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Sagittal deformity of Garden type I and II geriatric femoral neck fractures is frequently misclassified by lateral radiographs

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Objectives: The objective of this study was to determine the validity and inter-rater reliability of radiographic assessment of sagittal deformity of femoral neck fractures.

Design: This is a retrospective cohort study.

Setting: Level 1 trauma center.

Patients/Participants: Thirty-one patients 65 years or older who sustained low-energy, Garden type I/II femoral neck fractures imaged with biplanar radiographs and either computed tomography or magnetic resonance imaging were included.

Main Outcome Measurements: Preoperative sagittal tilt was measured on lateral radiographs and compared with the tilt identified on advanced imaging. Fractures were defined as "high-risk" if posterior tilt was ≥20 degrees or anterior tilt was >10 degrees.

Results: Of 31 Garden type I/II femoral neck fractures, advanced imaging identified 10 high-risk fractures including 8 (25.8%) with posterior tilt ≥20 degrees and 2 (6.5%) with anterior tilt >10 degrees. Overall, there was no significant difference between sagittal tilt measured using lateral radiographs and advanced imaging ($P = 0.84$), and the 3 raters had good agreement between their measurements of sagittal tilt on lateral radiographs (interclass correlation coefficient 0.79, 95% confidence interval [0.65, 0.88], $P < 0.01$). However, for high-risk fractures, radiographic measurements from lateral radiographs alone resulted in greater variability and underestimation of tilt by 5.2 degrees (95% confidence interval [−18.68, 8.28]) when compared with computed tomography/magnetic resonance imaging. Owing to this underestimation of sagittal tilt, the raters misclassified high-risk fractures as "low-risk" in most cases (averaging 6.3 of 10, 63%, range 6 − 7) when using lateral radiographs while low-risk fractures were rarely misclassified as high-risk (averaging 1.7 of 21, 7.9%, range 1 − 3, $P = 0.01$).

Conclusions: Lateral radiographs frequently lead surgeons to misclassify high-risk sagittal tilt of low-energy femoral neck fractures as low-risk. Further research is necessary to improve the assessment of sagittal plane deformity for these injuries.

Level of Evidence: Level IV diagnostic study.

Keywords: geriatric trauma, femoral neck fractures, sagittal angulation, biplanar radiographs, advanced imaging

1. Introduction

Internal fixation is a treatment option for elderly patients with Garden type I and II femoral neck fractures. However, recent studies have suggested higher rates of complications including fixation failure, nonunion, and avascular necrosis of the femoral head with internal fixation as opposed to arthroplasty.[1–3] In evaluating femoral neck fractures, many surgeons use lateral radiographs to assess sagittal plane posterior or anterior tilt and posterior comminution of what otherwise appears as a nondisplaced fracture on an anterior-posterior (AP) radiograph (XR).[4–6] Some studies have argued against the routine use of lateral radiographs; however, a recent study found that the addition of a lateral radiograph altered the management plan in 21% of cases.[6] One study found that sagittal plane deformity occurs in up to 79% of patients with femoral neck fractures first classified as Garden type I or II on AP radiographs.[7]

In 2009, Palm et al[1] proposed a new technique for measuring femoral neck posterior tilt on lateral hip radiographs. This method has been subsequently used to determine whether sagittal tilt of the femoral neck is associated with worse outcomes after internal fixation of femoral neck fractures. Previous studies have found that a femoral neck posterior tilt greater than or equal to 20 degrees and an anterior tilt greater than 10 degrees were associated with 1.7–4.7 times higher risk of fixation failure.[1,2,8,9] By contrast, 2 other studies found no association between sagittal tilt on the lateral view and postoperative complications.[7,10] One possible explanation for the discrepant findings is that the described methods for assessing sagittal deformity may have limited reliability, particularly when

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dichotomizing fractures as "low-risk" and "high-risk." Posterior tilt on the lateral radiograph is influenced by rotation and flexion of the femur.[11] While the measurement technique proposed by Palm et al [1] has been reported to have excellent inter-rater and intrarater reliability, it has never been externally validated and may not be an accurate representation of the actual femoral neck fracture sagittal tilt. Superimposed three-dimensional computed tomography (CT) imaging models that superimpose the fractured femur on the contralateral intact femur have been suggested as a possible tool for better assessing sagittal deformity of the femoral neck[12]; however, significant differences between bilateral femoral morphology question the validity of this methodology as well.[13,14]

In summary, we lack a universally accepted radiographic method of assessing sagittal deformity of femoral neck fractures and there is debate regarding the role of advanced imaging. The inability to accurately measure sagittal tilt may account for differing results in the literature regarding the relationship of this assessment with outcomes and complications after internal fixation. In this retrospective study of Garden type I and type II femoral neck fractures treated at our institution, we assessed sagittal tilt of femoral neck fractures on lateral radiographs using the methodology of Palm et al[1] and compared this with that acquired from CT imaging or magnetic resonance imaging (MRI). Our objectives were to (a) determine the external validity of the method proposed by Palm et al[1] for measuring femoral neck sagittal deformity on lateral radiographs using advanced imaging (CT/MRI) as a verification method and (b) assess how inter-rater reliability varies with severity of tilt.

2. Materials and Methods

2.1. Patients and Methods

Using ICD-9 and ICD-10 codes, all patients treated at a single Level 1 trauma and tertiary care academic hospital from January 1, 2007 through December 31, 2018 with acute femoral neck fractures were retrospectively reviewed in the electronic medical record. The study was deemed exempt from Institutional Review Board and Animal Use Committee Review. Additionally, the use of patient data for research purposes was approved by the committee on research ethics at our institution in accordance with the Declaration of the World Medical Association, and informed consent of all human subjects was obtained as required. Patients were included if they were 65 years or older, sustained an acute low-energy femoral neck fracture, and both biplanar radiographs of their affected hip and either CT or MRI scan of their hip or pelvis were obtained at the time of injury. Patients were excluded if they exhibited clinical or radiographic signs of a pathologic fracture or sustained their fracture because of a high-energy mechanism (including motor vehicle accident, falls from a height). Femoral neck fractures were then classified using the Garden classification based on AP radiographs, and fractures that were "nondisplaced" (Garden I or II) were included. A total of 432 patients were reviewed who sustained an acute femoral neck fracture, and 100 of these patients were classified as Garden Type I/II fractures. Thirty-one patients met all inclusion criteria including the availability of biplanar radiographs and advanced imaging. AP and lateral radiographs were obtained using a standardized technique,[15] and all lateral radiographs included were assessed to ensure adequate quality.

Initial injury radiographs were evaluated by 2 fellowship-trained orthopaedic traumatologists and a senior orthopaedic surgery resident. Each evaluator measured sagittal tilt of the femoral neck on lateral radiographs using the method described by Palm et al[1] for all patients (Fig. 1). As described by Palm et al,[1] first, a mid-collum line (MCL) was drawn along the femoral neck. Second, a best-fit caput circle was drawn around the femoral head. Next, the radius collum line (RCL) was drawn from the center of the caput circle to the intersection of the caput circle and the MCL. The angle (α) made by the MCL and RCL defines posterior tilt (apex anterior angulation). Anterior tilt (or apex posterior angulation) was included as negative posterior tilt as per Palm et al[1] and Sjöholm et al[8]

An attending fellowship-trained musculoskeletal radiologist then measured sagittal tilt of the patient's injured femoral neck on CT or MR images for all patients. The measurement of preoperative posterior tilt required reconstruction of CT/MR images in the axial oblique plane. This plane is identical to that described and utilized by Notzli et al[16] for the measurement of the alpha angle in the evaluation for cam-type femoral acetabular impingement. The axial oblique plane was reconstructed to be parallel to the axis of the femoral neck with the measurement made on the plane passing through the center of the femoral neck. The image in this plane provided a view analogous to a lateral radiographic view of the femoral neck. Once reconstructions were performed and the image slice passing through the center of the femoral neck was identified, posterior tilt was measured using the same technique described above by Palm et al[1] (Fig. 2).

2.2. Statistical Analyses

Measurements of femoral neck fracture sagittal deformity were analyzed as both a continuous variable and also a categorical variable. One method of grouping involved different tilt groups: (a) anterior tilt, (b) 0–9-degree posterior tilt, (c) 10–19-degree posterior tilt, and (d) ≥20-degree posterior tilt. A second method of grouping categorized fractures by risk categories as identified by Sjöholm et al[8] for fixation failure: (a) low-risk: <20 degrees of posterior tilt and ≤10 degrees of anterior tilt, and (b) high-risk: ≥20 degrees of posterior tilt or >10 degrees of anterior tilt.

The inter-rater reliability between the 2 orthopaedic traumatologists and the senior orthopaedic surgery resident for measuring sagittal tilt on lateral radiographs was obtained using interclass correlation coefficients (ICCs) and the Light kappa test. ICC was used to compare measurements between raters as a continuous variable, and the Light kappa test was used to compare fractures categorized into posterior/anterior tilt categories. Both the ICC and the Light kappa test provide values between 0 and 1. For the ICC, values below 0.5 suggest poor agreement, whereas between 0.5 and 0.75, between 0.75 and 0.9, and above 0.9 indicate moderate, good, and excellent agreement, respectively.[17] For the Light kappa test, values between 0 and 0.20 suggest slight agreement, between 0.21 and 0.40 fair agreement, between 0.41 and 0.60 moderate agreement, between 0.61 and 0.80 substantial agreement, and above 0.80 perfect agreement.[18]

Advanced imaging was used to assess the external validity of the method described by Palm et al[1] for measuring femoral neck sagittal deformity; measurements of posterior tilt based on the lateral radiograph were compared with that measured on advanced imaging using Tukey pairwise multiple comparison of means and analysis of variance tests. Statistical significance was defined as $P < 0.05$. The mean difference in tilt was calculated as the mean of the absolute differences between the measurements of the 3 raters from lateral radiographs and the measurement obtained by the radiologist on CT/MRI. Fractures were classified into high-risk and low-risk based on the measurement obtained by CT/MRI. Differences in measurements and misclassification rates were compared between frog-leg and cross-table laterals using chi-square tests to see whether the type of lateral radiograph affected measurement accuracy.

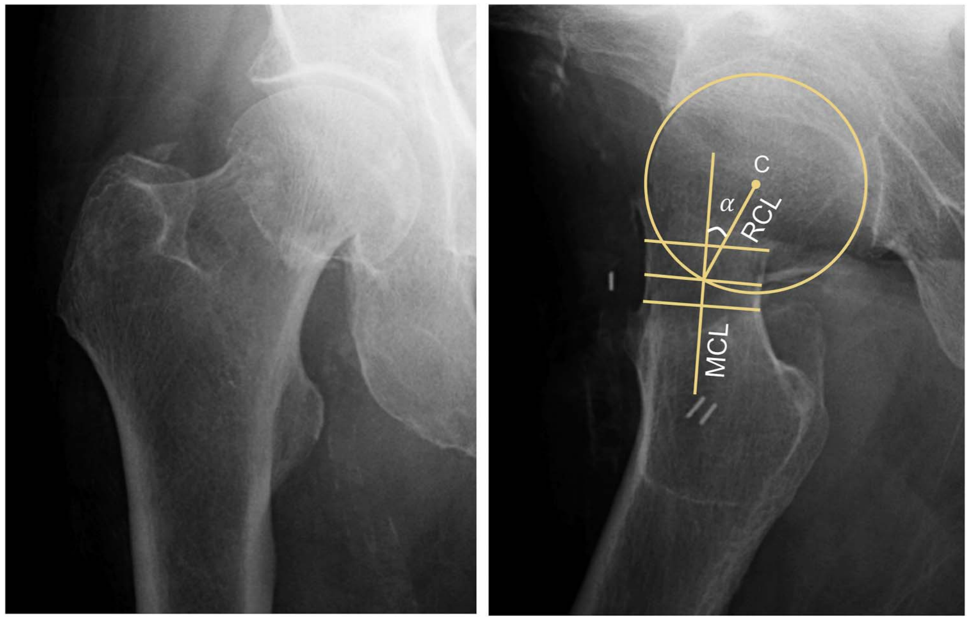

Figure 1. Posterior tilt measurement using the methodology described by Palm et al[1] on lateral hip radiographs. A lateral hip radiograph is used for measuring the posterior tilt with this methodology. As described in the article, the posterior tilt is the angle (α) measured between the mid-collum line (MCL) and the radius collum line (RCL). Three perpendicular lines are drawn across the collum with the middle one at the narrowest part of the neck. The MCL is drawn perpendicular to these 3 lines. The RCL runs from the center (c) of the femoral head caput circle to the crossing of the MCL and the caput circle.

3. Results

Of 31 fractures, 26 (83.9%) were classified as Garden type I and 5 (16.1%) were classified as Garden type II based on AP radiographs alone. In addition, 18 (58.1%) were right-sided injuries and 13 (41.9%) were left-sided. Five patients had MRI, and 26 had CT. Four patients were treated nonoperatively, 13 patients with 3 cannulated screws, 3 patients with a dynamic hip screw, one patient with a total hip arthroplasty, and the remaining 10 patients with hemiarthroplasty. Only 12 patients had at least 1 year of follow-up, with one patient dying intraoperatively and another 3 patients dying within 1 year of their injury. Of all the patients, 2 patients required reoperation: one who was treated nonoperatively and then sustained an intertrochanteric fracture on the same side after healing and the second who had an arthrogram performed with injection of steroid for post-traumatic arthritis.

Advanced imaging identified 21 fractures (67.7%) as low-risk: 11 patients (35.5%) had posterior tilt between 0 and 9 degrees, 9 (29.0%) had posterior tilt between 10 and 19 degrees, and 1

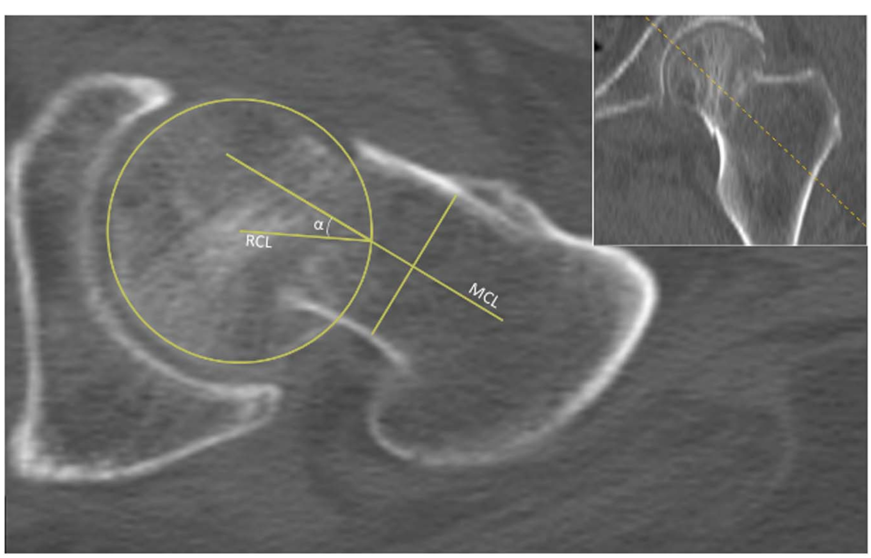

Figure 2. Posterior tilt measurement from CT/MRI. The axial oblique plane is reconstructed parallel to the axis of the femoral neck (inset), and the image slice passing through the center of the femoral neck is identified. A mid-collum line (MCL) is drawn along the femoral neck. A best-fit caput circle was drawn around the femoral head. A radius collum line (RCL) was drawn from the center of the caput circle to the intersection of the caput circle and the MCL. The angle (α) made by the MCL and RCL provides the posterior tilt.

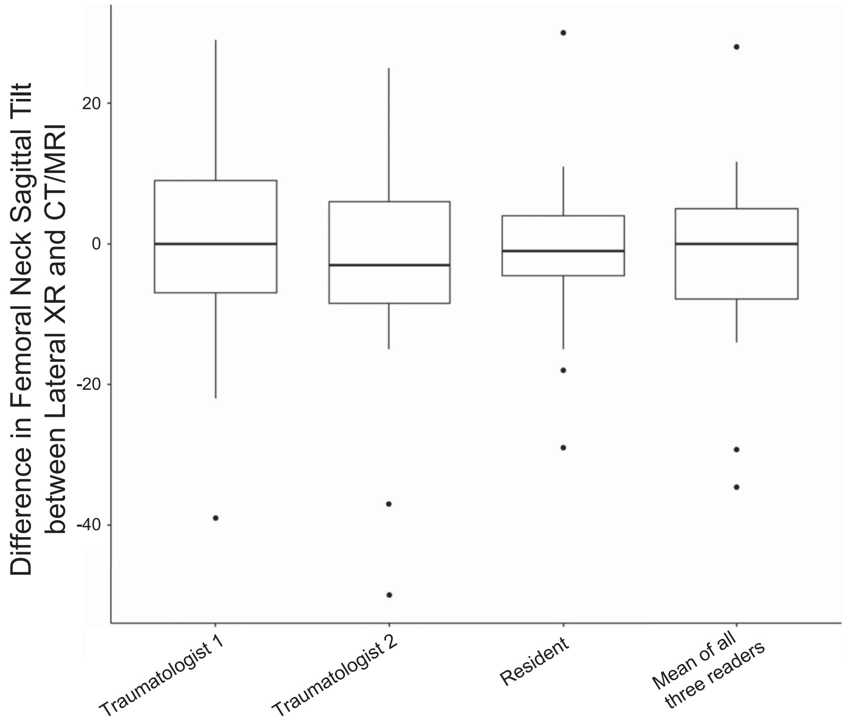

Figure 3. Difference in measurement of femoral neck tilt between lateral radiographs and advanced imaging based on the reader: Orthopaedic traumatologist 1, orthopaedic traumatologist 2, resident, and mean of all 3 readers.

(3.2%) had anterior tilt between 1 and 10 degrees. Alternatively, 10 patients (32.3%) were classified as high-risk on advanced imaging: 8 (25.8%) had posterior tilt ≥20 degrees and 2 (6.5%) had anterior tilt >10 degrees. Of 26 Garden type I femoral neck fractures as classified on AP radiographs, 7 (26.9%) were high-risk when classified on advanced imaging, with 5 (19.2%) having posterior tilt ≥20 degrees and 2 (7.7%) having anterior tilt >10 degrees. Of the 5 Garden type II fractures, 3 (60.0%) were high-risk with a posterior tilt ≥20 degrees.

The ICC of femoral neck sagittal tilt measured on lateral radiographs between the 2 orthopaedic traumatologists and the orthopaedic surgery resident was 0.79 (95% confidence interval [CI: 0.65, 0.88], $P < 0.01$), indicating good agreement. When fractures were categorized into (a) anterior tilt, (b) 0–9-degree posterior tilt, (c) 10–19-degree posterior tilt, and (d) ≥20-degree posterior tilt based on advanced imaging, the Light kappa coefficient was 0.52 ($P < 0.01$), suggesting moderate reliability. When fractures were categorized as (a) low-risk (<20 degrees of posterior tilt and ≤10 degrees of anterior tilt) versus (b) high-risk (≥20 degrees of posterior tilt or >10 degrees of anterior tilt), the Light kappa coefficient was no longer statistically significant (0.64, $P = 0.33$).

When comparing the mean measurement of sagittal tilt found by the 3 raters for lateral hip radiographs with that measured by the radiologist on advanced imaging, the ICC was 0.78 (95% CI [0.54, 0.89], $P < 0.01$). Each rater's measurements on lateral radiographs when compared with that of the radiologist on advanced imaging was found to be similar based on Tukey multiple pairwise comparisons of means (adjusted P range [0.84, 1.00]). Furthermore, analysis of variance tests comparing the measurements of all 3 raters on lateral radiographs and the radiologist on advanced imaging show no statistical difference between readings ($F_{4,\ 150} = 0.35$, $P = 0.84$). No significant difference was found in measurements for cross-table and frog-leg lateral radiographs ($F_{3,\ 24} = 0.30$, $P = 0.83$).

The mean difference in tilt measured by the first orthopaedic traumatologist on radiographs in comparison with the radiologist on advanced imaging was 0.13 degrees (95% CI [−4.64, 4.90]). Likewise, this mean difference was −3.29 degrees (95% CI [−8.32, 1.74]) for the second orthopaedic traumatologist and −1.19 degrees (95% CI [−5.07, 2.69]) for the resident. On average, the raters were −1.45-degree (95% CI [−5.71, 2.80]) different from the measurements obtained on advanced imaging by the radiologist (Fig. 3).

However, when specifically evaluating measurements of the high-risk fractures as categorized by the measurements from advanced imaging, the mean difference in sagittal tilt measured by the first orthopaedic traumatologist was −4.10 degrees (95% CI [−18.82, 10.62]) in comparison with the measurement by the radiologist on CT/MRI. Likewise, this mean difference was −9.20 degrees (95% CI [−24.72, 6.32]) for the second orthopaedic traumatologist and −2.30 degrees (95% CI [−14.18, 9.58]) for the resident. On average, the raters were −5.2-degree (95% CI [−18.68, 8.28]) different from the measurements obtained on advanced imaging for high-risk fractures (Fig. 4). On average, the raters misclassified 6.3 of 10 (63.3%, range 6 − 7) high-risk fractures relative to advanced imaging (Table 1). Of these misclassifications, the raters all similarly undermeasured tilt for 5 cases, misclassifying these as low-risk. All 5 of these misclassifications were for fractures that had been classified as Garden type I based on AP radiographs.

In comparison, for individuals with low-risk fractures as classified by advanced imaging, the mean difference in sagittal tilt measured by the first orthopaedic traumatologist on lateral radiographs was 2.14 degrees (95% CI [−1.06, 5.35]) in comparison with the measurement by the radiologist on CT/MRI. Likewise, this mean difference was −0.48 degrees (95% CI [−3.53, 2.57]) for the second

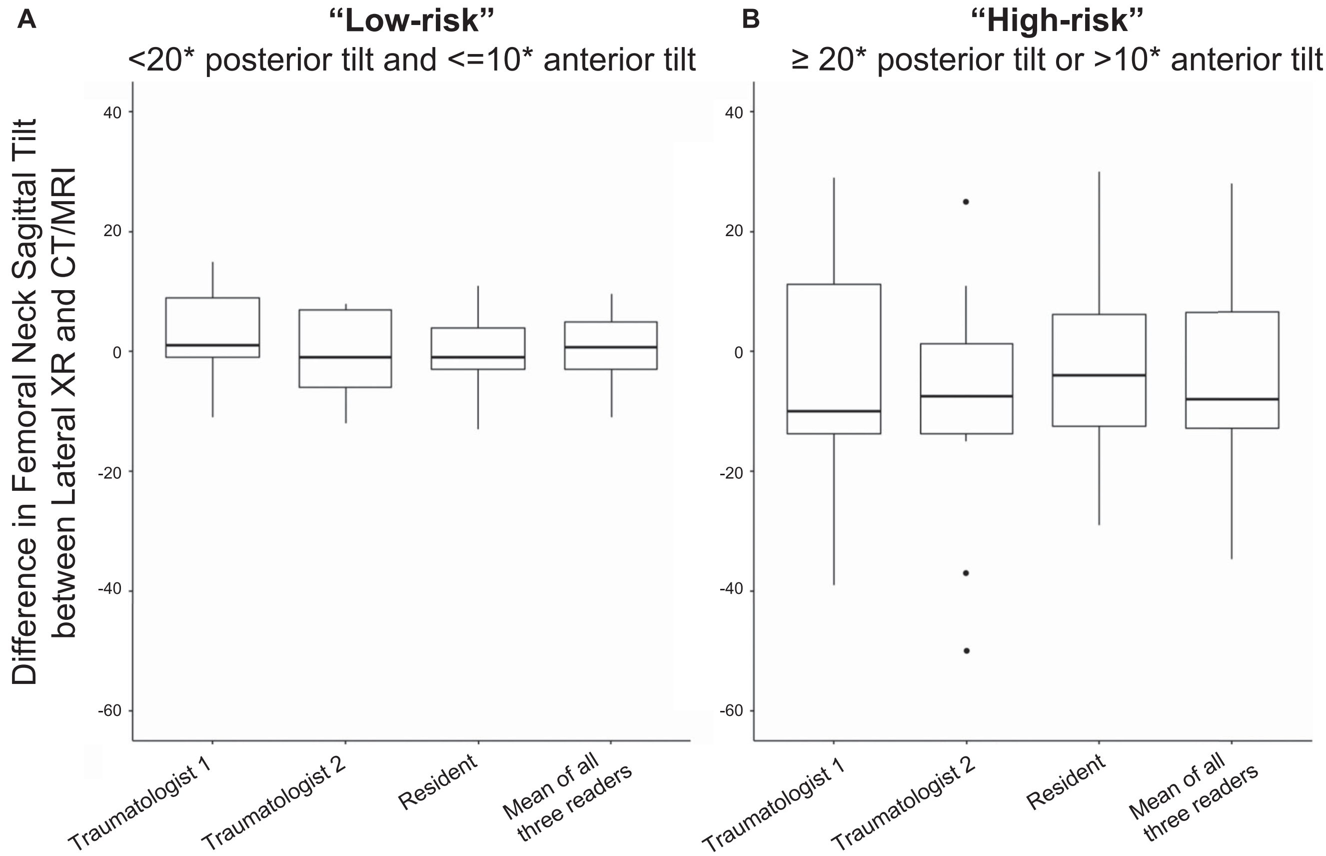

Figure 4. Difference in femoral neck tilt measurement between lateral radiographs and advanced imaging based on the reader when separated by sagittal tilt on advanced imaging (A) low-risk: <20 degrees and ≥−10 degrees (n = 21) versus (B) high-risk: ≥20 degrees or < −10 degrees (n = 10).

orthopaedic traumatologist and −0.67 degrees (95% CI [−3.65, 2.31]) for the resident. On average, the raters were 0.33-degree (95% CI [−2.23, 2.90]) different from the measurements obtained on advanced imaging (Fig. 4). Overall, the raters misclassified an average of 1.7 of 21 lateral radiographs (7.9%, reviewer range 1 − 3) of low-risk fractures in comparison with misclassifying an average of 6.3 of 10 lateral radiographs (63.3%, reviewer range 6 − 7) of high-risk fractures ($P < 0.01$, Table 1).

4. Discussion

We found that one-third of femoral neck fractures that were originally classified as Garden type I or type II based on AP radiographs were found to have a high-risk posterior tilt ≥20 degrees or anterior tilt >10 degrees on advanced imaging.[1,2,8] In agreement with previous studies, we found a high ICC when using the technique described by Palm et al[1] on lateral radiographs between raters as well as the Light kappa coefficient when our raters' measurements were placed into 10-degree categories. The methodology described by Palm et al[1] for measuring sagittal tilt on lateral radiographs seems generally reliable. Furthermore, the assessments were not significantly different among raters with varying levels of training, suggesting that residents and board-certified practicing orthopaedic traumatologists alike may be able to use this methodology with reproducible results.

However, when lateral radiographic measurements were categorized using the 20-degree posterior tilt and 10-degree anterior tilt threshold given by Sjöholm et al,[8] the inter-rater reliability coefficient was no longer statistically significant. Increased sagittal tilt was associated with greater variability of measurement and a tendency among all reviewers to underestimate tilt severity. Our results suggest that contrasting conclusions between studies examining reoperation rates and fixation failure

TABLE 1

Number of misclassifications by the rater on lateral radiographs relative to advanced imaging based on the thresholds of 20-degree posterior tilt or 10-degree anterior tilt.

Rater	Number (%) of radiographic misclassifications	
	Low-risk on CT/MRI: Posterior tilt <20 degrees and anterior tilt ≤10 degrees (n = 21)	High-risk on CT/MRI: Posterior tilt ≥20 degrees or anterior tilt >10 degrees (n = 10)
Traumatologist 1	3 (14.3%)	6 (60.0%)
Traumatologist 2	1 (4.8%)	7 (70.0%)
Resident	1 (4.8%)	6 (60.0%)
Mean of all raters	1.7 (7.9%)	6.3 (63.3%)

Misclassification is much more likely for the angulated, higher risk fractures (63.3% for high-risk fractures vs. 7.9% for low-risk fractures, $P < 0.01$).

based on posterior/anterior tilt thresholds may in part be because of this increased variability and decreased reliability of measuring tilt on lateral radiographs when clinically significant sagittal deformity is present. We found that raters routinely under-measured tilt on lateral radiographs for patients with clinically significant tilt on advanced imaging, meaning that more than half of patients with high-risk posterior tilt on advanced imaging were misclassified into a low-risk category based on lateral radiographs. Raters underestimated the femoral sagittal tilt by an average of 5.2 degrees based on the lateral radiograph for high-risk fractures but only overestimated by an average of 0.33 degrees for patients with low-risk fractures. Despite showing relative specificity in identifying sagittal tilt, lateral radiographs demonstrate poor sensitivity, resulting in the misclassification of many fractures as being well aligned that were in fact angulated to a clinically significant degree. Furthermore, when fractures were misclassified into a less severe tilt group, there was often agreement among the raters, with all 3 underestimating the amount of tilt. This may be because of the variable technique and quality of the lateral radiograph (ie, limb positioning, x-ray beam angle, detector position) that inherently affect the accuracy of this assessment as suggested by Hoelsbrekken and Dolatowski.[11] More research is needed to elucidate how to optimize radiographic techniques for the assessment of femoral neck sagittal tilt.

This study has limitations including the relatively limited population given few patients with femoral neck fractures underwent advanced imaging of the hip because that was not the standard at our institution at the time of the study and had frequently been obtained by our general surgery trauma or emergency departments before orthopaedic consultation. Some of the variability in measurement of sagittal tilt with greater deformity may be related to this small population; however, increased variability remained when the threshold was lowered to 10 degrees of posterior/anterior tilt and when both groups were nearly equal in size. There was also variability between our resident and the 2 orthopaedic traumatologists. This could be because of the normal variation between individuals; however, the assessment of what constitutes normal variability is beyond the scope of this study. Our study is retrospective in nature and does not allow us to standardize the technique used for lateral radiographs. In addition, lateral radiographs were obtained using a standardized technique[15]; however, little objective data exist for assessing lateral radiograph quality or rotation. These factors could be a plausible reason for the variability noted in measurements or in the misclassification of fractures into high-risk versus low-risk groups. For our study, there was no obvious difference between frog-leg and cross-table lateral radiographs in accuracy of measurement of sagittal deformity. Our standard for sagittal tilt was based on both CT and MRI, which could introduce variability as well. More research is needed to verify that CT and MRI measurements are valid as a "gold standard" for measuring femoral neck posterior tilt and to assess the natural variability of tilt within nonfractured femoral necks. Furthermore, this technique of using CT/MRI has practical limitations because most CTs are cut routinely in a plane perpendicular to the CT table, meaning that acquiring the necessary oblique axial plane may not be realistic within a more acute trauma period without a dedicated radiologist on site. Our study was retrospective in nature, and we are unable to comment on how advanced imaging findings guided decision-making in specific cases. Finally, limited follow-up with a high rate of patient mortality within 1 year of injury made it difficult to compare patient outcomes for our patient population and draw conclusions on the clinical implications of using advanced imaging to measure sagittal tilt.

Multiple research studies suggest sagittal plane deformity should be routinely assessed to better classify femoral neck fractures that may appear nondisplaced/impacted on AP radiographs alone. The 2007 OTA/AO classification system[19] and the original Müller OTA/AO classification[20] include a subdivision of valgus-impacted fractures based on posterior tilt; however, this subdivision has been removed in the newest OTA/AO 2018 compendium.[21] Our study found that the methodology given by Palm et al[1] for measuring femoral neck fracture posterior tilt generally has a good inter-rater reliability and overall similar results relative to advanced imaging; however, variability increases with sagittal deformity, leading to underestimation of tilt and misclassification of many high-risk fractures as low-risk.

Given high rates of reoperation and/or fixation failure reported for fixation of femoral neck fractures associated with significant preoperative sagittal deformity[1,2,8,9], careful patient selection should be exercised when considering fixation of such injuries. Our results add to the existing literature that seeks to develop a biplanar femoral neck fracture classification to aid in operative decision making between arthroplasty and nonarthroplasty treatment modalities. Percutaneous screw fixation remains a valuable hip-preserving technique for fixing low-risk femoral neck fractures given shorter operative time, lower blood loss, and infectious risk, something that remains beneficial for our elderly patients with multiple comorbidities. However, lateral radiographs may lead surgeons to misclassify high-risk sagittal deformity of low-energy femoral neck fractures as low-risk. Advanced imaging (CT) should be considered when evaluating whether a Garden I/II femoral neck fracture is amenable to fixation.

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