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Original Research

The Empty Ischial Fossa Sign: A Visual Representation of Relative Inadequate Anteversion in the Posteriorly Tilted Pelvis

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A B S T R A C T

Background: Instability is a known complication following total hip arthroplasty (THA) and is influenced by spinopelvic alignment. Radiographic markers have been investigated to optimize the acetabular cup position. This study evaluated if the empty ischial fossa (EIF) sign and the position of the trans-teardrop line were predictive of postoperative instability.
Methods: All patients who underwent THA from 2011 to 2018 at a single institution were retrospectively reviewed. Pelvic tilt was measured using a trans-teardrop line compared to the superior aspect of the pubic symphysis on standing anteroposterior pelvis radiographs. Postoperative dislocations were identified through chart review and radiographic review. The EIF sign was determined by the presence of uncovered bone below the posterior inferior edge of the acetabular component at the level of the native ischium and posterior wall on standing postoperative anteroposterior radiographs.
Results: One thousand seven hundred fifty patients (952 anterior approach and 798 posterior approach) were included. The EIF sign was present in 458 patients (26.2%) and associated with an increased dislocation rate (3.9% vs 0.9%, $P < .0001$). Patients with spondylosis/instrumented fusion, and positive EIF sign had a dislocation risk of 5.1% vs 1.3% ($P = .001$). A postoperative outlet pelvis was not significant for increased dislocation risk (odds ratio 2.16, $P = .058$). Patients with combined spondylosis/fusion, posterior approach, outlet pelvis, and EIF sign had a dislocation rate of 14.5%.
Conclusions: The EIF sign was an independent risk factor for postoperative instability and may represent failure to account for pelvic tilt. Avoidance of the EIF sign during cup positioning may help reduce dislocations following THA.

Introduction

Instability continues to be one of the most common complications following total hip arthroplasty (THA) [1-4]. As the utilization of THA continues to increase with an aging population, the number of patients with postoperative instability will likely rise as well [5,6].

Several preoperative and postoperative factors have been found to be associated with instability following THA [7-10]. In a previous study, we demonstrated that lumbar spondylosis, instrumented spinal fusion, and surgical approaches were all associated with postoperative instability at our institution [11]. These findings are supported by several other studies demonstrating that a stiff lumbar spine (either through spondylosis or instrumented fusion) increases the risk of dislocation [12-15]. This is most likely due to excessive femoro-acetabular motion compensating for lack of pelvic motion due to lumbar stiffness, leading to possible impingement in flexion or extension [16].

Consequently, when placing the acetabular component for THA, it is important to be cognizant of how the patient's standing pelvic

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tilt affects cup orientation, especially in patients with stiff lumbar spines. It has previously been demonstrated that as posterior pelvic tilt increases, the version and inclination of the native acetabulum on a standing anteroposterior (AP) radiograph will also increase [17-19]. To account for this, in a patient with significant posterior pelvic tilt preoperatively, the acetabular component should be placed such that there is increased anteversion and inclination on an AP pelvic radiograph (assuming the radiograph is taken to match the preoperative standing pelvic tilt). If the cup is placed with an inadequate amount of anteversion or inclination, a portion of the posteroinferior acetabular wall will remain uncovered by the implant, a finding we describe as the empty ischial fossa (EIF) sign. Theoretically, the presence of an EIF sign may indicate a higher risk of anterior impingement and subsequent posterior dislocation, or drop-out posterior dislocation, given the lack of coverage posteroinferiorly.

Therefore, we performed a retrospective study to assess if radiological signs, specifically the presence of an EIF sign and the position of a trans-teardrop line (a surrogate for pelvic tilt on the AP radiograph), were predictive of postoperative instability.

Material and methods

A retrospective comparative study was performed on all patients who underwent THA from the years 2011 to 2018 at a single institution. Exclusion criteria included THA for fracture/trauma, metal-on-metal implants, lack of clinical follow-up, and inadequate radiographs (Fig. 1). For all included patients, clinical and radiographic data were obtained up to final follow-up.

Dislocations in the postoperative period were identified through chart review and/or radiographic review. For those patients who had adequate radiographs showing the dislocation event, the direction of the dislocation was determined as well.

Radiographic evaluation was performed using a standing preoperative and postoperative AP pelvis. Each radiograph was analyzed for pelvic tilt using a trans-teardrop line, comparing this to the most superior aspect of the pubic symphysis. Patients were considered to have an “inlet pelvis” if the trans-teardrop line was above the symphysis, a “neutral pelvis” if the trans-teardrop line was at the level of the symphysis, and an “outlet pelvis” if the trans-teardrop line was below the level of the symphysis (Fig. 1). As shown in a previous publication from our institution, the patients with an inlet pelvis have anterior pelvic tilt, and conversely, the patients with an outlet pelvis have posterior pelvic tilt [20].

The presence of the EIF sign was determined by noting the presence of uncovered bone below the posterior inferior edge of the acetabular component at the level of the native ischium and posterior wall on standing postoperative AP radiographs. This was standardized by using the inferolateral sclerosis of the native acetabulum to determine the inferior aspect of the EIF area. This may arise through inadequate anteversion and abduction of the acetabular component, especially in the posteriorly tilted, given its increased native anteversion and inclination. In this scenario, the anterosuperior wall of the acetabulum is overreamed, which results in posteroinferior undercoverage, resulting in the EIF sign. Additionally, the EIF sign may occur if there is excessive medialization and superior placement of the acetabular component, as this will also result in posteroinferior undercoverage of the native acetabulum. If cup position (either through superomedial placement or inadequate anteversion and abduction) was such that an uncovered area could be noted on the standing AP radiograph, this was deemed a positive EIF sign (Fig. 2). Visual representation of the EIF sign is also demonstrated on a sawbone model (Figs. 3 and 4). All measurements were performed by 2 senior orthopaedic residents, with a set of 50 radiographs read by both residents in a blinded fashion to determine interrater reliability.

For the patients who had a confirmed dislocation, further radiographic analysis was performed by measuring inclination and anteversion of the cup on the AP view. Anteversion was measured using the method described by Widmer et al. [21] A comparison of cup position was also performed between patients with and without a positive EIF sign.

For statistical analysis, a chi-square test was performed to compare dislocation rates between patients with and without an EIF sign. Logistic regression was also performed using factors known to be associated with instability (body mass index, gender, spinal fusion, and approach) along with novel radiographic factors. Statistical significance was determined using an alpha of 0.05. Statistical analysis was performed using SPSS 26 Statistics Software (IBM, Armonk, NY: IBM Corp).

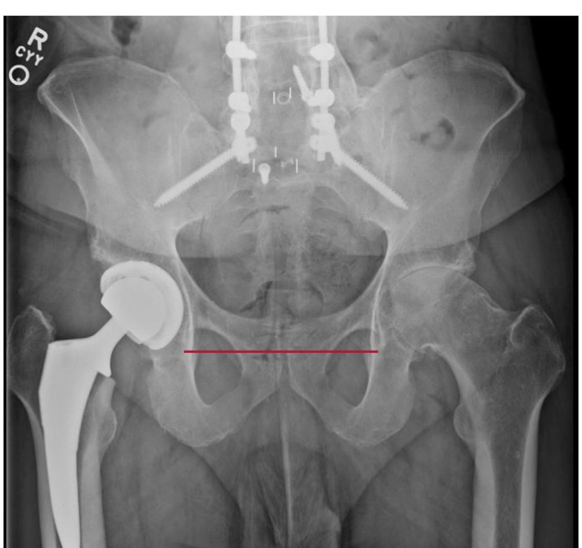

Figure 1. Example of “outlet pelvis” with trans-teardrop line.

Figure 2. Example of positive empty ischial fossa sign.

Figure 3. Saw bones pelvis model without EIF sign.

Results

In total, 1750 patients were included in the study. Of these, 952 patients received an anterior surgical approach (either anterior-based muscle sparing or direct anterior), and 798 patients received a posterior surgical approach. The average age of the patient was 61.2 (standard deviation [SD] = 17.4) and the average body mass index was 29.6 (SD = 7.0) (Table 1).

The EIF sign was present in 458 patients (26.2%). There were a significantly increased number of dislocations in patients with a positive EIF sign (3.9% vs 0.9%, P < .0001) (Table 2). When subdivided by surgical approach, a positive EIF sign was significantly associated with highe dislocation rates in the posterior approach and there was a non-significant treand toward the same finding in the anterior approach (Table 3). Furthermore, binary logistic regression demonstrated a positive EIF sign, along with surgical approach and presence of an instrumented spinal fusion, to be significantly predictive of dislocation, with EIF being the most impactful (odds ratio 4.74, P < .001) (Table 4). In those patients who had spondylosis/instrumented fusion, those with a positive EIF sign had a dislocation risk of 5.1% vs 1.3% (P = .001).

There were 732 patients (41.8%) with an outlet pelvis on postoperative radiographs. The presence of an outlet pelvis by itself was not significantly associated with an increased dislocation risk (odds ratio 2.16, P = .058).

Isolating patients with spondylosis/fusion, a posterior approach, an outlet pelvis, and a positive EIF sign, the rate of dislocation was 14.5%.

Figure 4. Saw bones pelvis model with positive EIF sign.

Table 1
Patient characteristics.

Patient characteristics	EIF not present	EIF present	P-value
Age	61.6 (SD = 13.2)	59.9 (SD = 15.4)	.023
Gender (% female)	57.1%	52.0%	.056
BMI (kg/m^2)	29.8 (SD = 6.5)	29.1 (SD = 8.4)	.086
Charlson comorbidity index	1.5 (2.1)	1.6 (2.2)	.24
Average follow-up time (y)	1.8 (1.8)	1.9 (2.0)	.49
Femoral head size (mm)	35.9 (2.7)	36.0 (2.7)	.448
Surgical approach (% anterior)	56.60%	48.40%	.002
Outlet pelvis	40.20%	46.30%	.023
Spondylosis present (without fusion)	53.60%	57.40%	.157
Fusion	7.50%	8.10%	.672
Dislocation postoperatively	0.90%	3.90%	<.001

BMI, body mass index.

For EIF identification of 50 patients by the 2 blinded readers, there was an overall agreement of 90% with a kappa of 0.746 (P < .0001).

Dislocations

There were 29 postoperative dislocations in the patient population, of which 5 were anterior dislocations and 21 were posterior dislocations. The EIF sign was present in 18 (62.1%) of the patients who had a dislocation. However, of the 21 patients with posterior dislocations, 17 (81.0%) had an EIF sign. Considering all dislocators with a positive EIF sign, all dislocations with a determined direction were posterior except for one (this patient received an anterior approach). After dividing patients by pelvic tilt determined on the postoperative standing AP pelvis, 23 patients (79.3%) had an outlet pelvis, while 6 patients (20.1%) had a neutral or inlet pelvis.

In the patients who experienced a dislocation, the average cup anteversion was 25.1 (SD = 4.9) and the average inclination was 43.2 (SD = 7.0). Of those patients who had a positive EIF sign, the average anteversion was not significantly different than those without an EIF sign (24.5 vs 26.0, P = .512). Likewise, inclination was not significantly different between those with and without a positive EIF sign (41.7 vs 45.7, P = .186). However, there was a trend noted toward decreased anteversion and abduction in the patients with a positive EIF sign.

In addition to evaluating cup position as a cause for dislocation, radiographic and implant record analysis was performed on all 29 dislocators to assess limb lengths, ipsilateral and contralateral global offset, differences in global offset, head sizes, and type of liner used (Table 5). There were no significant differences in any of these parameters for patients who had a positive EIF sign and dislocated compared to dislocators without an EIF sign. Additionally, implant records were reviewed for all 498 patients with a positive EIF sign, and there was no significant difference in dislocation risk for those who received a standard offset vs high offset stem (4.0% for standard offset vs 3.8% for high offset, P = .8944) (Table 6).

Table 2
Dislocation rates by presence of EIF sign.

Presence or absence of EIF sign	Dislocations	P-value
All patients		
EIF not present (n = 1292)	11 (0.9%)	P < .001
EIF present (n = 458)	18 (3.9%)	
Nonspondylosis/fusion		
EIF not present (n = 594)	2 (0.3%)	P = .013
EIF present (n = 200)	5 (2.5%)	
Spondylosis/fusion		
EIF not present (n = 687)	9 (1.3%)	P = .001
EIF present (n = 256)	13 (5.1%)	

Table 3
Dislocation rates subdivided by surgical approach.

Presence or absence of EIF sign	Dislocations	*P*-value
Anterior approach		
EIF not present (n = 721)	4 (0.6%)	*P* = .299
EIF present (n = 225)	2 (0.9%)	
Posterior approach		
EIF not present (n = 549)	7 (1.3%)	*P* < .001
EIF present (n = 226)	16 (6.6%)	

The average time from the index surgery to the first dislocation was 201.9 days (range 0-4.5 years). There was no significant difference in time to dislocation between those with and without an EIF sign (267.1 vs 91.2 days, *P* = .220).

Discussion

Postoperative instability after THA is a complex issue with multiple potential etiologies, including acetabular or femoral component malposition, impingement, inadequate soft-tissue tension, and spinopelvic stiffness. In previous work on this issue at our institution, we demonstrated that both surgical approaches and lumbar spondylosis/fusion were significant risk factors for instability [11]. The findings of the current study demonstrate the importance of matching patient-specific anatomy, primarily through avoiding under-coverage of the native posteroinferior acetabulum (a positive EIF sign). While several factors were demonstrated to be associated with instability, patients with a positive EIF sign had a substantially higher risk of dislocation.

The importance of acetabular component position to prevent instability has been well established in the literature. The concept of safe zones, initially popularized by Lewinnek et al, has been one of the most common ways to describe the parameters of cup position in relation to stability [22]. However, as our understanding of hip instability has evolved to account for patient-specific factors, such as pelvic tilt and functional positions, the simplicity of previous "safe" zones has begun to erode. As demonstrated by Abdel et al, the majority of dislocations may take place in patients who have acetabular components within these previously established safe zones [23]. A recent study by Sharma et al showed that when using their method of patient-specific positioning (utilizing standing/sitting radiographs), only 56% were within traditional Lewinnek safe zones [24]. This suggests that methods of component positioning must account for dynamic pelvic position to truly be "safe."

In concurrence with this concept, 9 of the dislocations in our study were within traditional safe zones, and all dislocators had acetabular components with anteversion beyond 15 degrees, despite over 70% of the dislocations being posterior. Furthermore, among those with a positive EIF sign (which suggests relative retroversion) and a posterior dislocation, the average anteversion was 24.1°. One explanation for this may be that such patients required *more* anteversion to match their specific anatomy and pelvic tilt, despite having what has been considered high-normal or even excessive anteversion based on Lewinnek safe zones. Therefore, the EIF sign may have been especially predictive in our study since it reflects the specific anatomy and tilt of the patient revealed by under-coverage of the posteroinferior acetabulum.

Table 4
Logistic regression of risk factors for instability.

Variables	OR (95% CI)	*P*-value
Age	0.99 (0.96-1.02)	.418
BMI (kg/m^2)	0.97 (0.91-1.03)	.28
Charlson comorbidity index	1.14 (1.00-1.32)	.058
Femoral head size (mm)	1.02 (0.87-1.19)	.795
Gender (ref = male)	1.33 (0.56-3.15)	.521
Surgical approach (ref = anterior)	4.31 (1.61-11.58)	**.004**
Instrumented fusion	4.55 (1.76-11.74)	**.002**
Presence of EIF	4.74 (2.08-10.78)	**<.001**
Outlet pelvic tilt	2.16 (0.98-4.79)	.058

BMI, body mass index; OR, odds ratio; CI, confidence interval.
Significant *P*-values (<.05) are bolded.

Table 5
Radiographic and implant analysis of all dislocators.

Radiographic measurement	Overall	EIF - (N = 13)	EIF + (N = 16)	
	mean (std)	mean (std)	mean (std)	*P*-value
Limb length	1.3 (3.8)	2.1 (3.5)	0.6 (4.0)	.3193
Global offset ipsilateral	69.5 (9.4)	72.8 (12.4)	66.7 (4.9)	.1167
Global offset contralateral	67.4 (9.4)	70.5 (11.9)	64.7 (5.8)	.1312
Difference in offset	2.1 (5.8)	2.4 (7.1)	1.9 (4.7)	.8484
Liner type		N (%)	N (%)	*P*-value
Lateral offset	6 (20.7)	2 (15.4)	4 (25.0)	.6628
Standard	23 (79.3)	11 (84.6)	12 (75.0)	

We did find a nonsignificant trend toward decreased anteversion and abduction in the patients with a positive EIF sign. This is noteworthy as the vast majority of EIF positive cases were in patients with neutral to posterior pelvic tilt (74%), and with posterior pelvic tilt, the ideal acetabular component position should have more inclination and anteversion rather than less. The finding of relatively too little abduction and anteversion for the posteriorly tilted pelvic position is the definition of the visual representation seen by the EIF sign.

In a paper on a simplified algorithm for treating hip-spine patients, Luthringer et al. describe the need for increased anteversion in patients with a posteriorly tilted pelvis (2A and 2B deformities) in order to prevent posterior dislocation [15]. Our description of the EIF sign is in line with these recommendations, as the EIF sign is simply a visual representation of an acetabular component that does not have adequate anteversion and abduction for the posteriorly tilted functional pelvic position.

Finally, our study demonstrated the cumulative risk seen with spinopelvic stiffness, surgical approach, and radiologic signs (EIF sign, outlet pelvis). Although each factor was shown to increase the risk of postoperative instability, those patients with all such risk factors had a dislocation risk of nearly 15%. Therefore, while postoperative instability is a binary outcome, prevention requires a multifaceted approach to reduce risk.

Limitations

Our study has several limitations, which should be considered. Perhaps most obvious is the limitation of the EIF sign, which was considered to be binary in this study despite there clearly being a qualitative component; for instance, some patients may have large uncovered areas of posteroinferior acetabulum while others have subtle amounts, but both are simply considered to have a positive EIF sign in this study. The consequences of this are unknown,

Table 6
Dislocations and femoral stem offset of all patients with + EIF sign.

Stem type	No dislocation (N)	Dislocation (N)	Dislocation rate (%)	*P*-value
Standard offset stem	262	11	4.0	.8944
High offset stem	178	7	3.8	

though logically we would presume that a “large EIF sign” is a greater risk for instability than a “small EIF sign.” Given the difficulty in quantifying the size of the EIF, we decided to simply utilize a binary approach, despite the limitations. Furthermore, the retrospective nature of the study allows for several potential confounding factors, which although we attempted to account for, may have contributed to the results.

Conclusions

In this study, we demonstrated that the presence of an EIF sign was an independent risk factor for postoperative instability, along with a posterior surgical approach and the presence of spinal spondylosis or fusion. The EIF sign may represent a failure to match patient-specific anatomy and pelvic tilt; avoidance of its presence during cup positioning may help prevent dislocation following THA.

Conflicts of interest

L. Anderson is a paid consultant of Medacta; has stock options in OrthoGrid; and receives research support from Zimmer/Biomet and Stryker. B. Blackburn is a committee member of American Association of Hip and Knee Surgeons (AAHKS). J. Gililland receives royalties from OrthoGrid and Stryker; is a paid consultant of Stryker, OrthoGrid, MiCare Path, and Enovis; has stock options in OrthoGrid, MiCare Path, and Connextions; receives research support from-Medacta, Zimmer/Biomet, and Stryker; is an editorial board member of Journal of Arthroplasty; and is a board/committee member of AAHKS. C. Pelt receives royalties from Total Joint Orthopaedics and Smith and Nephew; is a speaker bureau of Total Joint Orthopaedics; is a paid consultant for 3M and Total Joint Orthopaedics; has stock options in Joint Development, LLC; receives research support from Zimmer Biomet, Peptilogics, and Smith and Nephew; and is a board/committee member of AAHKS and American Academy of Orthopaedic Surgeons. All other authors declare no potential conflicts of interest.

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CRediT authorship contribution statement

Timothy L. Kahn: Data curation, Formal analysis, Writing – original draft. **Joshua P. Rainey:** Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Jeffrey J. Frandsen:** Writing – original draft. **Brenna E. Blackburn:** Data curation, Formal analysis. **Lucas A. Anderson:** Writing – original draft. **Jeremy M. Gililland:** Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. **Christopher E. Pelt:** Investigation, Methodology, Writing – original draft, Writing – review & editing.

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