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ORIGINAL ARTICLE

The role of postoperative piriformis fossa and greater trochanter tubercle distance to predict cutout failure after cephalomedullary nail fixation

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Abstract

Background: This study investigated the association between postoperative piriformis fossa and greater trochanter tubercle distance (distance from the deepest point of piriformis fossa to the most lateral greater trochanter tubercle [PG]) and cutout failure after cephalomedullary nail (CMN) osteosynthesis for intertrochanter fracture (ITF). A rotating femur model was designed to analyze PG variation during femur rotation.

Methods: From 2005 to 2010, 311 patients diagnosed of ITF (Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association [AO/OTA] 31-A2 and A3) underwent CMN fixation at our institute were reviewed. Of these, 281 (90.3%) patients achieved union without complication, 21 (6.8%) had cutout failure, six (1.9%) had femoral head osteonecrosis, and three (1%) had nonunion during postoperative 2-year follow-up. The side difference of postoperative PG compared to contralateral uninjured hip (dPG) was analyzed between patients who had cutout failure and those who did not. In the rotating femur model, the PG was measured for every 2.5° increments of internal and external rotation from 0° to 50°.

Results: The dPG was significantly higher in the failure group (10.2 ± 4.2 vs 6.6 ± 3.5 mm, p <0.001). The odds ratio for lag screw cutout was 6.35 (95% CI, 1.10-11.6, p =0.003) for every 1 mm dPG increment. dPG exhibited high diagnostic performance in predicting cutout failure according to receiver operating characteristic curve analysis. The area under the curve was 0.774 (95% CI, 0.711-0.837). dPG yielded the greatest sensitivity (78.4%) and specificity (78.4%) to predict lag screw cutout when cutoff value being 8.65 mm. In rotating femur model, PG change from baseline demonstrated significant (p <0.001) positive and negative correlation with increased external and internal rotation, respectively.

Conclusion: Increased dPG is a risk factor of cutout failure for ITF osteosynthesis with CMN. In conjunction with tip-apex distance, fracture displacement, and reduction quality; dPG can help surgeons interpret postoperative radiograph and predict failure. However, it should be noticed that a proper and standard patient positioning is critical for accurate dPG measurement.

Keywords: Femoral head; Odds ratio; Radiology; Receiver operating characteristic; Risk factors

1. INTRODUCTION

Intertrochanteric fracture (ITF) of the femur remains as one of the leading burdens on the health care system as the average population grows more elderly.[1,2] The surgical outcome and patient survival can be negatively affected by patients' comorbidities and osteoporotic status. Moreover, unstable ITFs distinguished by lateral wall fractures, medial calcar fragmentation, or reverse oblique fracture pattern can lead to increased postoperative complications and mortality.[3]

Surgical treatment with cephalomedullary nail (CMN) provides biomechanical advantage for fixation of unstable ITFs, but postoperative complications still arise in up to 16% of cases.[4–6] Varus collapse of the proximal fragment with lag screw cutout is one of the most devastating complications which requires arduous revision osteosynthesis,[7,8] or conversion total hip arthroplasty.[9,10] Factors associated with lag screw cutout after CMN osteosynthesis have been extensively studied in the past literatures.[11] Different nail designs,[12] fixation methods,[13] and many radiographic references, such as the tip-apex distance (TAD), reduction quality, and displacement after fixation have been well discussed to predict stable fixation construct and surgical failure.[14–20]

Hsu et al[4] have recently developed a simple radiographic method based on the side difference of the distance from the deepest point of piriformis fossa to the most lateral greater trochanter tubercle (dPG) after nailing, measured in anteroposterior radiograph (Fig. 1). The dPG may be adopted as an adjunctive tool to predict surgical failure. Evidence supports increased dPG after nailing of unstable ITFs is highly associated with fixation failure (Fig. 2).[4] The dPG can be utilized as an accessional radiographic parameter in addition to TAD, reduction quality and postoperative displacement to serve as a fast, highly sensitive, and specific tool for osteosynthesis stability assessment. However, the preliminary study proposed

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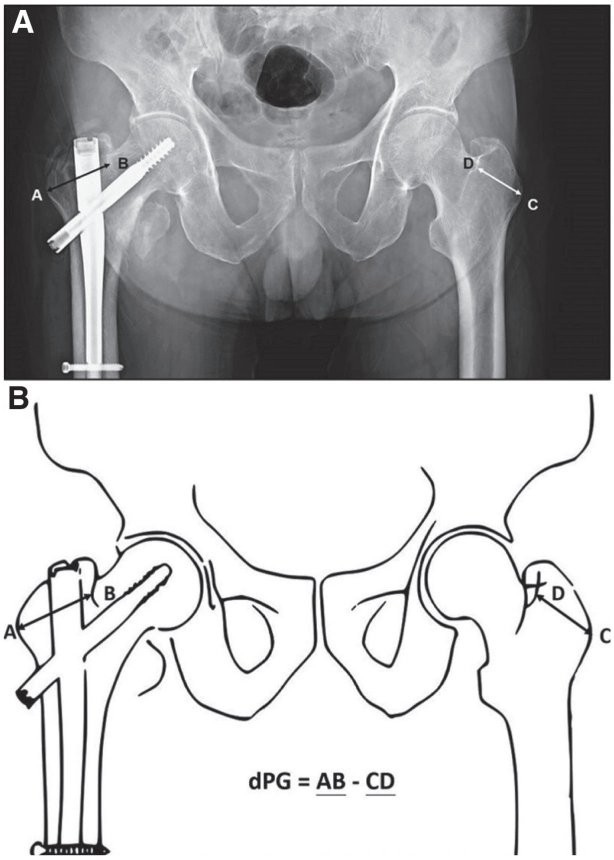

Fig. 1 Radiograph and illustration of dPG measurement. A, Definition of dPG measurement. In the anteroposterior radiograph, distance A to B was the length from the deepest point of piriformis fossa to the most lateral greater trochanter tubercle on the operative side, whereas distance C to D was the same distance measured on the contralateral uninjured side. The dPG was calculated as the distance AB minus distance CD. B, Illustration of the dPG measurement in figure A. dPG = side difference of the distance from the deepest point of piriformis fossa to the most lateral greater trochanter tubercle.

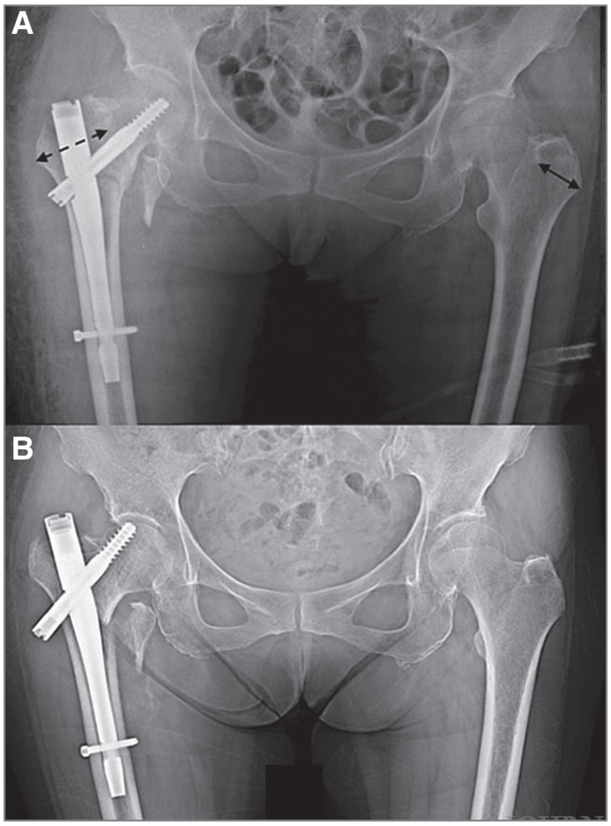

Fig. 2 Case demonstration of increased piriformis fossa to lateral greater tubercle distance with cutout failure. A, An 86-year old female patient underwent cephalomedullary fixation for unstable intertrochanter fracture. The radiograph on postoperative day 1 demonstrated increased piriformis fossa to lateral greater tubercle distance compared to the uninjured side (double-headed arrow), which may cause from over lateralization of nail entry point. The side difference was 9.3 mm in this patient. B, Follow-up radiograph at postoperative 2 months showed varus collapse with lag screw cutout failure.

by Hsu et al[4] was limited to short-term follow-up and single CMN design (Gamma-3 nails; Stryker, Mahwah, NJ). The accuracy of dPG interpretation was also questioned because the measurement may be affected by patient positioning on the postoperative radiograph. Evidence regarding the clinical utility of dPG in mid- to long-term follow-up, in different CMN devices and how femur rotation affects its calculation are relatively scarce and less discussed.

Accordingly, the primary objective of this study was to investigate the reliability of dPG in predicting surgical failure in mid-term follow-up and in CMN design different from Gamma-3 nail (G3N). The secondary objective was to assess the dPG variation in different degree of femur rotation.

2. METHODS

This retrospective study was conducted from January 2005 to December 2010 using data from a Level I trauma center. The hospital medical records database was screened for all ITFs (Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association [AO/OTA] 31-A2 and A3) treated with CMN fixation during the study period. Unstable ITFs were defined as fractures with a displaced lateral wall, posteromedial comminution, subtrochanteric extension, or reverse oblique fracture pattern. Patients with unstable ITFs who underwent osteosynthesis with the Asian Pacific Gamma Nail (APGN; Howmedica Osteonics, Mahwah, NJ) and had follow-up radiographs and medical records for at least 2 years were included. Baseline patient characteristics including age, sex, Harris hip scores (HHS) at postoperative one year, Carlson comorbidity index, bone mineral density, body mass index, and American Society of Anesthesiologists' Physical Status Classification was investigated. Perioperative variables, including operation time, length of hospital stay, and blood loss were documented. Patients were excluded if their medical records documented less than 2 years of follow-up, incomplete patient records, previous ipsilateral or contralateral hip fractures precluding precise dPG measurement, poor image quality for accurate radiographic parameter interpretation, pathological fractures, and patient age younger than 60 years, and postoperative surgical site infection or osteomyelitis. This study was performed in accordance with the ethical principles set out in the 1964 Declaration of Helsinki and was approved by the Institutional Review Board of our institution (IRB Number: 2022-04-013CC).

2.1. Surgical treatment and rehabilitation

All surgical procedures were performed by one of the six orthopedic trauma surgeons or by supervised senior residents. The patient was placed in a supine position on a traction table, and closed reduction was performed under fluoroscopic control. Osteosynthesis was performed using APGN according to the manufacturer's instructions. All the lag screws were locked to prevent sliding through the nail. All the nails were statically locked distally. On postoperative day one, hip and knee range of motion exercises were initiated and all patients were mobilized with a walker and weight-bearing as tolerated. Each patient underwent radiographic follow-up with pelvic anteroposterior and lateral radiographs on postoperative day one, then subsequently at the outpatient clinic at 4 weeks, 8 weeks, 3 months, 6 months, 12 months, and 24 months postoperatively.

2.2. Radiographic evaluation

Radiographic parameters were measured from the postoperative day one radiograph. The patient was positioned supine on the radiographic table with hip joint located 1.2 m from the collimator. Patients' feet were internally rotated by approximately 15° to overcome the normal anteversion of the femoral necks and to place the longitudinal axes parallel to the film.[21] The qualified hip radiograph selection criteria were as follows: correct centering evidenced by both ilia and greater trochanter equidistant to the edge of the radiograph, with the coccyx and pubic symphysis centered at the midline; no rotation was demonstrated by symmetric appearance of the two obturator foramina, as well as symmetric iliac alae and ischial spines. Radiographic parameters of interest including dPG, TAD, reduction quality, and fracture displacement in the lateral view were evaluated. The dPG was defined as the side difference of the distances from the deepest point of piriformis fossa to the most lateral point of greater tubercle in pelvis anteroposterior radiograph (Fig. 1). TAD was calculated as the sum of the distance from the tip of the lag screw to the apex of the femoral head on anteroposterior and lateral radiograph as described by Baumgaertner et al[22]; the results were further divided into TAD >25 mm and ≤25 mm groups. Reduction quality was rated as good, acceptable, or poor based on criteria described by Baumgaertner et al[22] and Kashigar et al.[23] The reduction quality was categorized as "good" if: (1) the neck-shaft angle was between 120° and 135° or slight valgus but not more than 145° on anteroposterior radiograph with <20° angulation on lateral view and (2) fragment displacement <4 mm on both anteroposterior and lateral films; reduction quality was rated "acceptable" if only one of two criterion was fulfilled; a "poor" rating was given if neither criteria was met. Fracture displacement on lateral radiographs was assessed by the classification proposed by Tsukada et al.[24] Cases involving reduced continuity of the anterior cortex at the fracture site were defined as type 1; cases showing head and neck fragments displaced anteriorly and posteriorly relative to the femoral shaft fragment were defined as types 2 and 3, respectively.

The outcome was classified as union or failure according to the radiological results at postoperative 2 years. Independent of the clinical symptoms of the patient, union was defined as the presence of bridging callus across the fracture line on both anteroposterior and lateral radiographs, without a radiolucent line around the lag screw or distal locking screw, indicating implant loosening. Failure was defined as the collapse of the neck-shaft angle into varus, leading to lag screw extrusion from the femoral head by more than 1 mm (cutout),[25] femoral head osteonecrosis observed on any follow-up radiograph, or nonunion after postoperative 9 months.

A single observer (consultant trauma surgeon) measured all radiographic parameters and outcomes to minimize interobserver variability. To ensure consistency of measurements, the observer measured the dPG, TAD, reduction quality, and fracture displacement in the lateral view of anonymized radiographs from 50 patients. The same observer, blind to patient information and previous results, repeated the image interpretation of the same 50 patients 4 weeks later. The results showed high consistency between two measurements, with intraclass correlation coefficient being 0.88 (95% CI, 0.81-0.95) for the dPG and 0.91 (95% CI, 0.84-0.98) for the TAD measurements; the Cohen's kappa coefficient was 0.93 (95% CI, 0.87-0.99) for the reduction quality and 0.87 (95% CI, 0.84-0.90) for the displacement on lateral film.

2.3. Rotating cadaver imaging models

Two cadaveric femurs were designed as rotating models to evaluate the consistency of dPG with different femur rotations. Femur A was donated by a 61-year old female weighting 60 kg weight and 165 cm in height, whereas femur B was donated by a 57-year old male weighting 70 kg and 170 cm in height. After soft-tissue desiccation, a radiolucent plastic rod with hot glue was implanted into the femoral canals and aligned parallel to the axis of the femoral shaft. The femur models were fitted onto a camera tripod platform with a rotation degree marker (Canon Corp., Tokyo, Japan) (Fig. 3A). Each femur was radiographed

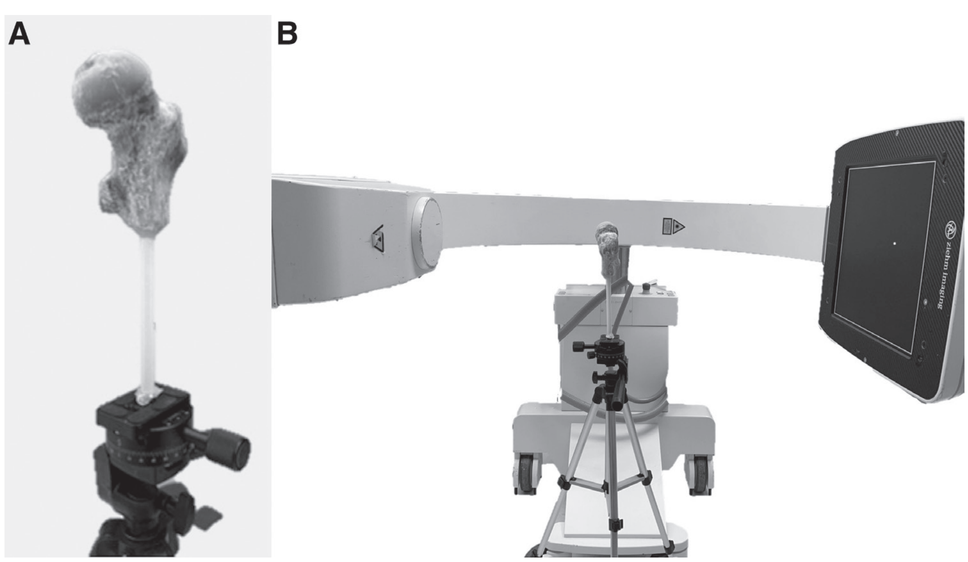

Fig. 3 The setting of rotating cadaveric femur model. A, Rotating platform for cadaveric femur model. B, Portable fluoroscopy set up for image acquisition of rotating femur model.

using a standard postoperative anteroposterior radiograph with a portable fluoroscope (Ziehm Imaging GmbH, Nuremburg, Germany). We followed the standard hip radiograph positioning protocol, placing the femur model 1.2 m from the collimator, with 15° internal rotation to compensate for the normal femoral neck anteversion (Fig. 3B).[21] One radiograph was captured for each femur after every additional 2.5° of internal and external rotation was made until the femur reached 50° of internal and external rotation.

Femur B was further processed to mimic unstable ITFs for radiographic analysis. Three ITFs models including 10°, 15°, and 20° of proximal fragment varus deformity were created sequentially (Fig. 4). Simulated fracture lines were created through the intertrochanteric region using an osteotome and completed with a sagittal saw. Proximal femur fragments were aligned at the designated fracture angle, guided by a goniometer, and then fixated with silicon modeling putty. Each fracture model was radiographed using the same internal and external rotating platform protocols set up in the standard femur models. The change in PG from baseline was measured on all radiographs obtained from the standard femur A and B models and the fractured femur B models with serial internal and external rotation changes. One traumatology orthopedic surgeon performed the PG calculations for all cadaver models to minimize inconsistencies between different observers.

2.4. Statistical analyses

The chi-square test was used to compare categorical variables between groups. For categorical data with an expected cell frequency ≤5, the Fisher exact test was performed. Mann-Whitney U test was employed to analyze differences in continuous variables. A multivariate logistic regression test was used to evaluate the independent risk factors for cutout failure. Receiver operating characteristic (ROC) curve analysis was conducted to investigate the diagnostic ability and cutoff for dPG value to predict lag screw cutout. The Pearson correlation coefficient was calculated to determine the correlation between PG change from baseline and serial femoral external and internal rotations. Statistical significance was defined as p <0.05. All statistical analyses were performed using SPSS version 22 software (IBM Corp., Armonk, NY).

The primary outcome of this study was the dPG in the union and failure groups, and the secondary outcome measure was the variation in PG from baseline in different degrees of internal and external femoral rotation.

3. RESULTS

From January 2005 to December 2010, 732 unstable ITFs were identified from our hospital registry. Three hundred and eighty-nine cases were treated with APGN, 255 cases were treated with G3N, and 88 cases were treated with the dynamic hip screw system. Of 389 patients treated with APGN, 78 patients met the exclusion criteria and were excluded. Data from 311 patients who fulfilled the study criteria were included for radiographic parameter interpretation and radiological outcome assessment (Fig. 5).

Of the 311 enrolled patients, 281 (90.3%) and 30 (9.7%) were divided into union and failure groups, respectively, according to their radiologic outcome at postoperative 2 years. In the failure group, 21 (6.8%) patients had cutout failure, six

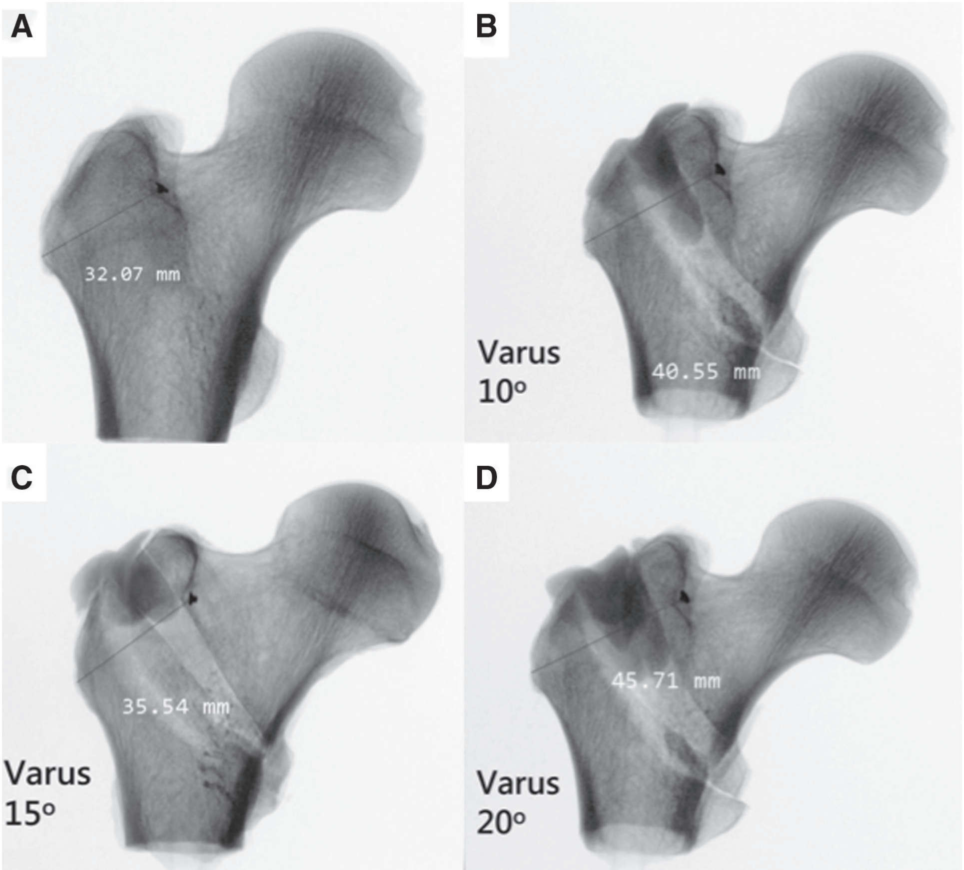

Fig. 4 Distance from the deepest point of piriformis fossa to the most lateral greater trochanter tubercle measured in the cadaveric femur B before simulated fracture was created (A), and the serial fractured models with 10 (B), 15 (C), and 20 (D) degrees varus tilt. All radiographs shown were obtained in neutral rotation. A radiopaque indicator was placed on the deepest point of piriformis fossa to improve consistency between measurements.

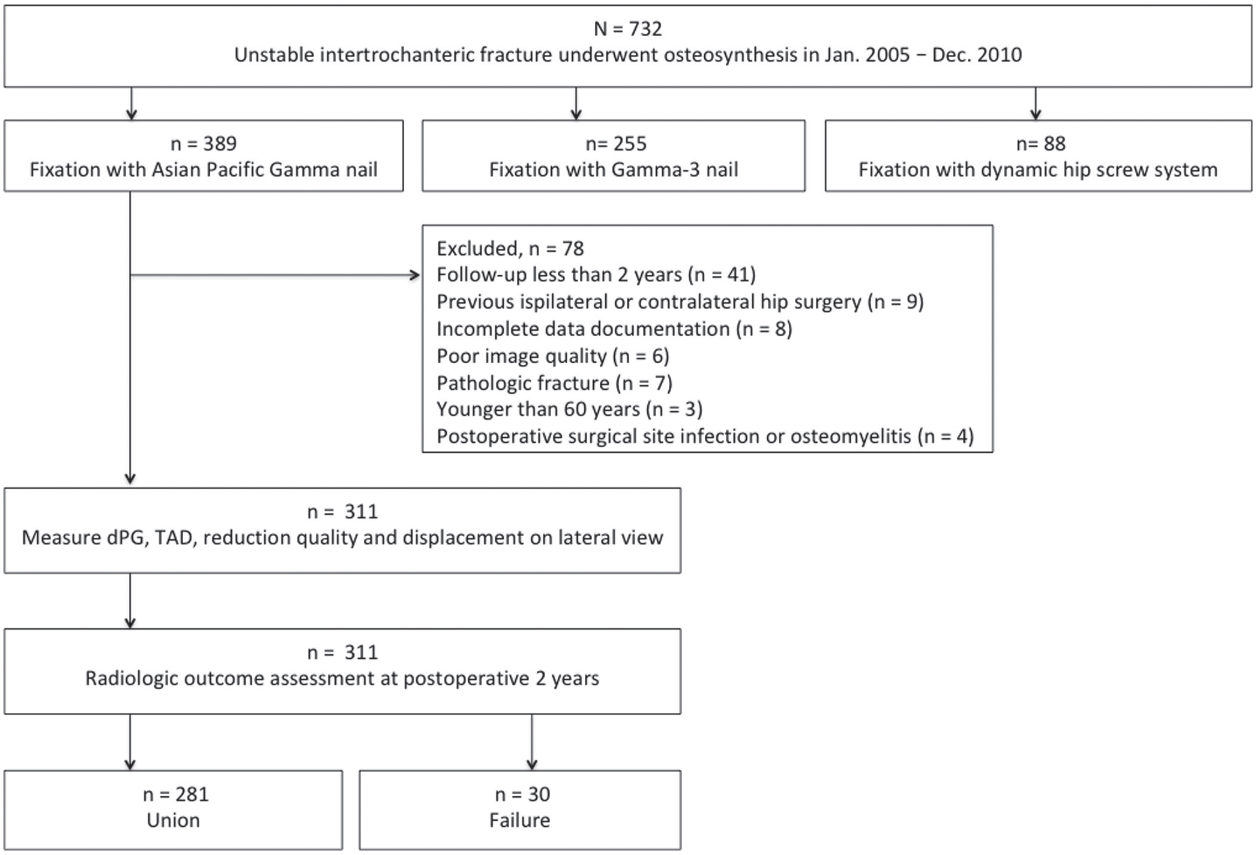

Fig. 5 Flowchart of patients inclusion and exclusion in this study.

(1.9%) had femoral head osteonecrosis and three (1%) had nonunion. Regarding the radiologic parameters (Table 1), the failure group demonstrated significantly higher dPG compared to the union group (10.2 ± 4.2 vs 6.6 ± 3.5 mm, p <0.001), significantly higher proportion of patients with TAD >25 mm (63% vs 24%, p <0.001), significantly less patients with good reduction quality (3% vs 21%, p <0.001) and significantly less patients with no fracture displacement on lateral view (13% vs 60%, p <0.001). When we further divided the patients according to their AO-OTA fracture classification, the same results were observed in patients with AO-OTA 31-A2 and 31-A3 fracture patterns (Table 2). Patients in the failure group also demonstrated a significantly lower HHS at postoperative one year compared to those in the union group (58.4 vs 72.3, p <0.001). The patient characteristics between groups were summarized in Table 1.

In multivariate logistic regression analysis (Table 3), dPG and TAD were statistically significant risk factors for cutout failure. The odds ratio was 6.35 (95% CI, 1.10-11.6, p =0.003) for every 1 mm dPG increment, and 5.04 (95% CI, 1.15-8.93, p =0.004) for patients with TAD >25 mm compared to patients with TAD ≤25 mm.

The relation between dPG and the risk factors for cutout failure was analyzed (Table 4). Patients in groups of TAD ≤25 mm and good reduction quality had significantly lower dPG (p <0.001) compared to their counterparts. The dPG was not significantly different between patients with type 1 to type 3 displacements on lateral view.

The dPG exhibited high diagnostic performance in predicting lag screw cutout according to the ROC curve analysis (Fig. 6). The area under ROC curve was 0.774 (95% CI, 0.711-0.837). The dPG yielded the greatest sensitivity (78.4%) and specificity (78.4%) to predict cutout failure when the cutoff value of dPG was 8.65 mm.

In the rotating cadaver femur models, the PG increased from baseline when additional external rotation was applied and decreased with internal rotation (Fig. 7). The PG change from baseline demonstrated a significant positive correlation with increased external rotation (p <0.001) and a significant negative correlation with increased internal rotation (p <0.001). Similar results were observed in all models, including the standard cadaver femurs and fracture models with different degrees of varus tilt (Fig. 8 and Table 5).

4. DISCUSSION

In this study, increased dPG and TAD were significant risk factors for cutout failure in unstable ITF fixed by APGN, and dPG exhibited good diagnostic ability to predict lag screw cutout. The PG change from baseline demonstrated a significantly positive trend with increased external rotation and a significantly negative trend with elevated internal rotation of the femur.

The premier study conducted by Hsu et al[4] proposed increased dPG was highly associated with cutout failure for ITFs treated with G3N. They reported dPG >7.95 mm had the greatest sensitivity and specificity to predict cutout failure. To evaluate whether this novel parameter can be used in different CMN design, dPG in ITF fixed with APGN was analyzed in this study. The APGN is a modification of the Standard Gamma Nail (SGN) after studies found the latter caused increased lateral wall fractures in Chinese femurs.[26] The APGN was designed to be shorter with less valgus curvature than the SGN to better fit Asian proximal femur anatomy and avoids cortical

Table 1

Patient characteristics

	Union (n = 281)	Failure (n = 30)	*p*
Gender			
Female	78	11	0.30
Male	203	19	
Age, y (mean ± SD)	77.5 ± 9	79.4 ± 7	0.23
Follow-up years (mean ± SD)	2.2 ± 0.5	2.3 ± 0.7	0.48
ASA classification			
I	5	2	0.37
II	107	12	
III	157	15	
IV	12	1	
Carlson comorbidity index (95% CI)	4.9 (4.3-5.4)	5.3 (4.8-5.8)	0.53
Bone mineral density (T score, 95% CI)	−3.1 (−3.5 to −2.7)	−3.3 (−3.9 to −2.7)	0.33
Operation time, min (95% CI)	52.5 (41.8-63.2)	55.7 (42.8-68.6)	0.42
Total hospital stay, d (95% CI)	10.2 (8.1-12.3)	11.7 (9.2-14.2)	0.28
Blood loss, mL (95% CI)	150.4 (113.4-187.4)	183.6 (127.5-239.7)	0.17
BMI, kg/m^2 (95% CI)	22.1 (20.6-23.6)	21.1 (18.9-23.3)	0.48
Injury side			
Right	111	16	0.15
Left	170	14	
AO/OTA classification			
31-A2	244	27	0.62
31-A3	37	3	
HHS at postoperative 1 y (95% CI)	72.3 (66.2-82.4)	58.4 (52.1-64.7)	<0.001
dPG, mm (mean ± SD)	6.6 ± 3.5	10.2 ± 4.2	<0.001
TAD			
>25 mm	68	19	<0.001
≤25 mm	213	11	
Reduction quality			
Good	59	1	<0.001
Acceptable	191	14	
Poor	31	15	
Lateral view displacement			
Type 1	168	4	<0.001
Type 2	65	10	
Type 3	48	16	
Failure mode			
Loss of reduction with lag screw cutout	N/A	21	N/A
Osteonecrosis of femoral head	N/A	6	
Nonunion	N/A	3	

AO/OTA, Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association; ASA classification = American Society of Anesthesiologists' Physical Status Classification; BMI = body mass index; dPG = side difference of the distance from the deepest point of piriformis fossa to the most lateral greater trochanter tubercle; HHS = Harris hip scores; N/A, not applicable; TAD = tip-apex distance.

impingement.[27] Compared with G3N, APGN has wider proximal diameter (17 vs 15.5 mm), wider lag screw diameter (12 vs 10.5 mm), and a wider distal screw diameter (6.28 vs 5 mm).[27] Both CMNs share the 11-12 mm distal nail diameter, the 4° valgus offset and 180 mm length design. Irrespective of different designs, our results support the previous study showing dPG to be a significant predictor of cutout failure for ITF osteosynthesis with CMN device.

The dPG may be capable of depicting the proximal femur morphology after reduction and nail insertion; which may explain why the dPG is a reliable predictor of cutout failure despite different CMN designs. From our cohorts, many factors can lead to increased dPG after CMN fixation. For example, the distance from the piriformis fossa to lateral greater trochanter increases when the nail is inserted from an improper entrance. With incorrect entry point, over lateralization of the nail can occur, leading to lateral wall buttress loss, fracture fragment rotation or proximal fragment varus tilt.[3] Erroneous nail insertion followed by inadequate reaming indirectly cause malreduction by the wedge effect. The poorly prepared proximal femur is distracted by nail insertion, causing lateralization of the distal fragment and varus tilt of the femoral head and neck.[28] Besides the suboptimal nail entry point, poor reduction, especially varus malreduction, can directly increase dPG, which was observed in our fractured cadaver model analysis (Fig. 4). Varus malreduction, lateral buttress support loss, and femoral shaft lateralization have been significantly associated with increased cutouts, nonunions, and nail breakage.[3,28–30] The varus malreduction makes optimal lag screw insertion challenging, leading to increased TAD. This explains the strong association between increased dPG and elevated TAD as well as poor reduction quality in our study. However, although our findings support that dPG can be used as a simple and straightforward parameter to summarize these potential risk factors and predict cutout failure, the displacement on lateral view may be overlooked if simply use dPG to interpret postoperative radiograph. In our results, there was no significant difference in dPG among patients with type 1

Table 2

Radiographic characteristics in patients with AO/OTA 31-A2 and 31-A3 fracture pattern

	AO/OTA 31-A2			AO/OTA 31-A3		
Radiographic parameters	Union (n = 244)	Cutout failure (n = 18)	*p*	Union (n = 37)	Cutout failure (n = 3)	*p*
dPG, mm (mean ± SD)	6.2 ± 2.7	9.3 ± 4.2	<0.001	5.9 ± 3.4	11.2 ± 5.8	<0.001
TAD			<0.001			
>25 mm	68	14		3	2	
≤25 mm	176	4		34	1	
Reduction quality			<0.001			
Good	48	1		8	0	
Acceptable	175	2		27	1	
Poor	21	15		2	2	
Lateral view displacement			<0.001			
Type 1	140	3		29	0	
Type 2	57	14		4	0	
Type 3	47	1		4	3	

AO/OTA = Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association; dPG = side difference of the distance from the deepest point of piriformis fossa to the most lateral greater trochanter tubercle; N/A = not applicable; TAD = tip-apex distance.

Table 3

Multivariate logistic regression test for the odds of lag screw cutout in radiographic parameters

Radiographic parameters	Odds ratio (95% CI)	*p*
dPG	6.35 (1.10-11.6)	0.003
TAD		
≤25 mm	Reference	N/A
>25 mm	5.04 (1.15-8.93)	0.004
Reduction quality		
Good	Reference	N/A
Acceptable	2.5 (0.98-4.02)	0.41
Poor	4.14 (1.59-6.69)	0.18
Displacement on lateral view		
Type 1	Reference	N/A
Type 2	1.79 (0.28-3.3)	0.54
Type 3	4.6 (0.86-8.34)	0.07

dPG = side difference of the distance from the deepest point of piriformis fossa to the most lateral greater trochanter tubercle; N/A = not applicable; TAD = tip-apex distance.

Table 4

Relation between dPG and radiographic risk factors of cutout failure

	dPG, mm (mean ± SD)	*p*
TAD		<0.001
>25 mm	10.4 ± 3.7	
≤25 mm	6.5 ± 2.8	
Reduction quality		<0.001
Good	6.8 ± 3.1	
Acceptable	8.1 ± 2.2	
Poor	10.1 ± 4.5	
Lateral view displacement		0.07
Type 1	6.6 ± 2.5	
Type 2	9.8 ± 3.3	
Type 3	9.4 ± 4.1	

dPG = side difference of the distance from the deepest point of piriformis fossa to the most lateral greater trochanter tubercle; TAD = tip-apex distance.

to type 3 lateral displacements. We suggest the displacement on lateral view should be cautiously assessed when use dPG to predict cutout failure.

Cadaver femur rotational radiographic analysis emphasizes the importance of standard positioning when interpreting dPG. We found proper hip positioning with controlled internal/external rotation to be critical for dPG measurement accuracy. Excessive external hip rotation can overestimate whereas elevated internal hip rotation leads to underestimation of dPG. For supine hip radiographs of the hip, the lower extremities should be internally rotated 15°-20° or until both patellae are facing anteriorly to correct for natural external rotation.[31] The ideal radiograph shows a clearly outlined greater trochanter without significant overlap with femoral neck. A distinguishable lesser trochanter should have width less than 5 mm.[31] If the standard position cannot be achieved, both hips should be placed in symmetric rotation when performing dPG measurement.

The main strength of this study lies in providing medium-term follow-up results for dPG efficacy and its variation with internal/external femoral rotation that were lacking in past reports. The dPG is a relatively novel radiographic parameter for predicting cutout failure after CMN fixation for ITF. Our results suggest that dPG may have the potential to outline the well-established risk factors, such as femur varus malreduction, loss of lateral wall buttress and lateralization of distal fragment, to predict cutout failure.

Our study had several limitations. First, this was a retrospective study based on data from patient medical records. Loss of follow-up or inappropriate diagnostic keywords may have excluded relevant patients. Second, although the intraobserver variability was low, it may still have affected the interpretation of radiographs. Finally, this was a single-center study; further research with larger sample size and longer follow-up period can more clearly identify the relation between dPG and other major complications, such as nonunion and femoral head osteonecrosis, in patients with ITF treated with CMN.

In conclusion, increased dPG is a significant risk factor for cutout failure in ITF osteosynthesis with CMN. In conjunction with TAD, fracture displacement and reduction quality, dPG can serve as a simple and reliable tool to help surgeons interpret postoperative radiographs and predict cutout failure. Standard patient positioning is critical for obtaining accurate dPG measurements.

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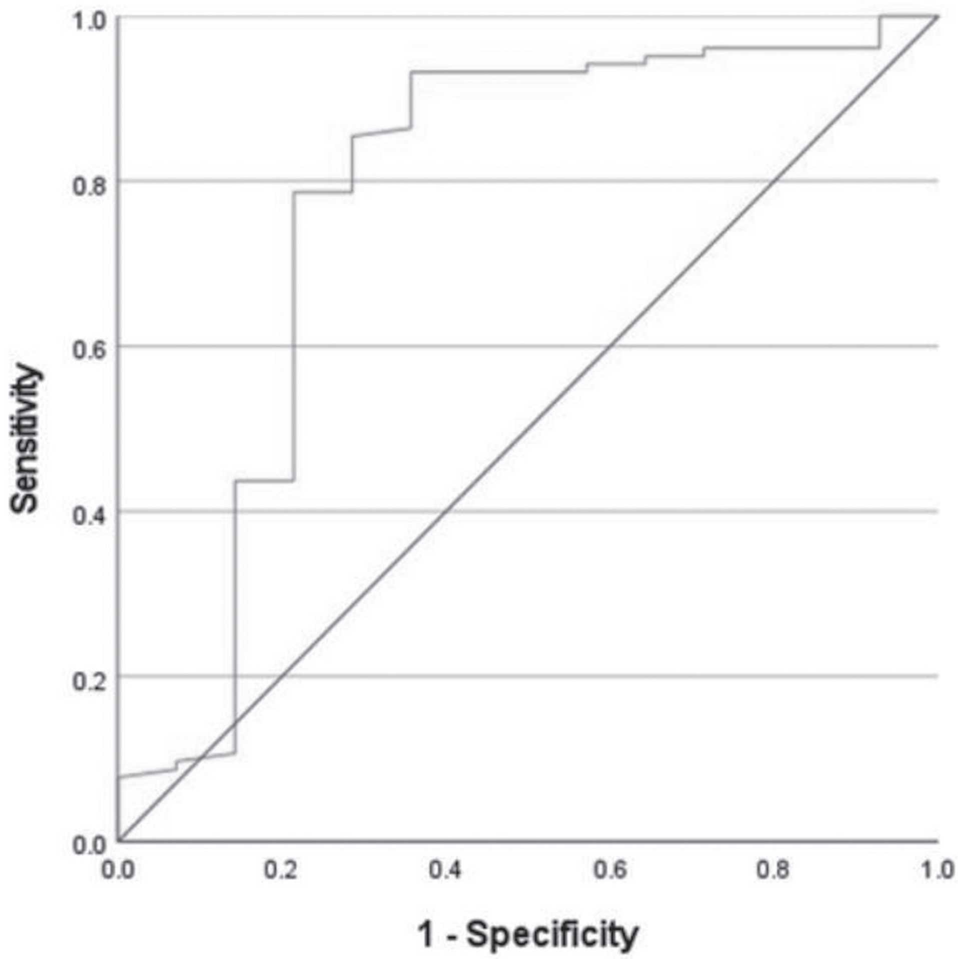

Fig. 6 Receiver operating characteristic curve analysis for using dPG to predict cutout failure after cephalomedullary nail fixation for intertrochanteric fracture. dPG = side difference of the distance from the deepest point of piriformis fossa to the most lateral greater trochanter tubercle.

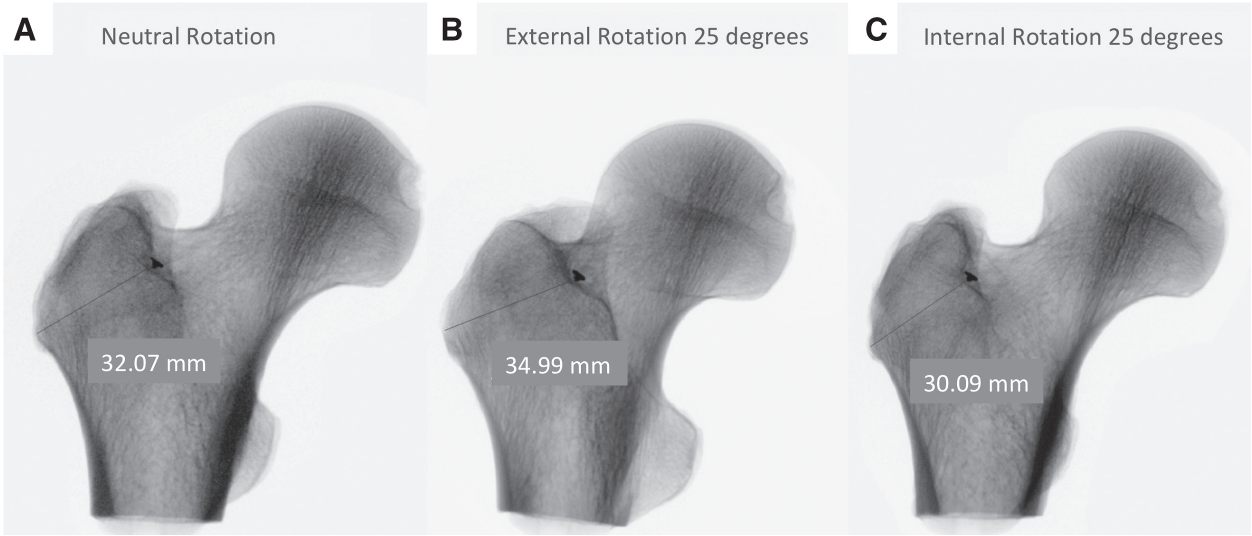

Fig. 7 Radiographs from standard cadaver femur B obtained in neutral (A), external rotation 25° (B), and internal rotation 25° (C). Using the PG at neutral rotation as baseline, the measured PG increased in external rotation and decrease in internal rotation. A radiopaque indicator was placed on the deepest point of piriformis fossa to improve consistency between measurements. PG = distance from the deepest point of piriformis fossa to the most lateral greater trochanter tubercle.

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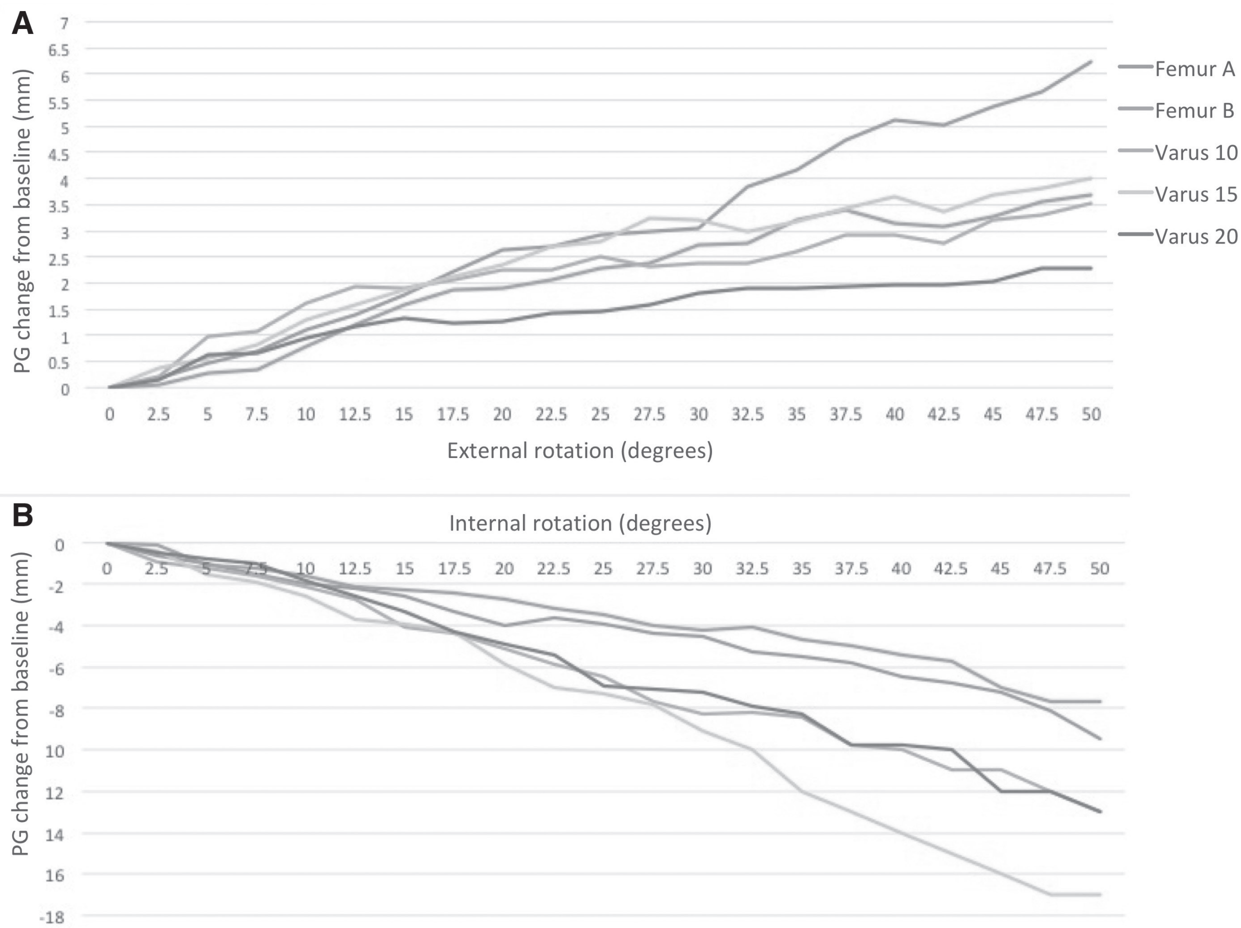

Fig. 8 Correlation between the PG change from baseline in the standard and simulated fractured cadaver models with serial increments of femur external rotation (A) and internal rotation (B). PG = distance from the deepest point of piriformis fossa to the most lateral greater trochanter tubercle.

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Table 5

Distribution of PG change from baseline according to cadaver models design and rotation degrees

		External rotation, °																				
ΔBaseline, mm	**0**	**2.5**	**5**	**7.5**	**10**	**12.5**	**15**	**17.5**	**20**	**22.5**	**25**	**27.5**	**30**	**32.5**	**35**	**37.5**	**40**	**42.5**	**45**	**47.5**	**50**	**PCC**	***p***
Femur A	0	0.2	0.5	0.7	1.1	1.4	1.8	2.2	2.7	2.7	2.9	3.0	3.1	3.9	4.2	4.8	5.1	5.0	5.4	5.7	6.2	0.995	<0.001
Femur B	0	0.1	0.3	0.3	0.8	1.2	1.6	1.9	1.9	2.1	2.3	2.4	2.7	2.8	3.2	3.4	3.1	3.1	3.7	3.6	3.7	0.975	<0.001
Varus 10°	0	0.2	1.0	1.1	1.6	1.9	1.9	2.1	2.2	2.3	2.5	2.3	2.4	2.4	2.6	2.9	2.9	2.7	3.2	3.3	3.5	0.940	<0.001
Varus 15°	0	0.4	0.6	0.8	1.3	1.6	1.9	2.1	2.4	2.7	2.8	3.2	3.2	3	3.2	3.4	3.7	3.4	3.7	3.8	4	0.964	<0.001
Varus 20°	0	0.2	0.6	0.7	1.0	1.2	1.3	1.2	1.3	1.4	1.5	1.6	1.8	1.9	1.9	1.9	2.0	2.0	2.1	2.3	2.3	0.960	<0.001
		Internal rotation, °																				
ΔBaseline, mm	**0**	**2.5**	**5**	**7.5**	**10**	**12.5**	**15**	**17.5**	**20**	**22.5**	**25**	**27.5**	**30**	**32.5**	**35**	**37.5**	**40**	**42.5**	**45**	**47.5**	**50**	**PCC**	***p***
Femur A	0	−0.6	−1	−1.5	−2	−2.2	−2.6	−3.3	−4	−3.6	−3.9	−4.4	−4.5	−5.3	−5.5	−5.8	−6.5	−6.8	−7.2	−8.1	−9.5	−0.988	<0.001
Femur B	0	−0.1	−1.1	−1.2	−1.6	−2.1	−2.3	−2.4	−2.7	−3.2	−3.5	−4	−4.2	−4.1	−4.7	−5	−5.4	−5.7	−7	−7.7	−7.7	−0.987	<0.001
Varus 10°	0	−0.9	−1.2	−1.6	−2.1	−2.7	−4.1	−4.4	−5.1	−5.9	−6.5	−7.7	−8.3	−8.2	−8.4	−9.8	−10	−11	−11	−12	−13	−0.996	<0.001
Varus 15°	0	−0.4	−1.5	−1.9	−2.6	−3.7	−3.9	−4.3	−5.9	−7	−7.3	−7.8	−9.1	−10	−12	−13	−14	−15	−16	−17	−17	−0.993	<0.001
Varus 20°	0	−0.5	−0.8	−1	−1.8	−2.6	−3.3	−4.3	−4.9	−5.4	−6.9	−7.1	−7.2	−7.9	−8.3	−9.8	−9.8	−10	−12	−12	−13	−0.995	<0.001

PG = distance from the deepest point of piriformis fossa to the most lateral greater trochanter tubercle; PCC = Pearson correlation coefficient.

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