabular placement. Anatomical landmarks, specifically the anterior superior iliac spine (ASIS) and pubic tubercle, function as inputs for other CAS navigation systems, and anatomical variations, such as the thickness of soft-tissue overlying these regions, may contribute to these differences. We found no significant correlation between BMI and soft-tissue thickness is less likely to affect its accuracy and, as our results show, BMI and sex did not have a significant interaction.
Critically, our results suggest that abnormal spinopelvic mobility increased the risk of error even after controlling for BMI and sex. In recent literature, spinopelvic hypermobility has been correlated with worse outcomes following THA. Grammatopoulos et al. showed that patients who had spinopelvic hypermobility had poorer patient-reported outcome measures (PROMs), such as Oxford Hip Score, which was statistically significant. In their study, spinopelvic hypermobility was also more present in patients who underwent revision secondary to dislocation even despite acceptable cup orientation. Kanawade et al. found that the hypermobile group was associated with a larger change in ante-inclination of the acetabular component due to higher spinopelvic motion, potentially leading to a more vertical cup in the seated position and increased risk of anterior dislocation. No dislocations were reported at a minimum three-year follow-up in the study cohort. Although we report no dislocations to date in our study, the results of the THAs in the patient cohort with high spinopelvic mobility are of continued interest.

A greater error in cup placement within the hypermobile spinopelvic mobility group may be a contributing factor to the poorer outcomes and greater dislocation rates reported in literature among patients with spinopelvic hypermobility. One potential explanation for the increased error observed in these patients is that they have more pelvic tilt variation in the surgical position, making it difficult to reliably estimate the APP when registering the coronal plane using the alignment rod. This suggests that CAS systems with similar registration methods may benefit from patient-specific adjustments in individuals with hypermobile and stiff spinopelvic mobility during positioning to account for this variability. Furthermore, another possible explanation for the increased error is that patients with hypermobile spinopelvic mobility can undergo large changes in spinopelvic mobility after THA, due to resolution of flexion contractures and hip stiffness, which may change the standing pelvic position postoperatively. This may leading to a possible discrepancy between intraoperative and postoperative cup measurements. This was recently reported in a study where 67% of patients who had hypermobile spinopelvic mobility preoperatively no longer had hypermobile spinopelvic mobility after THA at six weeks’ follow-up as “hip driven” spinopelvic hypermobility resolved. However, all postoperative measurements were taken according to the APP, making this a less likely explanation in this study.

There were several limitations. First, it was underpowered to determine whether spinopelvic mobility increased the risk of a clinical error, although the results still demonstrated a significant difference. Second, patient-specific sensitivity and specificity analysis were not conducted based on individual intraoperative targets but rather intraoperative target distributions. Studies investigating system performance based on specific targets are warranted. Third, spinal alignment in the coronal plane for spinal pathologies such as scoliosis and fixed pelvic obliquity were not included in this study. Fourth, the exact cause for the low accuracy of the optical system for cup anteversion angle restoration against postoperative measurements is still an investigation of interest. In particular, postoperative imaging was conducted in the standing position whereas intraoperative registration was conducted in the lateral decubitus position, which may have contributed to increased variability in accuracy. Finally, the findings in this study may be unique to this CAS system, as anatomical landmarks were not used for registration as in other systems. Comparative studies are still necessary to determine this CAS system’s ability to improve cup orientation placement against other systems, as well as its impact on long-term clinical outcomes. Nonetheless, we highlight that the large patient cohort findings reported here still emphasize the importance of considering spinopelvic mobility when using similar CAS systems, as abnormal spinopelvic mobility can increase error in acetabular component placement.

In conclusion, the use of this computer-assisted navigation system demonstrated high accuracy and reliability in acetabular component position and orientation for inclination, but less so for anteversion, when compared to 3D stereotactic imaging. The CAS system provides an additional intraoperative tool for surgeons to facilitate THA and enable real-time intraoperative values. Despite high reliability for inclination, we demonstrated that abnormal spinopelvic mobility is a potential risk factor leading to clinically relevant errors. As such, we suggest patient-based modifications and precautions are taken when patients with an abnormal spinopelvic mobility undergo primary THA using CAS navigation systems. Furthermore, future studies are necessary to evaluate long-term clinical outcomes and cost-effectiveness of this CAS navigation system for THA compared to conventional THA, as well as the use of CAS navigation systems for patients with abnormal spinopelvic mobility.

Take home message
- Despite using a highly reliable computer-assisted surgical navigation system for acetabular component placement, abnormal spinopelvic mobility was a potential risk factor for clinically relevant placement error.
- This suggests that patient-based modifications and precautions should be taken when patients with an abnormal spinopelvic mobility undergo primary total hip arthroplasty using certain computer-assisted surgical navigation systems.

References
1. Berry DJ, Harmsen WS, Cabanela ME, Morrey BF. Twenty-five-year survivorship of two thousand consecutive primary Charnley total hip replacements: factors affecting survivorship of acetabular and femoral components. J Bone Joint Surg Am. 2002;84-A(2):171–177.
18. Ransone M
19. Christ A
12. Tsukada S
11. Ybinger T
20. Murray DW
17. Grammatopoulos G
23. Dorr LD
22. Attenello JD
6. Snyder GM
9. Liu Z
7. Hohmann E
24. O’Connor PB
2004;426:159–163.
Clin Orthop Relat Res. 2011;6:40.
J Arthroplasty navigated total hip arthroplasty.
2004;28(4):198–201.
, the effect of spinal arthrodesis.
radiograph is necessary to predict spinopelvic mobility accurately.
2007;22(6):812–817.
J Arthroplasty. Accuracy of navigation-assisted acetabular component positioning studied,
J Arthroplasty. 2005;29(5):272–276.
J Bone Joint Surg Am
positioning system in total hip arthroplasty. A prospective, randomized, controlled study.
Bone Joint J. 2021;36(7S):S111–S120.
how to execute the plan.
Orthop Relat Res.
Bone & Joint Open
28. Lass R, Kubista B, Olischar B, Frantal S, Windhager R, Giurea A. Total hip arthroplasty using imageless computer-assisted hip navigation: a prospective randomized study. J Arthroplasty. 2014;29(4):786–791.
29. Ryan JA, Jamali AA, Bangar WL. Accuracy of computer navigation for acetabular component placement in THA. Clin Orthop Relat Res. 2010;468(1):169–177.
27. Buller LT, McLawhorn AS, Romero JA, Sculco PK, Mayman DJ. Accuracy and precision of acetabular component placement with imageless navigation in obese patients. J Arthroplasty. 2019;34(4):693–699.
2019;34(4):68–75.
Bone & Joint Open
25. Sharma AK, Vigdorcherk JM. The hip-spine relationship in total hip arthroplasty: how to execute the plan. J Arthroplasty. 2021;36(7S):S111–S120.
28. Vandevelde D, Niu S, Ei Alexis MM, Ren R, Ojard C, Waddell BS. Can robotic technology mitigate the learning curve of total hip arthroplasty? Bone Jt Open. 2021;28(3):385–390.
25. Alkete T, Handel M, Herold T, Perlick L, Baethis H, GriIka J. Greater accuracy in positioning of the acetabular cup by using an image-free navigation system. Int Orthop. 2005;29(5):272–276.
26. Nam D, Rieger V, Clohisy JC, Nunley RM, Barrack RL. The impact of total hip arthroplasty on pelvic motion and functional component position is highly variable. J Arthroplasty. 2017;32(4):1200–1205.
24. Sculco PK, Windsor EN, Jerabek SA, et al. Preoperative spino pelvic hypermobility resolves following total hip arthroplasty. Bone Joint J. 2021;103(8-B):1768–1773.
21. Sariali E, Lazennec JY, Khiami F, Gorin M, Catonne Y. Modication of pelvic orientation after total hip replacement in primary osteoarthritis. Hip Int. 2009;19(3):257–263.
22. Johnston RC, Bracha P, Liu S, Piyaworakhun S, Gofton W, Takao M, Yoshikawa H. Influence of component positions on dislocation: computed tomographic evaluations in a consecutive series of total hip arthroplasty. J Arthroplasty. 2004;19(2):162–166.
5. Saxler G, Marx A, Vandevelde D, et al. The accuracy of free-hand cup positioning—a CT based measurement of cup placement in 105 total hip arthroplasties. Int Orthop. 2004;28(4):198–201.
6. Snyder GM, Lozano Calderón SA, Lucas PA, Russinoff S. Accuracy of computer-navigated total hip arthroplasty. J Arthroplasty. 2012;27(3):415–420.
10. Vigdorcherk JM, Sculco PK, Inglis AE, Schwarzkopf R, Murr JM. Evaluating alternate registration planes for imageless, computer-assisted navigation during total hip arthroplasty. J Arthroplasty. 2021;36(10):3527–3533.
2019;2(6):365–370.
Arthroplasty. 2010;468(1):169–177.
37. Ike H, Dorr LD, Trasolini N, Steil M, McKnight B, Beckmann N. Spine-Pelvis-Hip Relationship in the Functioning of a Total Hip Replacement. J Bone Joint Surg Am. 2018;100-A(18):1608–1615.
37. Ike H, Dorr LD, Trasolini N, Steil M, McKnight B, Beckmann N. Spine-Pelvis-Hip Relationship in the Functioning of a Total Hip Replacement. J Bone Joint Surg Am. 2018;100-A(18):1608–1615.
38. Sculco PK, Windsor EN, Jerabek SA, et al. Preoperative spino pelvic hypermobility resolves following total hip arthroplasty. Bone Joint J. 2021;103(8-B):1768–1773.
39. Sariali E, Lazennec JY, Khiami F, Gorin M, Catonne Y. Modifications of pelvic orientation after total hip replacement in primary osteoarthritis. Hip Int. 2009;19(3):257–263.
39. Sariali E, Lazennec JY, Khiami F, Gorin M, Catonne Y. Modifications of pelvic orientation after total hip replacement in primary osteoarthritis. Hip Int. 2009;19(3):257–263.
39. Sariali E, Lazennec JY, Khiami F, Gorin M, Catonne Y. Modifications of pelvic orientation after total hip replacement in primary osteoarthritis. Hip Int. 2009;19(3):257–263.
39. Sariali E, Lazennec JY, Khiami F, Gorin M, Catonne Y. Modifications of pelvic orientation after total hip replacement in primary osteoarthritis. Hip Int. 2009;19(3):257–263.
39. Sariali E, Lazennec JY, Khiami F, Gorin M, Catonne Y. Modifications of pelvic orientation after total hip replacement in primary osteoarthritis. Hip Int. 2009;19(3):257–263.
39. Sariali E, Lazennec JY, Khiami F, Gorin M, Catonne Y. Modifications of pelvic orientation after total hip replacement in primary osteoarthritis. Hip Int. 2009;19(3):257–263.
39. Sariali E, Lazennec JY, Khiami F, Gorin M, Catonne Y. Modifications of pelvic orientation after total hip replacement in primary osteoarthritis. Hip Int. 2009;19(3):257–263.
39. Sariali E, Lazennec JY, Khiami F, Gorin M, Catonne Y. Modifications of pelvic orientation after total hip replacement in primary osteoarthritis. Hip Int. 2009;19(3):257–263.
options in Imagen, InSight, OrthAlign, and Wishbone, and membership on the Hip and Knee Society boards, all of which are unrelated to this study.

Ethical review statement:
This study was approved by the institutional review board at the Hospital for Special Surgery.

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