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Cut-Through versus Cut-Out: No Easy Way to Predict How Single Lag Screw Design Cephalomedullary Nails Used for Intertrochanteric Hip Fractures Will Fail?

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Purpose: This study aims to compare patients in whom fixation failure occurred via cut-out (CO) or cut-through (CT) in order to determine patient factors and radiographic parameters that may be predictive of each mechanism.
Materials and Methods: This retrospective cohort study includes 18 patients with intertrochanteric (IT) hip fractures (AO/OTA classification 31A1.3) who underwent treatment using a single lag screw design intramedullary nail in whom fixation failure occurred within one year. All patients were reviewed for demographics and radiographic parameters including tip-to-apex distance (TAD), posteromedial calcar continuity, neck-shaft angle, lateral wall thickness, and others. Patients were grouped into cohorts based on the mechanism of failure, either lag screw CO or CT, and a comparison was performed.
Results: No differences in demographics, injury details, fracture classifications, or radiographic parameters were observed between CO/CT cohorts. Of note, a similar rate of post-reduction TAD>25 mm (P=0.936) was observed between groups. A higher rate of DEXA (dual energy X-ray absorptiometry) confirmed osteoporosis (25.0% vs. 60.0%) was observed in the CT group, but without significance.
Conclusion: The mechanism of CT failure during intramedullary nail fixation of an IT fracture did not show an association with clinical data including patient demographics, reduction accuracy, or radiographic parameters. As reported in previous biomechanical studies, the main predictive factor for patients in whom early failure might occur via the CT effect mechanism may be related to bone quality; however, conduct of larger studies will be required in order to determine whether there is a difference in bone quality.

Key Words: Hip fractures, Osteoporosis, Radiographic film, Intramedullary nailing, Equipment failure

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INTRODUCTION

Intertrochanteric (IT) hip fractures are a common injury in the elderly population, and the incidence of IT fractures is increasing with the aging population[1-3]. Operative fixation, most often using a cephalomedullary nail, is standard of care for this injury[4,5]. Despite its relatively rarity, failure of a cephalomedullary nail can have significant effects on the patient. As the incidence of IT fractures continues to rise, a comprehensive understanding of implant failure as well as effective management are important.

Two distinct mechanisms, varus collapse of the head with an antero-superior cut-out (CO) of the implant's lag screw or medial migration of the lag screw or cut-through (CT), are most often responsible for failure of a cephalomedullary nail[6-12]. While many studies examining the factors associated with the occurrence of implant failure have been reported, data regarding which factors may be predictive of one type of failure mechanism over the other are limited. Therefore, the purpose of this study is to compare clinical data from patients treated with a single lag screw design intramedullary nail in whom fixation failure occurred via the CT mechanism versus CO out in order to determine patient factors, injury details, reduction quality, or radiographic parameters that may be predictive of each mechanism.

MATERIALS AND METHODS

This retrospective chart review study involving human participants was in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The Human Investigation Committee (IRB) of NYU Langone approved this study (approval No. i20-01766). Due to the approved IRB, informed consent was not required as study was retrospective in nature and information was anonymized.

In this retrospective cohort study, a database on hip fractures which was approved by an IRB was queried for a consecutive series of patients who presented to a single academic medical center (that includes four hospitals) with an IT hip fracture (AO/OTA classification 31A1, 31A2, 31A3) from 2014 to 2022. Inclusion criteria for this analysis included any patient who presented with an IT hip fracture during the study period and received treatment with a cephalomedullary nail, including both long and short options. Exclusion criteria included patients treated with a dynamic sliding hip screw and those who died within three months of surgery. The records for each patient were reviewed for demographic features and radiographic parameters. Demographic features included age, body mass index, comorbidity profile as compiled by the Charlson comorbidity index (CCI), baseline ambulatory status, osteoporosis diagnosis (as determined by previous dual energy X-ray absorptiometry [DEXA] scan), and smoking status at the time of injury (current vs. not current). Additional recorded clinical data included the respective time from surgery to fixation failure, the Score for Trauma Triage in the Geriatric and Middle Aged (STTGMA), a validated tool for assessment of orthopedic trauma risk, and the Fracture Risk Assessment Tool (FRAX) tool for each patient[13-17]. The STTGMA score utilizes various clinical variables including demographic data (age, comorbidities), injury details (AIS [Abbreviated Injury Scale] for the head/neck and chest), and baseline functional status for determination of a mortality risk score. Previous work by Konda et al.[16] was used to determine risk cohorts for each patient's respective STTGMA score with the following breakdown: high risk, >9.0%; moderate risk, 3.4-8.2%; low risk, 0.8-3.4%; and minimal risk, <0.8%. The FRAX tool utilizes clinical variables including age, gender, height, weight, history of previous fracture, smoking, alcohol or glucocorticoid use, the presence of osteoporosis, and others to determine a risk score for the occurrence of future fracture. A FRAX score >20% was used as a cutoff for recommended medical therapy for intervention based on the US-based World Health Organization algorithm.

Review of radiographs included films of preoperative injury of the hip and pelvis for assessment of anteroposterior (AP) and traction/internal rotation[18]. A review of intraoperative fluoroscopy was performed for both AP and lateral views. All fractures were classified according to the system of the OTA[19]. Follow-up radiographs were reviewed to determine the mechanism of failure, and classified as either lag screw CO or medial migration/CT.

Fracture reduction and radiographic parameters of the implant were recorded. All thickness, length, or angular measurements were performed using PACS tools (ruler, goniometer PACS tool; Siemens). Measurement of the tip-apex distance (TAD) was performed according to measurements reported by Baumgaertner et al.[20]. Measurements of the lateral femoral wall were performed using the method described by Palm et al.[21] and Hsu et al.[22]. Assessment of reduction quality was performed using post-fixation angulation and cortical translation as measured on intraoperative fluoroscopy for comparison of any differences.

1. Surgical Technique

All intramedullary nailing procedures were performed in a similar manner. For each patient, reduction and confirmation of the fracture in acceptable alignment was obtained intraoperatively on both AP and lateral image intensifier X-rays. A lateral incision was made proximal to the tip of the trochanter through skin, subcutaneous tissue, and the iliotibial band using a scalpel. A guide wire was placed on the tip of the trochanter, at the standard starting point for a cephalomedullary nail. The wire was advanced under fluoroscopic control and the proper position was confirmed on both the AP and lateral views. For each case, reaming of the opening portal for the proximal femur was performed prior to insertion of the intramedullary nail. Utilizing the side arm targeting jig through the stab incision laterally, a wire was placed from the lateral cortex through the femoral neck and into a central position within the femoral head. After reaming, compression of the fracture was performed with placement of an end cap locking screw through the top of the nail, which was tightened before being turned back a quarter turn. Distally, the nail was locked with two lateral to medial bolts for long nails, and one lateral to medial bolt for short nails. Distal locking bolts were inserted using the perfect circle technique. Following confirmation of the placement of the implants on both AP and lateral views using intraoperative fluoroscopy, the targeting jig was removed and the incision sites were appropriately closed. Following closure, final AP and lateral X-rays were taken in order to confirm that reduction and implant placement were maintained.

2. Statistical Analysis

All failures were identified at the time of follow-up and grouped into cohorts based on the mechanism of failure, either CO or CT. The remaining patients were classified as a non-failure cohort. Comparative analyses of the CO, CT, and non-failure cohorts were performed. Comparative analyses were performed using chi-square tests and ANOVA as appropriate. Calculation of statistics was performed using IBM SPSS Statistics (ver. 25; IBM). Significance was set at an alpha of 0.05.

RESULTS

Of the 1,232 IT fractures treated during the study period, fixation failure occurred at an average of three months or 90 days from the initial surgery in 18 patients with 18 fractures (1.5%). Treatment with short cephalomedullary nails was administered in 17 patients, and one patient received treatment with a long cephalomedullary nail. Failed implants

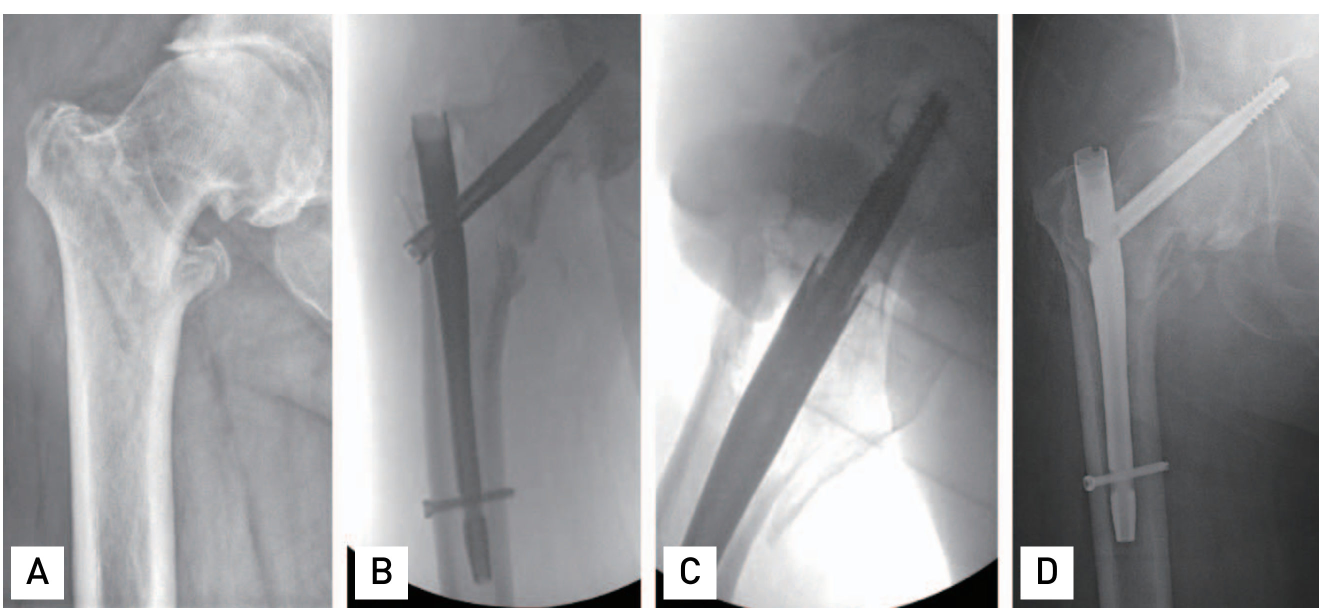

Fig. 1. (A) Anteroposterior (AP) injury film demonstrating a right intertrochanteric hip fracture (AO/OTA 31A1.2). (B) AP and (C) lateral intraoperative fluoroscopy demonstrating a right intertrochanteric hip fracture treated with an intramedullary nail. (D) AP radiograph at follow-up demonstrating implant failure via the cut-through mechanism with medial intrapelvic migration.

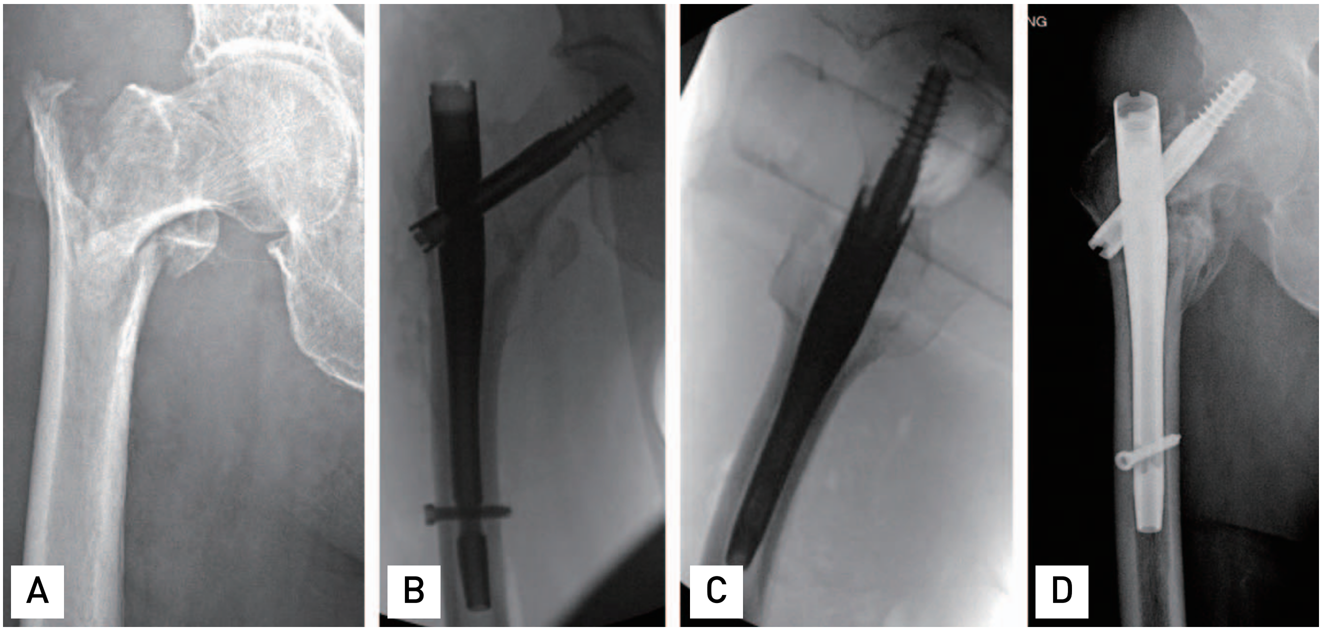

Fig. 2. (A) Anteroposterior (AP) injury film demonstrating a right intertrochanteric hip fracture (AO/OTA 31A2.3). (B) AP and (C) lateral intraoperative fluoroscopy demonstrating a right intertrochanteric hip fracture treated with an intramedullary nail. (D) AP radiograph at follow-up demonstrating implant failure via the lag screw cut-out mechanism.

included: 17 Stryker Gamma nails (Stryker) and one Zimmer Biomet Nail (Zimmer). The average age of patients in the failure cohort was 77.67±10.35 years, younger than those in the non-failure cohort (*P*=0.168). The failure cohort included six males (33.3%) and 12 females (66.7%). Medial migration of the lag screw was detected in 10 patients (55.6%) (Fig. 1) while lag screw CO was detected in eight patients (44.4%) (Fig. 2). No difference in demographic parameters was observed between the CO, CT, and non-failure cohorts including injury mechanism (96% of patients had a low energy injury mechanism), fracture classification, percentage of patients in each respective STTGMA score risk cohort (*P*=0.540) or FRAX score >20% (*P*=0.647). The highest CCI was observed in patients in the CT cohort, demonstrating a larger comorbidity profile compared to the non-failure cohort (*P*=0.002). The highest rate of DEXA confirmed osteoporosis (25.0% vs. 60.0% vs. 11.4%) was observed in the CT group, which was not significant compared to the CO group (*P*=0.138) but significantly higher compared with the non-failure cohort with *P*<0.001 (Table 1).

In addition, no differences in radiographic parameters were observed between the CO, CT, and non-failure cohorts (Table 2), including but not limited to TADs; only one patient in each failure cohort had a TAD >25 mm.

DISCUSSION

The findings of this study demonstrated an association of both mechanisms of screw failure with similar clinical data including patient demographics, injury parameters, and radiographic data. It is more likely that the main predictive factor for patients in whom early failure occurs via the mechanism of medial migration is related to bone quality as described in previous biomechanical studies.

Although all patients who underwent treatment had some form of osteoporosis, no significant difference in the rate of osteoporosis diagnosis via DEXA scan and FRAX score >20% was observed between the CT and CO cohorts, and the CT cohort included a much higher percentage of patients with a diagnosis of osteoporosis at the time of injury. This was particularly notable in the comparison of the CT and non-failure cohorts. The mechanism of medial migration is thought to mimick the “Z effect” mechanism observed with two screw design nails due to relative differences in bone quality in the femoral head. According to a biomechanical study reported by Strauss et al.[23], poor bone quality showed strong correlation with failure via a mechanism similar to the Z effect. Multiple causes for this incidence of the single screw Z effect were hypothesized in a case study on intrapelvic migration of the lag screw that included a subsequent review of possible mechanisms reported

Table 1. Comparison of Demographic Features between Cut-Out (CO), Cut-Through (CT), and Non-Failure Cohorts

Variable	Failure type comparison			Total (n=1,232)	*P*-value
	CO (n=8)	CT (n=10)	Non-failure (n=1,214)		
Demographics					
Age (yr)	76.00±8.67	79.00±11.81	81.93±10.07	77.67±10.35	0.168
Body mass index (kg/m²)	24.42±5.53	25.63±6.01	24.06±5.59	25.09±5.67	0.666
Charlson comorbidity index	1.88±2.59	3.10±1.91	1.42±1.57	2.56±2.25	0.002*
FRAX score >20%	1 (12.5)	1 (10.0)	76 (6.3)	78 (6.3)	0.647
STTGMA risk quartile					0.540
High risk	0 (0)	1 (10.0)	32 (2.6)	33 (2.7)	
Moderate risk	0 (0)	1 (10.0)	173 (14.3)	174 (14.1)	
Low risk	3 (37.5)	5 (50.0)	440 (36.2)	448 (36.4)	
Minimal risk	5 (62.5)	3 (30.0)	569 (46.9)	577 (46.8)	
Sex					0.909
Male	3 (37.5)	3 (30.0)	369 (30.4)	375 (30.4)	
Female	5 (62.5)	7 (70.0)	845 (69.6)	857 (69.6)	
Ambulatory status					0.250
Community ambulator	8 (100)	7 (70.0)	803 (66.1)	818 (66.4)	
Household ambulator	0 (0)	2 (20.0)	364 (30.0)	366 (29.7)	
Non-ambulatory	0 (0)	1 (10.0)	47 (3.9)	48 (3.9)	
Time to failure (day)	85.63±58.93	93.10±100.85	-	89.78±82.64	0.855
Osteoporosis diagnosis at time of injury	2 (25.0)	6 (60.0)	138 (11.4)	146 (11.9)	<0.001*
Current smoker at time of injury	1 (12.5)	1 (10.0)	112 (9.2)	114 (9.3)	0.912
Fracture classification					0.242
31A1.1	0 (0)	0 (0)	5 (0.4)	5 (0.4)	
31A1.2	3 (37.5)	3 (30.0)	299 (24.6)	305 (24.8)	
31A1.3	0 (0)	0 (0)	284 (23.4)	284 (23.1)	
31A2.2	2 (25.0)	2 (20.0)	303 (25.0)	307 (24.9)	
31A2.3	2 (25.0)	5 (50.0)	174 (14.3)	181 (14.7)	
31A3.1	1 (12.5)	0 (0)	53 (4.4)	54 (4.4)	
31A3.2	0 (0)	0 (0)	12 (1.0)	12 (1.0)	
31A3.3	0 (0)	0 (0)	84 (6.9)	84 (6.8)	
Low energy injury mechanism	7 (87.5)	10 (100)	1,171 (96.5)	1,188 (96.4)	0.329

Values are presented as mean±standard deviation or number (%).
FRAX: Fracture Risk Assessment Tool, STTGMA: Score for Trauma Triage in the Geriatric and Middle Aged.
* P<0.05.

by Flint et al.[7]. Many of these causes were related to bone quality, notably persistent instability of the fracture, avascular neecrosis of the femoral head, and detection of osteoporotic bone[7]. Patients in both the CT and CO cohorts were significantly younger than those in the non-failure cohort, thus both failure mechanisms may be invovled in older patients with worse bone quality. Therefore, a patient's bone quality is likely a factor in the mechanism of failure that may occur; however, conduct of a larger study will be required in order to provide conclusive evidence.

In addition, comparison of the CT and CO cohorts found no difference in various radiographic parameters from the preoperative and intraoperative time periods. Findings from many studies have demonstrated that specific radiographic parameters, such as TAD, show high correlation with failure rate. A consistent approach to measurement of the TAD of sliding hip screw implants utilizing AP and lateral radiographs of the hip was developed by Baumgaertner et al.[20]. In their retrospective study, out of an overall cohort of 193 patients, there were 19 cases of fixation failure (9.8%). A strong statistical relationship was observed between increasing TAD and the rate of screw CO. According to another comparative study reported two years later by Baumgaertner and Solberg[24], use of good surgical technique with an emphasis on minimizing TAD resulted in lower rates of screw CO and implant failure for both sliding hip screws and intramedullary devices. A biomechanical study conducted by Kuzyk et al.[25] reported that an inferior place-

Table 2. Comparison of Radiographic Parameters between Cut-Out (CO), Cut-Through (CT), and Non-Failure Cohorts

Radiographic parameter	Failure type comparison			*P*-value
	CO (n=8)	CT (n=10)	Non-failure (n=1,214)	
Fracture parameter				
Lateral femoral wall thickness on the AP view (mm)	29.92±19.76	25.59±19.76	22.69±5.25	0.554
Lateral femoral wall thickness on the TIR view (mm)	27.55±18.23	21.34±18.23	27.17±6.41	0.317
Injury film NSA on the AP view (°)	123.14±45.29	117.86±45.29	117.48±45.74	0.907
Injury film NSA on the TIR view (°)	130.95±70.48	127.17±70.48	123.75±61.33	0.397
Contralateral leg NSA on the AP view (°)	134.38±69.66	132.89±69.66	131.84±45.20	0.719
Fracture side – ischial tuberosity to greater trochanter (mm)	93.79±35.55	99.39±35.55	86.82±27.85	0.057
Contralateral side – ischial tuberosity to greater trochanter (mm)	81.13±37.76	81.64±37.76	74.58±27.71	0.207
Fracture side – ischial tuberosity to lesser trochanter (mm)	30.56±15.57	36.16±15.57	32.62±19.87	0.783
Contralateral side – ischial tuberosity to lesser trochanter (mm)	18.80±10.46	19.61±10.46	18.14±11.44	0.901
Lesser trochanter – intact (yes or no)	3 (37.5)	1 (10.0)	307 (25.3)	0.307
Pre-fixation lateral angulation (apex anterior or apex posterior)				0.504
Apex anterior	0 (0)	3 (30.0)	218 (18.0)	
Apex posterior	2 (25.0)	0 (0)	208 (17.1)	
Pre-fixation lateral angulation absolute value (°)	10.20±5.02	8.50±5.02	11.72±8.59	0.840
Reduction parameters				
Tip-apex distance >25 mm (yes or no)	1 (12.5)	1 (10.0)	109 (9.0)	0.936
Calcar mal-reduction distance (mm)	8.65±4.86	5.88±4.86	5.40±3.42	0.136
Posteromedial cortex continuity (yes or no)	3 (37.5)	1 (10.0)	574 (47.3)	0.053
Post-fixation film NSA on the AP view (°)	134.88±69.89	133.18±69.89	129.38±38.67	0.323
Post-fixation lateral angulation (apex anterior or apex posterior)				0.570
Apex anterior	2 (25.0)	4 (40.0)	417 (34.3)	
Apex posterior	2 (25.0)	3 (30.0)	393 (32.4)	
Post-fixation lateral angulation absolute value (°)	5.66±4.75	4.59±4.75	5.62±5.63	0.881
Post-fixation lateral translation (anterior or posterior)				0.920
Apex anterior	1 (12.5)	3 (30.0)	297 (24.5)	
Apex posterior	3 (37.5)	2 (20.0)	331 (27.3)	
Post-fixation lateral translation (mm)	4.45±2.94	2.27±2.94	3.10±4.06	0.666
Implant parameters				
Lag screw placement				0.951
Distal end lateral	2 (25.0)	5 (50.0)	480 (39.5)	
Distal end flush	2 (25.0)	2 (20.0)	348 (28.7)	
Distal end medial	1 (12.5)	2 (20.0)	263 (21.7)	
Lateral lag screw prominence (inferior side) (mm)	2.05±2.56	-0.62±2.56	1.02±2.35	0.075
Lateral lag screw prominence (superior side) (mm)	4.61±3.81	3.05±3.81	3.57±3.03	0.650

Values are presented as mean±standard deviation.
AP: anteroposterior, TIR: traction/internal rotation, NSA: neck shaft angle.

ment of a lag screw showed the most axial and torsional stiffness, resulting in the highest load to failure. This was supported by the results of a computational analysis by Quental et al.[26] which demonstrated that an inferior and deep placement of the screw would provide the greatest resistance to CO in treatment using a proximal femoral nail implant. A review article by Socci et al.[5] discussing recommendations for management of IT fractures noted the importance of proper reduction and minimizing TAD for stability and fixation in treatment with either a sliding hip screw or intramedullary device. Therefore, while the original hypothesis asserted that treatment with an intramedullary nail rather than an extramedullary device would have less impact on the failure rate, multiple studies have emphasized its importance. A retrospective study by John et al.[27)] demonstrated that a high TAD would predispose nails to higher rates of CO. A radiographic review by Stern et al.[28)] reported an association of a high TAD with higher rates of failure for both helical blade and lag screw intramedullary nails. Similarly, the quality of reduction, which can be approximated using intraoperative radiographic parameters such as post-fixation angulation and cortical translation has shown high correlation with failure rates. Turgut et al.[29)] reported that poor reduction, notably varus, was a strong predictor of failure when using the helical blade nail design. Of note, 16/18 of the cases of failure included in this study had an acceptable TAD <25 mm, suggesting that factors other than a TAD greater than 25 mm are predictive of implant failure.

This study has several limitations. First, the retrospective nature presents inherent biases commonly associated with this type of study. However, selection of patients was based on the occurrence of implant failure, thus it is likely that selection bias is minimal. Another challenge was the group of patients who were lost to follow-up, or those who may have experienced failure and presented for follow-up elsewhere, neither of whom were included in the analysis. Second, this analysis only included patients who were treated with intramedullary nail fixation using a single lag screw nail design; therefore, factors associated with each mechanism of failure cannot be predicted in cases where fixation is provided using alternative implants such as a helical blade nail or sliding hip screw. Third, due to the small failure cohort, this study may be underpowered, so that significant differences in demographic and radiographic factors associated with each mechanism of failure cannot be distinguished. Specifically, despite our suspicion that bone quality would be a significant factor in predicting the mechanism of failure, with such a small sample size, it may be that our study is simply underpowered so that the significance of this difference in bone quality cannot be determined. Future study may include multi-center collaboration in order to increase the size of the cohort.

CONCLUSION

As mechanisms of failure, neither migration of the medial lag screw through the femoral head nor screw CO showed an association with identifiable patient demographics, initial fracture reduction, or radiographic implant parameters. As reported in previous biomechanical studies, the main predictive factor for patients in whom early failure might occur via the CT mechanism may still be related to bone quality; however, conduct of larger studies will be required in order to determine whether there is truly a difference in bone quality between the mechanisms of failure.

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CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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