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CT scans better assess lateral wall morphology of “stable appearing” intertrochanteric (IT) femur fractures and predict early failure of sliding hip screw (SHS) fixation

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Objectives: To compare the efficacy of plain x-ray images and computed tomography (CT) to assess the morphology of the lateral wall (LW) component of intertrochanteric (IT) femur fractures and determine predictors of early fixation failure.

Design: Retrospective cohort study.

Setting: Level-one trauma center.

Patients/Participants: One hundred forty-two adult patients with IT fractures treated with either a sliding hip screw (SHS) or a cephalomedullary nail (CMN) who had both pre-op plain x-ray images and CT scans with at least 6 weeks of follow-up were reviewed.

Intervention: Preoperative CT scan and plain radiographs of the affected hip.

Main Outcome Measurements: Lateral wall assessment based on plain x-rays versus CT imaging in relation to implant failure.

Results: One hundred forty-two patients met inclusion criteria, 105 patients treated with a CMN, and 37 with a SHS. There was a poor correlation between the assessment of the LW on plain x-ray images and CT scans. Failures in the SHS group were significantly associated with all CT measurements ($P < .05$) but not with plain film LW assessment ($P = .66$). Fifteen patients had an early implant failure (6 CMN, 9 SHS). There were no statistically significant associations between any radiographic measurement (plain images and CT) and CMN failures.

Conclusions: Plain film images are not accurate for assessing lateral wall morphology/integrity and are not predictive of SHS implant failures. Our novel CT measurements were effective at detecting lateral wall patterns at risk for treatment failure with SHS implants.

Level of Evidence: Level III

Keywords: cephalomedullary nail, geriatric hip fracture, intertrochanteric hip fracture, LATERAL wall, sliding hip screw, stable, unstable

1. Introduction

Intertrochanteric (IT) femur fractures are common injuries with an estimated incidence of more than 400,000 annually in the United States.^[1] IT fractures can be classified as “stable” or

“unstable,” and this classification implies that implant selection for stabilization affects the success of fixation.^[2,3] Failures after fixation include fracture shortening, peri-implant fracture, implant cutout, nonunion, and varus collapse. Although failure of IT fracture fixation is uncommon, improper implant selection or unfavorable fracture patterns, especially when combined with poor bone quality, leads to more frequent failures.^[4] Revision fixation, with or without bone grafting or osteotomy, has good outcomes in younger patients, but has high complication and failure rates for elderly patients.^[5] Hip arthroplasty for older patients is available as a salvage procedure with improved pain and mobility scores but has a complication rate as high as 47%.^[6–8] Given that primary treatment failures lead to high morbidity in geriatric patients, increased understanding of the fracture patterns may improve these patients’ outcomes by reducing predictable implant-associated failures.

“Stable” IT fracture patterns have a fracture obliquity that compresses with physiologic loading and requires a lateral wall of the femoral shaft that will buttress the proximal fracture fragment if it settles.^[9,10] Therefore, correct assessment of the morphology of the lateral wall is critical. Lateral wall morphology has taken on such importance that in 2018 the AO/OTA Fracture and Dislocation Compendium was updated for pertrochanteric femur fractures.^[11] The differentiation

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between groups 31A1 and 31A2 is now defined by the lateral wall height (LWH) or thickness (LWT). The LWT is defined as the distance in millimeters measured from a reference point 3 cm below the innominate tubercle of the greater trochanter and angled 135° upward to the fracture line on the plain film anteroposterior radiograph. That radiograph is ideally a traction view with the leg in neutral rotation, which is not the typical image that is obtained in the emergency room. 31A2 fractures are defined as having a lateral wall thickness of less than 20.5 mm and are classified as “unstable.”^[12,13]

Radiographic assessment of the lateral wall on plain images, even with a traction view (a source of patient discomfort and not routinely obtained), can be difficult, unreliable, and misleading compared with assessment using a CT scan.^[14–16] At our institution, many hip fractures get a CT scan of their pelvis and abdomen as part of their initial assessment by the general surgery trauma service. We use the CT to help assess lateral wall integrity, determine fracture stability, and guide implant selection. To do this, we developed novel CT measurements to quantify the morphology of the lateral wall. We hypothesized that CT measurements of the lateral wall (LWA) are more accurate than plain x-ray radiograph measurements, can better classify fractures as stable or unstable, and are predictive of failure when a SHS is used.

2. Methods

A retrospective chart review was performed of all patients with an IT fracture treated at an academic level-one trauma center from January 2005 to October 2016. Our institution’s IRB approved this study. A total of 825 patients were identified. One hundred forty-two of those (51 males, 91 females; age 77 ± 11 years) met our inclusion criteria: an AO/OTA 31A1.2 or 31A1.3 fracture pattern based on injury plain x-ray radiographs, a preoperative CT scan that was available for review, operative treatment with either a CMN (n = 105) or a SHS (n = 37), and at least 6 weeks of radiographic and clinical follow-up (Table 1). Since some of the fracture classifications changed after our CT reviews, some AO/OTA 31A.2 fractures that would have been classified as stable in the prior AO/OTA classification system were included as well.

The following measurements were performed independently by 4 orthopedic surgeons (residents, fellow, attending) on the injury AP plain films and CT scan:

1. Lateral wall thickness (LWT) was measured on the injury plain x-ray images using previously described techniques (Fig. 1).^[12]
2. We developed and measured several novel parameters to quantify the morphology of the lateral wall on the preop CT scan:
 - A. Coronal thin point (CTP): Measured on the *coronal reconstruction view* of the CT scan It was defined as the narrowest distance between the lateral wall of the shaft and the most distal extent of the lateral aspect of the proximal fracture fragment (Fig. 2). This measures the medialization of the distal fragment and is a method to estimate the size of the void created by compression of the cancellous bone within the fracture zone.
 - B. Three other measurements were performed on the *axial CT image* taken at the level where we thought the SHS lag screw would cross the fracture line:
 - i. Midpoint axial lateral wall thickness (MALWT): Defined as the thickness of the lateral wall measured at its mid-sagittal center point
 - ii. Average axial lateral wall thickness (AALWT): Defined as the average of 3 parallel measurements centered on the midpoint measurement. One line is measured at the midline and the 2 other lines are parallel and measured 6mm anterior and posterior from the midline, respectively.
 - iii. Lateral Wall Axial Area (LWAA): Defined as the area of the intact portion of the lateral wall calculated at the midpoint axial measurement using a region of interest tracing (Fig. 3).

Table 1
Patient demographics and AO/OTA Classification of patients treated with cephalomedullary nail and sliding hip screw

	Cephalomedullary nail*	Sliding hip screw*	P values†
Number of patients	105	37	
Age (years)	77 ± 11 (52–106)	75 ± 12 (56–97)	.2890
Female gender	67 (64%)	24 (65%)	1.0000
AO/OTA Classification			.0010‡
31-A1.1	0 (0%)	0 (0%)	
31-A1.2	29 (28%)	24 (65%)	
31-A1.3	48 (45%)	9 (24%)	
31-A2.2	21 (20%)	3 (8%)	
31-A2.3	7 (7%)	1 (3%)	

* The values are presented as the number of patients with the percentage in parentheses, except for age which is given as the mean and standard deviation with minimum and maximum in parentheses.

† The P values were determined with the Fisher exact test, except for age which was derived with the Wilcoxon Rank-Sum Test.

‡ Indicates statistical significance.

3. The CT scans were analyzed for the presence of any coronal plane fracture lines.
4. The tip–apex distance (TAD) was measured on postoperative AP and lateral plain x-ray radiographs.^[17]

Early failures were detected by reviewing images of patients with at least 6 weeks of follow-up. Implant-related failures were defined as: iatrogenic lateral wall fractures leading to loss of fixation, and/or varus collapse with lag screw or side plate cutout, and /or symptomatic shortening of the limb (> 15mm) and/or patients who required additional treatment.

Postoperative fracture shortening was measured by comparing the immediate postoperative x-ray radiographs to the last follow up x-ray radiographs that were available. For the SHS constructs, we measured the exposed length of the smooth portion of the lag screw from the proximal edge of the plate barrel to the first screw thread. For the CMN constructs, we measured the exposed length of the lag screw or blade lateral to the body of the intramedullary nail. Magnification was corrected for by using the known implant diameter as a reference. We defined shortening greater than or equal to (≥) 15mm along the axis of the lag screw/blade as “significant” shortening. This corresponds to 10 mm of shortening of the limb, which has been shown to be symptomatic after hip arthroplasty.^[18]

2.1. Statistical analysis

To quantify the inter-observer repeatability of the plain x-ray radiographs and CT measurements, 4 surgeons measured the LWT, CTP, MALWT, AALWT, and LWAA on 15 randomly selected patients. A single factor analysis of variance (ANOVA) with repeated measures computed the intraclass correlation coefficient (ICC) for all measurements. A linear regression

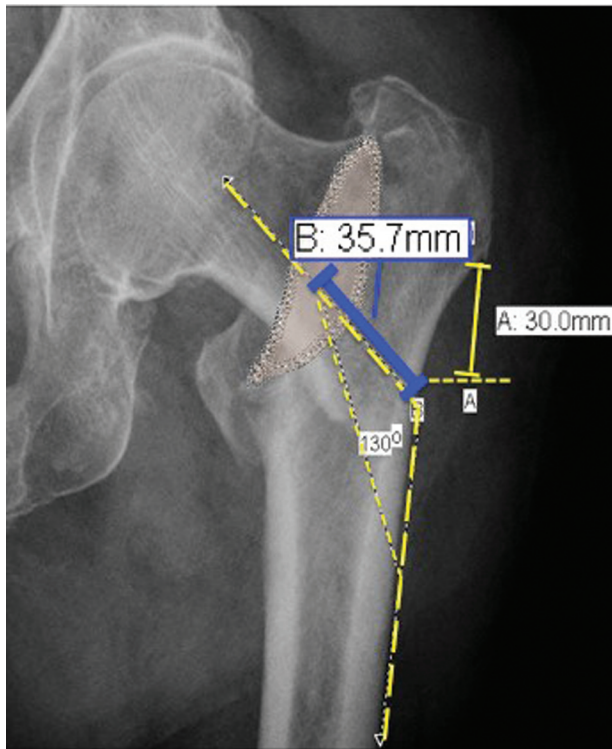


Figure 1. Lateral wall thickness (LWT) is measured on an AP hip x-ray (blue line). It is the distance in millimeters from a reference point 3 cm (yellow line) below the innominate tubercle of the greater trochanter, angled at 130° upward to the fracture line (the midline between the two cortex lines).

analysis was used to compute the coefficient of determination (r^2) to determine whether the measurements of LWT on radiographs predicted the CT measurements of CTP, MALWT, AALWT, and LWAA.

Continuous variables (e.g., CT measurements) were reported as the mean ± standard deviation and range. Categorical variables (e.g., gender) were reported as either the number of patients or a percentage of patients. A Fisher exact test was used to determine differences between categorical variables (e.g., AO Classification, presence of coronal fracture) for patients who had implant failure and those who did not, for each implant type. A Wilcoxon Rank-Sum Test was used to determine the significance of continuous variables (e.g., X-ray and CT measurements, tip-apex distance) for patients who had implant failure versus those who did not have implant failure in patients treated with a CMN or SHS. Computations were performed with statistical software (JMP Pro, 13.0, <http://www.jmp.com>) and significance was set at $P < .05$.

3. Results

There were no significant differences between the CMN group and SHS group with regards to age and gender (Table 1). All image measurements had a good or excellent interobserver reliability based on the ICC analysis. The CTP (Fig. 2) had the best ICC (0.83), followed by the AALWT (0.81), then the LWAA (0.79), then MALWT (0.72) (Fig. 3), and the LWT (Fig. 1) had the worst ICC of 0.63. There was a poor correlation between the LWT values measured on plain x-ray radiographs compared with those measured on a CT ($r^2 = 0.16$ for CTP, 0.13 for MALWT, 0.14 for AALWT, and 0.28 for LWAA).

Fifteen patients had an implant failure (6 CMN, 9 SHS) by 6 weeks. The SHS failures were due to shortening (6) or varus collapse with cutout (3). The CMN failures were due to shortening (5) and superior cutout (2). The CMN fixation group had no statistically significant differences in age, gender, AO/OTA classification, presence of coronal plane fracture, tip-apex distance, LWT, CTP, MALWT, AALWT, or LWAA between CMN fixations that failed and those that did not (Table 2). The SHS group had no differences in age, gender, AO/OTA

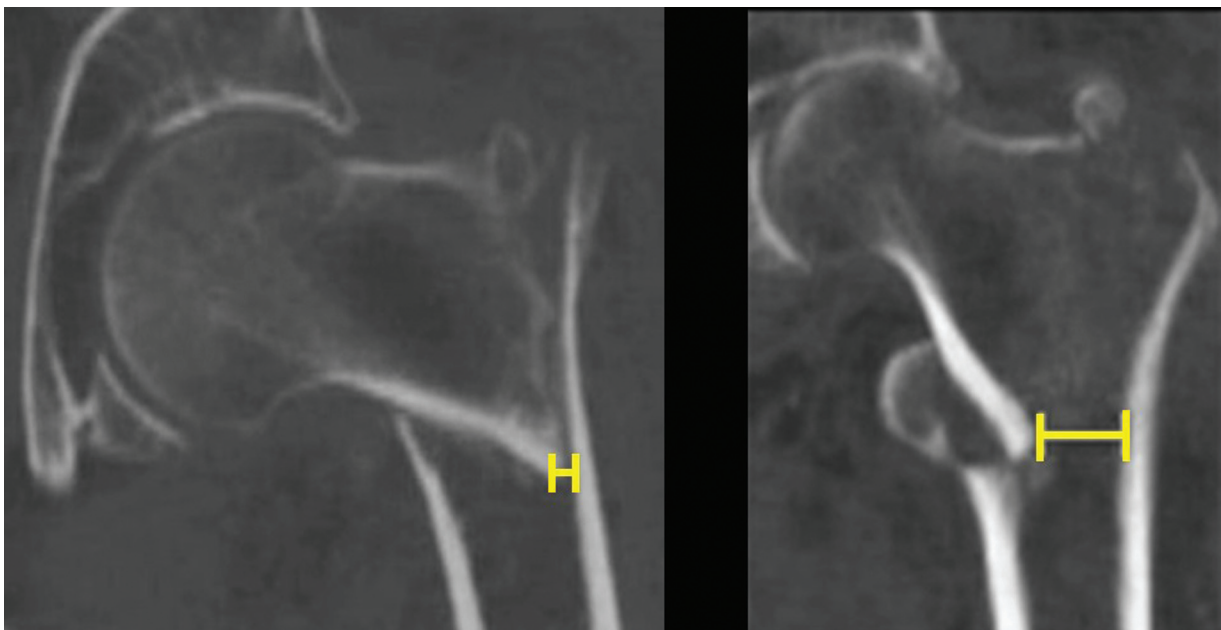


Figure 2. The coronal thin point (CTP) is measured on coronal CT reformats of the intertrochanteric fracture. It is the distance between the lateral wall cortex and the most distal extent of the lateral aspect of the proximal fragment.

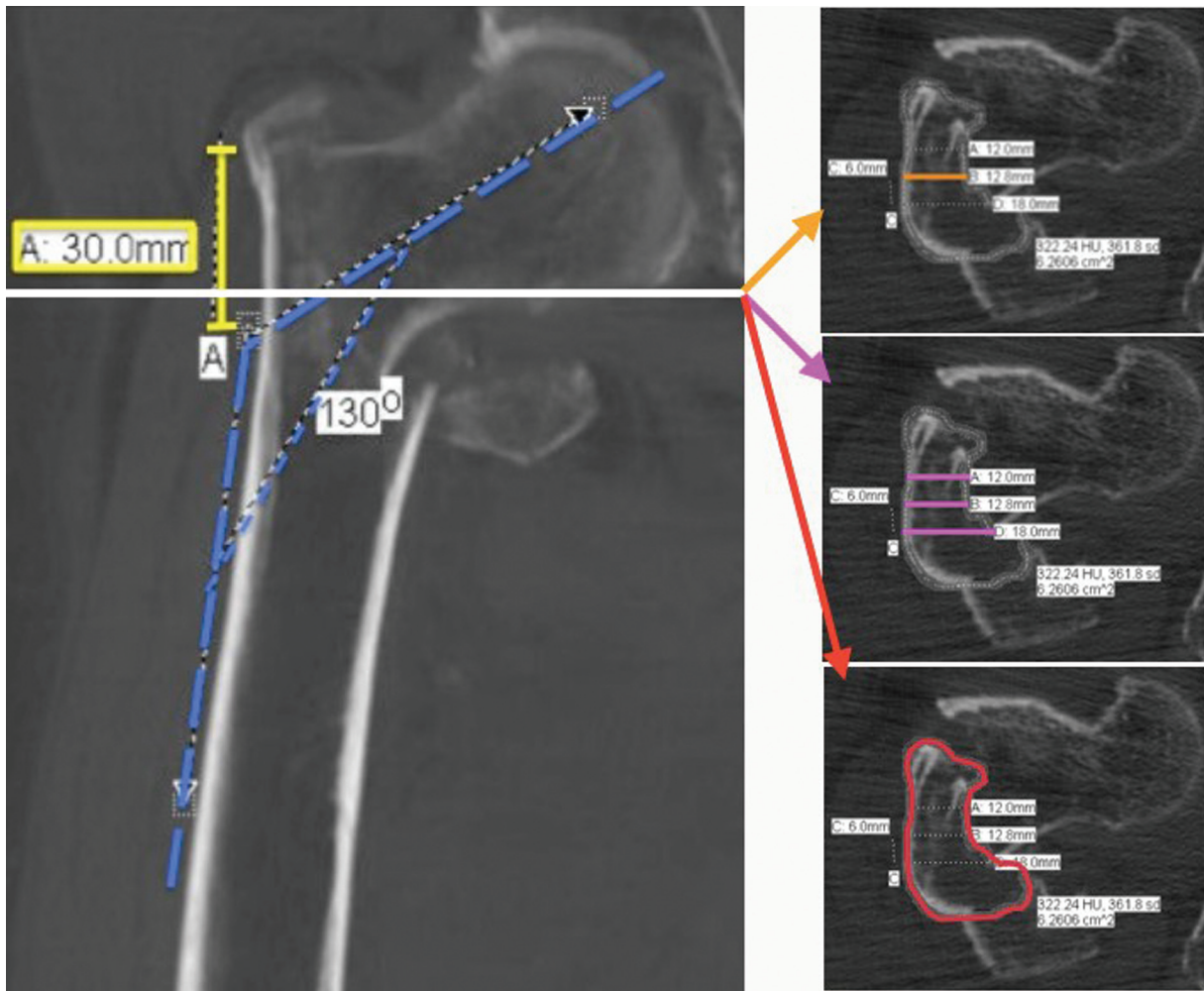


Figure 3. Coronal image of a CT scan showing how to select the axial image at the level where the lag screw would cross the fracture line (white line). The midpoint axial lateral wall thickness (MALWT), defined as the thickness of the LW wall measured at the mid-sagittal center point of the lateral wall (orange line), the average axial lateral wall thickness (AALWT), defined as the average of 3 lateral wall thicknesses and parallel measurements made 6 mm anterior and posterior to the point where the midpoint was measured (magenta line), and the lateral wall axial area (LWAA) defined as the area of the intact portion of the lateral wall (red line).

classification, tip–apex distance, or LWT between SHS’s that failed and those that did not fail (Table 3). However, coronal plane fractures were seen in 6 of the 9 (67%) SHS failures, but in only 5 of the 28 (18%) SHS that did not fail, which was statistically significant ($P=.0106$) (Table 3). All SHS fixation failures had CT measurements (MALWT, AALWT, LWAA, CTP) of their lateral wall morphology that were smaller (indicating a smaller lateral wall) compared with the patients with SHS fixation that did not fail (P values ranging from .0044 to .0269) (Table 3). No combination of variables was better than a single variable at predicting failure. Additionally, the CT measurements were predictive of failure in the SHS group, but no specific variable was more predictive than the others.

Threshold values were established to determine fracture measurements that were predictive of failure when using a SHS implant. A LWT measurement of 25.9 mm or less based on radiographs correlated with failure (sensitivity 0.444, specificity 0.734, $P=.373$). CTP of 9 mm or less based on CT correlated with failure (sensitivity 0.667, specificity 0.897, $P=.0161$). A LWAA measurement of 6.8 mm or less based on CT predicted failure (sensitivity 1.0, specificity 0.429, $P=.023$). A MALWT of

19.0 mm or less based on CT predicted failure (sensitivity 1.0, specificity 0.464, $P=.050$). Finally, an AALWT measurement of 17.8 mm or less based on CT predicted failure when using a SHS (sensitivity 1.0, specificity 0.429, $P=.023$).

4. Discussion

Our study demonstrates that CT imaging is more accurate and reliable for the assessment of the lateral wall size and morphology for fractures that appear to be “stable” patterns when assessed using plain film images. LWT measurements based on plain x-ray radiographs have worse intra- and inter-observer reliability when compared with measuring them on CT using our novel CT measurement of lateral wall thickness and size. Also, there was poor correlation between the LWT measured on plain x-ray radiographs and CT measurements. Furthermore, the morphology of the LWT determined via a plain x-ray radiograph was not associated with implant fixation failure; in contrast, CT measurements were predictive of implant failure when a SHS implant was used. The failures had a smaller and/or thinner lateral wall when compared with those who did not fail as further

Table 2
Characteristics of intertrochanteric hip fracture implant failure for patients treated with cephalomedullary nails

	Failure*	No failure*	P values†
Number of patients	6	99	
Age (years)	78 ± 15 (60–99)	77 ± 11 (52–106)	.8143
Female gender	2 (33%)	65 (66%)	.1860
AO/OTA Classification			.5320
31-A1.1	0 (0%)	0 (0%)	
31-A1.2	3 (50%)	26 (26%)	
31-A1.3	3 (50%)	45 (46%)	
31-A2.2	0 (0%)	21 (21%)	
31-A2.3	0 (0%)	7 (7%)	
Presence of coronal plane fracture	5 (83%)	58 (59%)	.3980
Tip–apex distance (mm)	16 ± 8	17 ± 5	.7772
X-ray measurements			
Lateral wall thickness (mm)	26 ± 4	27 ± 8	.8144
CT measurements			
Coronal thin point (mm)	14 ± 7	13 ± 7	.7042
Midpoint axial lateral wall thickness (mm)	14 ± 3	14 ± 5	.4770
Average axial lateral wall thickness (mm)	15 ± 3	14 ± 4	.6095
Lateral wall axial area (cm ²)	6 ± 2	6 ± 2	.5030

*The values are presented as the number of patients with the percentage in parentheses, except for age which is given as the mean and standard deviation with minimum and maximum in parentheses.
 †The P values were determined with the Fisher exact test, except for age which was derived with the Wilcoxon Rank-Sum Test.

demonstrated by CT-based cutoff values for predicting failures. Additionally, a decreased coronal thin point (CTP) on CT, which represents a more impacted and medialized distal fragment/lateralized proximal fragment with compression of the cancellous bone at the fracture site with resulting void when the fractures are pulled out to length and reduced, was also associated with SHS implant fixation failures. However, no measurement on CT or x-

Table 3
Characteristics of intertrochanteric hip fracture implant failure for patients treated with sliding hip screw

	Failure*	No failure*	P values†
Number of patients	9	28	
Age (years)	74 ± 9 (61–89)	75 ± 13 (56–97)	.9717
Female gender	6 (67%)	18 (64%)	1.0000
AO/OTA Classification			1.0000
31-A1.1	0 (0%)	0 (0%)	
31-A1.2	6 (67%)	18 (64%)	
31-A1.3	2 (22%)	7 (25%)	
31-A2.2	1 (11%)	2 (7%)	
31-A2.3	0 (0%)	1 (4%)	
Presence of coronal plane fracture	6 (67%)	5 (18%)	.0106‡
Tip–apex distance (mm)	17 ± 4	17 ± 6	1.0000
X-ray measurements			
Lateral wall thickness (mm)	31 ± 8	33 ± 8	.6581
CT measurements			
Coronal thin point (mm)	11 ± 10	18 ± 9	.0269‡
Midpoint axial lateral wall thickness (mm)	13 ± 4	18 ± 5	.0102‡
Average axial lateral wall thickness (mm)	13 ± 3	19 ± 5	.0044‡
Lateral wall axial area (cm ²)	5 ± 1	7 ± 2	.0234‡

*The values are presented as the number of patients with the percentage in parentheses, except for age which is given as the mean and standard deviation with minimum and maximum in parentheses.
 †The P values were determined with the Fisher exact test, except for age which was derived with the Wilcoxon Rank-Sum Test.
 ‡Indicates statistical significance.

ray was associated with failures in the CMN group, presumably because CMN fixation does not rely on lateral wall integrity.

Twenty-two percent of the IT fractures were classified as stable (AO/OTA 31A1) based on initial plain film radiographs but were reclassified as unstable (AO/OTA 31A2) fractures once the CT scan was reviewed. This illustrates the pitfalls of relying on plain films to assess the stability of IT fractures and the increased accuracy of CT imaging, and 1 patient was treated with a SHS that failed when the CT scan ordered as a trauma scan may not have been scrutinized. When examining these fractures on axial CT scans, it is apparent that the lateral cortex of the femur is not simply a wall but rather the portion of the cylindrical femoral shaft that is divided from the head and neck segment by the main intertrochanteric fracture plane. When the lateral cortex has an additional coronal plane fracture separating the posterior portion of the trochanter from the anterolateral cortex, the lateral cortex becomes much smaller despite a LWT measurement on x-ray that would classify the injury as “stable.”^[19] Fracture treatment with a SHS was a significant risk factor for failure for patients with coronal plane secondary fracture lines. In our patient cohort, fracture characteristics that can be hidden on plain films accounted for the higher failure rate with SHS treatment, and when selecting them out, the success rate of SHS matched that of CMNs in otherwise stable patterns.

We are not the first group to use CT scans to assess the lateral wall. A study that examined IT fracture morphology with CT measurements to assess the posteromedial fragment of AO/OTA 31A1 and 31A2 fractures treated with SHS implants found that fracture collapse was associated with the 31A2 fracture pattern and lateral wall fractures.^[20] This study noted that CT imaging was critical to accurately classify IT fractures. While most measurements had good-to-excellent interobserver reliability, their quantification of the “lateral” aspect of the lateral wall—intended to measure where the drill contacts the shaft—had only a fair correlation.^[20] Furthermore, this study had a high failure rate which may be due to the fact that all the 31A2 fractures were treated with a SHS.^[20] In contrast, our study used the more recent AO/OTA classification scheme and showed that many fractures may have patterns that make them “unstable” that cannot be evaluated using plain radiographs but are readily visible on CT.

This study represents a contemporary look at peritrochanteric femur fractures using the updated AO/OTA Fracture and Dislocation Compendium. Furthermore, all fracture fixations had a tip–apex distance of less than 25 mm for every patient, eliminating a confounder for fixation failure; in other words, we analyzed the cause of failure despite an acceptable TAD. Since no single CT measurement nor any combination of measurements was more predictive of failure than another, in real clinical situations the lateral wall assessment can be simplified by using any single CT measurement that we describe.

Limitations of our study exist, including its retrospective nature. This precluded us from determining the operating surgeon’s intraoperative assessment and classification of the fracture, which may change, hence altering implant selection. Furthermore, 6 weeks of follow-up underestimates failure rates for patients in whom failure occurs at a later time, although comparable studies have a similar follow-up period and have shown that failures tend to occur early.^[16,21] Due to the low incidence of treatment failure with the use of modern fixation techniques for IT fractures, all of our failures regardless of the mechanism of failure had to be grouped together without the ability to analyze different types. Additionally, the overall number of SHS implanted was less than CMN. During

measurement, the rotation of the fragments was not controlled for, although similar techniques based on prior studies were used for the radiographic measurements and the CT measurements were based on axial measurements where rotation would less affect validity as the lateral wall is more easily identified. We did not assess that the center point for the proposed screw crossing the fracture ended up being where the actual implant crossed. This would matter less for the reliability of the measurements but could be a factor regarding the measurements' correlation with surgical technique. Finally, none of the SHS hip failure groups used a trochanteric side plate which has been demonstrated to prevent failures in intertrochanteric femur fractures with lateral wall weakness although with limitations as the fixation is less reliable and femoral shaft medialization is frequent.

Shortening of greater than 15 mm was the most common failure mechanism noted. We set a threshold of 15 mm for shortening failure since this degree of shortening is symptomatic.^[18] We believe this shortening is due to impaction of the cancellous bone within the intertrochanteric region between the distal and proximal fragments at the time of injury and is reflected by our CTP measurement. This shortening places the lateral wall at risk of fracture since the proximal segment can slide until it hits the lateral cortex of the distal fragment. In contrast, a CMN prevents the proximal fragment from sliding as far laterally by providing a more medial stopping point. Other implant-associated failures associated with SHS reflected the side plate and barrels inability to hold the fracture in space with weight bearing—these included cutout and varus collapse. Consequently, our study showed that CMN implant failures are rare and that their failure mechanisms appear to be different than associated with SHS implants. Studies with increased sample sizes could lead to better understanding of the relationships between fracture pattern type and failure mechanism for SHS and CMNs.

Our study compares IT fracture implants, so it is important to discuss the global increased use of CMN implants, which is due to many factors including training biases. Traditionally, a SHS is used for a stable fracture pattern and CMN for unstable fractures since a nail provides an intramedullary buttress that is not dependent on the integrity of the lateral wall. There is a trend in the United States to use CMN implants for IT fractures that are thought to be stable^[22] that is attributed to training and surgeon preferences that changed with the introduction of short CMNs.^[23] However, this trend has also coincided with evidence that assessment of IT fracture stability using plain x-ray images only is not able to accurately detect all fracture patterns at risk of failure when treated with a SHS. This raises the concern that we are essentially guessing whether a fracture pattern is stable or not when using plain x-ray images. Studies have published differing results on their cost-effectiveness, outcomes, and benefits.^[22,24–26] Our study demonstrates that the morphology of the lateral wall may not be an important factor for predicting failures with CMN implants, but is important for SHS failures.

Strengths of our study include its clinically applicable findings. Our study is not intended to advocate for increased CMN use. No study to date has proven a demonstrable benefit for the use of CMN vs. a SHS for “stable” IT fracture patterns.^[22,24,27] Some studies have even found a lower complication rate for SHS implants when compared with CMN implants.^[27] At our institution, the SHS remains an option for fixation of “stable” IT fracture patterns given its low-cost, abductor-sparing approach, and successful outcomes. As a result of this study, we advocate to obtain a CT scan when a displaced IT fracture appears “stable” based on x-ray alone but has features

concerning for lateral wall compromise (e.g., impaction, possible fracture lines, thin cortices). CT will demonstrate the true morphology of the intact lateral wall: the presence or absence of lateral comminution, coronal splits, and impaction of the proximal segment into the lateral wall. With this new and detailed information, then implant selection can be optimized. Additionally, intraoperative assessment of the lateral wall and fracture pattern if performing a surgical approach for a SHS may guide the decision to utilize a trochanteric slide plate. Hopefully, this strategy can minimize failures of treatment in geriatric IT fracture patients.

5. Conclusion

This study demonstrates that for 31A1.2 and 31A1.3 intertrochanteric hip fractures, a CT offers better assessment of the lateral wall integrity and morphology when compared with plain radiographs. As such, using CT affords the opportunity for more informed decision-making regarding implant selection for fracture fixation. Hence, for fractures suspicious for loss of lateral wall integrity, if a CT scan is obtained preoperatively then a SHS with a TSP or a CMN device should be considered to avoid collapse and complications. However, if a CT scan is completed preoperatively, then the implant selection decision can be determined based on the CT findings. Our novel CT measurements (CTP, MALWT, AALWT, and LWAA), and associated cutoff values, can predict which intertrochanteric hip fractures are at risk of failure when stabilized with a SHS implant.

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