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Short cephalomedullary nail toggle: a closer examination

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Abstract

Objectives: In patients with wide femoral canals, an undersized short nail may not provide adequate stability, leading to toggling of the nail around the distal interlocking screw and subsequent loss of reduction. The purpose of this study was to identify risk factors associated with nail toggle and to examine whether increased nail toggle is associated with increased varus collapse.

Design: Retrospective cohort study.

Setting: Level 1 and level 3 trauma center.

Patients/Participants: Seventy-one patients with intertrochanteric femur fractures treated with short cephalomedullary nails (CMN) from October 2013 to December 2017.

Intervention: Short CMN.

Main Outcome Measurements: Nail toggle and varus collapse were measured on intraoperative and final follow-up radiographs. Risk factors for nail toggle including demographics, fracture classification, quality of reduction, Dorr type, nail/canal diameter ratio, lag screw engaging the lateral cortex, and tip-apex distance (TAD) were recorded.

Results: On multivariate regression analysis, shorter TAD ($P = .005$) and smaller nail/canal ratio ($P < .001$) were associated with increased nail toggle. Seven patients (10%) sustained nail toggle >4 degrees. They had a smaller nail/canal ratio (0.54 vs 0.74, $P < .001$), more commonly Dorr C (57% vs 14%, $P = .025$), lower incidence of lag screw engaging the lateral cortex (29% vs 73%, $P = .026$), shorter TAD (13.4 mm vs 18.5 mm, $P = .042$), and greater varus collapse (6.2 degrees vs 1.3 degrees, $P < .001$) compared to patients with nail toggle < 4 degrees.

Conclusions: Lower percentage nail fill of the canal and shorter TAD are risk factors for increased nail toggle in short CMNs. Increased nail toggle is associated with increased varus collapse.

Level of evidence: Therapeutic Level III

Keywords: canal width, intertrochanteric femur fracture, nail toggle, short cephalomedullary nail, varus collapse

1. Introduction

The use of cephalomedullary nails (CMN) is a validated treatment option for both stable and unstable intertrochanteric femur fractures. They confer the advantage of acting as a lateral buttress for the proximal fragment and have been shown to provide superior outcomes to extramedullary devices for unstable fracture patterns.[1] Despite the overall success of intramedullary nails, there remain several potential treatment complications including screw cutout, nonunion, and peri-implant fracture. Prior studies have identified factors such as tip-apex distance (TAD) and quality of fracture reduction that influence the rate of these complications.[2–7]

There are multiple factors that go into choosing between use of a short or long CMN, including fracture pattern, femoral anatomy, and surgeon preference.[8] Historically, fracture at the tip of the implant was a concern with short nails, but the incidence of this has decreased with modern nail designs.[9,10] Recent studies show no difference in peri-implant fracture rate, complication rate, or reoperation rate between short and long nails.[11–17] In addition, studies have found shorter surgical times and lower costs with the use of short nails.[14–19]

Canal width has been suggested as a factor to consider when deciding between a short and long CMN. In patients with wide femoral canals, an undersized short nail may not provide adequate stability, leading to toggling of the nail around the distal interlocking screw and subsequent loss of reduction.[8,20] To our knowledge, there have been no published studies investigating the risk factors for, or consequences of, short nail toggle after intertrochanteric femur fractures. The purpose of this study was to identify risk factors for nail toggle and to examine whether

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increased nail toggle is associated with increased varus collapse which was chosen as a surrogate for loss of reduction.

2. Patients and methods

Institutional review board approval was obtained for this study. All patients with an intertrochanteric femur fracture treated with a CMN from October 1, 2013 to December 31, 2017 at 2 teaching hospitals: an urban level 1 trauma center and a suburban level 3 trauma center were identified by searching for Current Procedural Terminology code 27245 (treatment of intertrochanteric, pertrochanteric, or subtrochanteric femoral fracture with intramedullary implant). Exclusion criteria were fixation with a long nail (>200 mm), pathological fracture, or less than 12 weeks of radiographic follow up. Patients who were revised before 12 weeks due to significant nail toggle were included in the study.

A total of 492 patients were identified. Patients were excluded for the following reasons: 299 patients underwent fixation with a long nail, 22 patients had a pathologic fracture, and 102 patients had less than 12 weeks of radiographic follow-up, leaving 71 patients for analysis. Demographics, surgical details, and postoperative complications were recorded.

Patients were treated with either the DePuy Synthes TFN-Advanced (TFN-A) (Paoli, Pennsylvania) or Smith and Nephew Trigen InterTAN (Memphis, Tennessee). The TFN-A nails were all 170 mm in length, except for 1 patient with a 200 mm length nail, and all were placed with either a single lag screw or helical blade per surgeon discretion. All InterTAN nails were 180 mm in length and placed with integrated dual screws. All nails were locked distally with a single interlocking screw.

Fractures were classified according to the Orthopaedic Trauma Association/Arbeitsgemeinschaft für Osteosynthesefragen (OTA/AO) fracture classification and grouped as either stable (31A1.2-3) or unstable (31A2.2-3, 31A3.1-3). TAD was measured on the intraoperative anteroposterior (AP) and lateral views and the sum of the distance combined using the lag screw width to control for magnification as previously described.[4,21] We recorded whether or not the end of the lag screw/helical blade engaged the lateral cortex.

Quality of fracture reduction was graded as good, acceptable, or poor based on the modified Baumgaertner criteria.[4,22] Good reductions were defined as having <4 mm of fragment displacement, a neutral or slightly valgus neck-shaft angle (NSA) (<5 degrees of varus or <20 degrees of valgus), and <20 degrees angulation on the lateral x-ray. Acceptable reductions met the criteria for alignment or displacement, but not both. Poor reductions met neither of the criteria. Grading of reductions was done in a blinded fashion by 3 fellowship-trained, orthopedic trauma surgeons (JH, WMH, and STG). There was excellent interobserver reliability with an intraclass correlation coefficient of 0.76.

Canal morphology was classified according to the Dorr classification (A, B, or C) based on AP and lateral radiographs. Type A femurs have thick cortices and a narrow diaphyseal canal (champagne flute shape). Type B femurs exhibit some medial and posterior cortex bone loss and a wider canal. Type C femurs have significant cortical bone loss particularly medially and posteriorly and a wide, capacious canal (stovepipe shape).[23] The percentage nail fill of the intramedullary canal was determined by measuring the ratio between the nail diameter and canal width at the distal aspect of the nail on AP and lateral views (nail/canal ratio) (Fig. 1).

In order to determine nail toggle, the angle between the axis of the femoral canal and the axis of the nail was measured. Nail toggle was defined as the change in this angle from the intraoperative AP to the final follow-up AP radiograph (Fig. 2). This was measured twice by 2 senior orthopedic residents at 3 months apart (AVG and KB). The interrater and intrarater reliability were both excellent, with an intraclass correlation coefficient of 0.95 for interrater reliability and correlation coefficient of 0.83 for intrarater reliability.

Varus collapse was measured as a surrogate for loss of reduction. It was measured by calculating the change in the femoral NSA from the intraoperative AP fluoroscopy to the final follow-up AP radiograph. In order to control for differences in rotation between radiographs, the implant NSA was measured

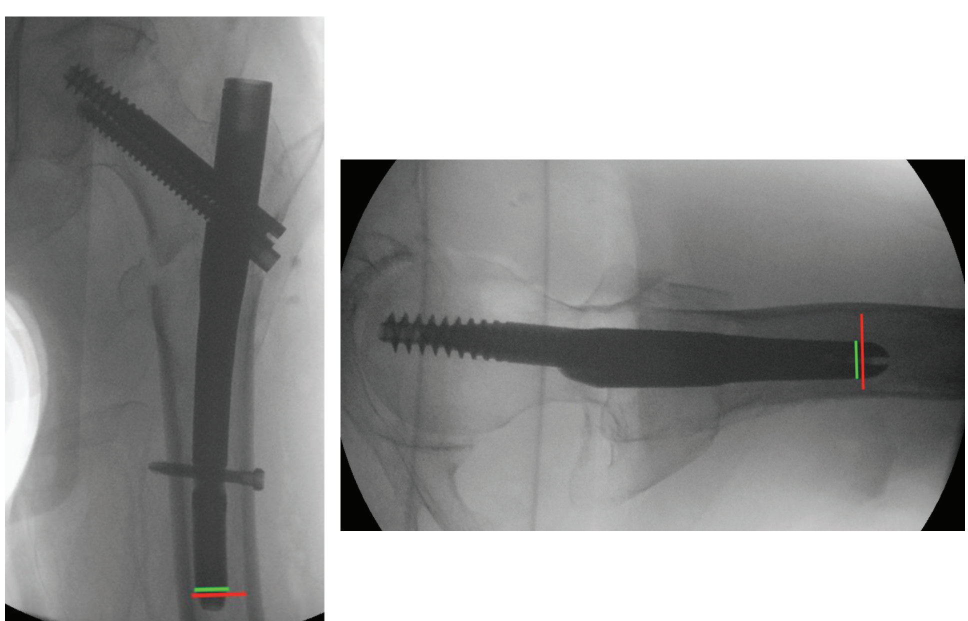

Figure 1. Example of how nail/canal ratio was measured on intraoperative AP and lateral radiographs. Green line = nail diameter. Red line = femoral canal diameter.

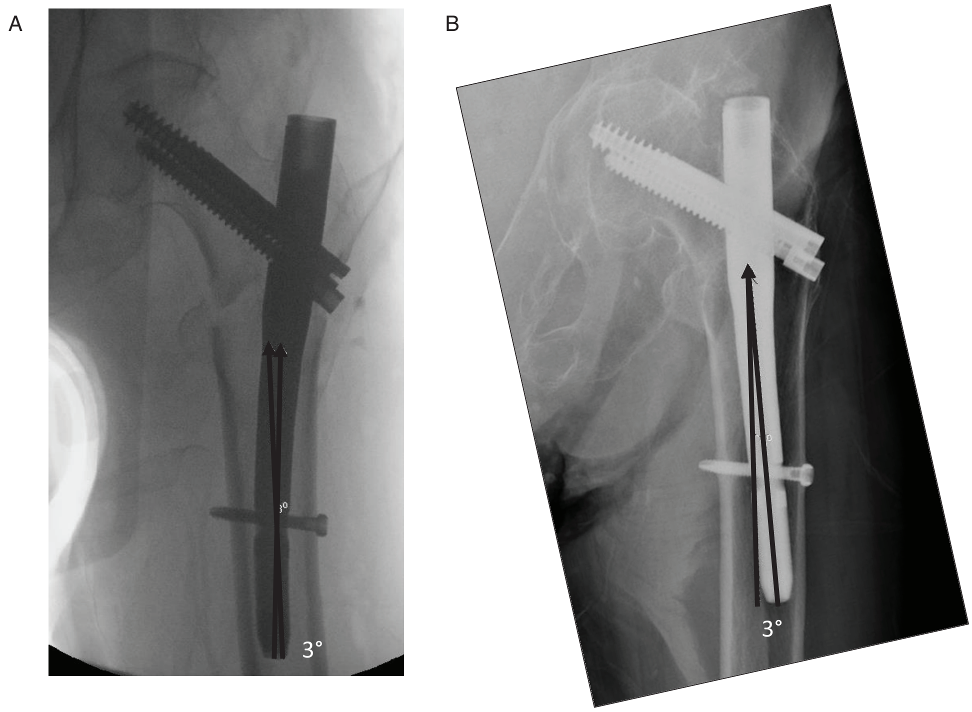

Figure 2. Example of how nail toggle was measured. (A) Intraoperative AP shows nail in 3 degrees of valgus relative to the femoral axis. (B) Final AP radiograph, over 4 years post-op, shows nail in 3 degrees of varus relative to the femoral axis. Nail toggle is 6 degrees of varus.

and the following correction formula was applied as previously described (Actual NSA = Actual Nail Angle × Measured NSA/Measured Nail Angle).[24]

Univariate regression analysis was performed to see which risk factors were associated with increased nail toggle. Multivariate regression analysis was then performed to assess the contribution of each factor, controlling for all other factors. All variables with $P < .1$ in the univariate analysis were included in the multivariate analysis.

Patients with nail toggle <4 degrees were compared to those with nail toggle ≥4 degrees using univariate 2-group analysis. For continuous variables, univariate 2-group comparisons were performed using independent 2-sample *t* tests if the variable was normally distributed, and Wilcoxon rank sum tests if the variable was not normally distributed. For categorical variables, univariate 2-group comparisons were performed using chi-square tests when expected cell counts were >5, and Fisher exact tests when expected cell counts were <5. Statistical significance was set at $P < .05$. All analyses were performed using SAS 9.4 (SAS Institute Inc, Cary, North Carolina).

3. Results

Demographics and radiographic measurements are summarized in Table 1. The mean age of the 71 patients in this study was 80.1 years old (range 53–99 years). All patients had a low-energy mechanism of injury. The mean radiographic follow-up was 55.2 weeks (range 1–244 weeks). All patients had at least 12 weeks of radiographic follow-up, except for 1 patient who was revised on postoperative day 9 due to loss of reduction/significant nail toggle and inability to ambulate due to severe pain.

Fifty-three patients (75%) were classified as having a stable fracture pattern (OTA/AO 31A1.2–3) and 18 (25%) had unstable fracture patterns (31A2.2-3, 31A3.1-3). Quality of reduction was graded as good 57 (80%), acceptable 13 (18%), or poor 1 (1%). The end of the lag screw/helical blade engaged the lateral cortex in 49 patients (69%). Average TAD was 18.0 mm (range 0–33.8 mm).

Nail widths used ranged from 10 to 13 mm. One (1%) femoral canal was classified as Dorr A, 57 (80%) as Dorr B, and 13 (18%) as Dorr C. The mean nail/canal ratio was 0.80 (range 0.47–0.98) on the AP view, 0.63 (range 0.37–0.94) on the lateral view, and 0.72 (range 0.46–0.96), averaged between the AP and lateral views. Dorr C femurs were associated with a smaller nail/canal ratio ($P < .001$). The average nail toggle was 1.1 degrees of varus (range 1.5 degrees of valgus to 8.5 degrees of varus).

Univariate regression analysis results are summarized in Table 2. Dorr type C ($P = .006$), lag screw not engaging the lateral cortex ($P = .033$), shorter TAD ($P = .049$), and smaller nail/canal ratio ($P < .001$), were found to be associated with increased nail toggle. Multivariate regression analysis was then performed on all risk factors with $P < .1$ in the univariate analysis. On multivariate analysis, shorter TAD ($P = .005$) and smaller nail/canal ratio ($P < .001$) were associated with increased nail toggle as seen in Table 3.

Increased nail toggle was found to be associated with increased varus collapse ($P < .001$), and there was a trend for an association with reoperation ($P = .065$) on univariate regression analysis. There was a total of 7 reoperations in the cohort (10%). Reasons for reoperation included significant loss of reduction (1), nonunion (1), blade cut-out with nonunion (2), blade cut-out with union (1), and peri-implant fracture (2). In the 3 patients who sustained blade cut-out, the TAD ranged from 13.7 to 19.3 mm. There was an additional patient with a peri-implant fracture who died prior to undergoing revision.

Patients who sustained ≥4 degrees of nail toggle were compared to patients with <4 degrees of nail toggle as seen in Table 4. Seven patients (10%) sustained ≥4 degrees of nail toggle from the intraoperative AP fluoroscopy to the final follow-up AP

Table 1

Demographics and radiographic measurements.

Variable	Mean (SD) or No. (%)
Age (y)	80.1 (12.1)
Sex	
Male	25 (35%)
Female	46 (65%)
Height (m)	1.64 (0.12)
Weight (kg)	66.5 (18.1)
BMI	24.4 (5.1)
ASA	
2	6 (8%)
3	49 (69%)
4	16 (23%)
Laterality	
Right	34 (48%)
Left	37 (52%)
OTA/AO Fracture classification	
Stable	53 (75%)
Unstable	18 (25%)
Dorr type	
A	1 (1%)
B	57 (80%)
C	13 (18%)
Nail company	
DePuy Synthes	25 (35%)
Smith and Nephew	46 (65%)
Type of lag screw	
Single lag screw	7 (10%)
Helical blade	18 (25%)
Integrated dual screw	46 (65%)
Nail width	
10 mm	23 (32%)
11 mm	10 (14%)
11.5 mm	30 (42%)
12 mm	3 (4%)
13 mm	5 (7%)
Quality of reduction	
Good	57 (80%)
Acceptable	13 (18%)
Poor	1 (1%)
Lag screw engages lateral cortex	
Yes	49 (69%)
No	22 (31%)
Tip apex distance (mm)	18.0 (6.4)
Nail/canal ratio (AP)	0.80 (0.12)
Nail/canal ratio (lateral)	0.63 (0.13)
Nail/canal ratio (AP+lateral)	0.72 (0.12)

ASA = American Society of Anesthesiologists, BMI = body mass index, OTA/AO = Orthopaedic Trauma Association/Arbeitsgemeinschaft für Osteosynthesefragen, SD = standard deviation.

radiograph. These patients had a smaller nail/canal ratio (0.54 [range 0.46–0.60] vs 0.74 [range 0.52–0.96], $P < .001$), more commonly Dorr C morphology (57% vs 14%, $P = .025$), lower incidence of the lag screw engaging the lateral cortex (29% vs 73%, $P = .026$), and shorter TAD (13.4 mm vs 18.5 mm, $P = .042$). They also had greater varus collapse (6.2 degrees vs 1.3 degrees, $P < .001$). There were 2 reoperations in this group (29% vs 8%, $P = .138$).

Figures 3 and 4 show 2 examples where an undersized short nail did not adequately maintain the reduction leading to failure and reoperation. One of the reoperations was for an 87-year-old male who sustained nail toggle of 4.5 degrees of varus with associated loss of reduction and 5 degrees of varus collapse from the intraoperative AP fluoroscopy to the AP radiograph immediately taken after transfer from the operating room to the postanesthesia care unit (Fig. 3). An 11 mm nail was used yielding a nail/canal ratio of 0.49. The patient was unable to ambulate due to severe pain and underwent revision to a long cephalomedullary nail on postoperative day 9.

The other reoperation was for an active 59-year-old male who sustained a symptomatic nonunion with limb-length discrepancy. The nail toggled into 5 degrees of varus from the intraoperative AP fluoroscopy to the final follow-up AP radiograph with associated loss of reduction and 4 degrees of varus collapse (Fig. 4). A 10 mm nail was used, and the nail/canal ratio was 0.6. Computed tomography scan confirmed a hypertrophic nonunion and he elected to undergo revision intertrochanteric valgus osteotomy 10 months postoperatively.

Both patients had low percentage nail fill of the canal, and, in addition, the end of the lag screw did not engage the lateral cortex in either patient, which may have also contributed to the lack of construct stability. Notably, both patients had good reductions as rated by all 3 graders and were classified as having Dorr B femurs.

Table 2

Univariate regression analysis of risk factors for increased nail toggle.

Risk factor	*P* value
Age	.170
Sex	.976
Height	.204
Weight	.240
BMI	.664
ASA	.659
OTA/AO fracture classification	.383
Nail company	.166
Type of lag screw	.335
Nail width	.617
Quality of reduction	.087
Dorr type	**.006**
Nail/canal ratio	<**.001**
Lag screw does not engage the lateral cortex	**.033**
Tip-apex distance	**.049**

ASA = American Society of Anesthesiologists, BMI = body mass index, OTA/AO = Orthopaedic Trauma Association/Arbeitsgemeinschaft für Osteosynthesefragen.

4. Discussion

To our knowledge, this is the first study to analyze the phenomenon of short CMN toggle in intertrochanteric femur fractures. We found that nail toggle can be measured using a picture archiving and communication system with high inter- and intra-observer reliability. Nail toggle primarily occurred in varus because the distal aspect of the nail typically rides along the

Table 3

Multivariate regression analysis of risk factors for increased nail toggle.

Risk factor	*P* value
Quality of reduction	.155
Dorr type	.843
Nail/canal ratio	<**.001**
Lag screw does not engage the lateral cortex	.413
Tip-apex distance	**.005**

All risk factors with $P < .1$ in the univariate regression analysis were included in the multivariate analysis.

Table 4

Univariate 2 group comparisons between patients who sustained <4 degrees of nail toggle and those who sustained ≥4 degrees of nail toggle.

Variable	< 4° nail toggle (n = 64) Mean (SD) or No. (%)	≥ 4° nail toggle (n = 7) Mean (SD) or No. (%)	*P* value
Age (y)	79.8 (12.2)	82.6 (11.7)	.524
Sex			
Male	22 (34%)	3 (43%)	.691
Female	42 (66%)	4 (57%)	
Height	1.64 (0.12)	1.70 (0.13)	.228
Weight	65.5 (17.6)	75.1 (21.9)	.261
BMI	24.3 (5.1)	25.7 (5.6)	.698
ASA			
2	5 (8%)	1 (14%)	.522
3	45 (70%)	4 (57%)	
4	14 (22%)	2 (29%)	
Laterality			
Right	31 (48%)	3 (43%)	1.000
Left	33 (52%)	4 (57%)	
OTA/AO Fracture classification			
Stable	49 (77%)	4 (57%)	.359
Unstable	15 (23%)	3 (43%)	
Dorr Type			
A	1 (2%)	0 (0%)	**.025**
B	54 (84%)	3 (43%)	
C	9 (14%)	4 (57%)	
Type of screw/blade			
Single lag screw	6 (9%)	1 (14%)	.354
Helical blade	15 (23%)	3 (43%)	
Integrated lag screw	43 (67%)	3 (43%)	
Nail width (mm)	11.1 (0.89)	10.9 (0.63)	.357
Quality of reduction			
Good	53 (83%)	4 (57%)	.201
Acceptable	10 (17%)	3 (43%)	
Poor	1 (1%)	0 (0%)	
Lag screw engages lateral cortex			
Yes	47 (73%)	2 (29%)	**.026**
No	17 (27%)	5 (71%)	
Nail/canal ratio	0.74 (0.11)	0.54 (0.05)	**<.001**
Tip apex distance (mm)	18.5 (6.42)	13.4 (4.65)	**.042**
Varus collapse (deg)	1.3 (3.38)	6.24 (2.09)	**<.001**
Reoperation			
Yes	5 (8%)	2 (29%)	.138
No	59 (92%)	5 (71%)	
Nonunion			
Yes	2 (3%)	1 (14%)	.271
No	62 (97%)	6 (86%)	
Lag screw cutout			
Yes	3 (5%)	0 (0%)	1.000
No	61 (95%)	7 (100%)	
Periprosthetic Fracture			
Yes	3 (5%)	0 (0%)	1.000
No	61 (95%)	7 (100%)	

For continuous variables, univariate 2-group comparisons were performed using independent 2-sample *t* tests if the variable was normally distributed, and Wilcoxon rank sum tests if the variable was not normally distributed. For categorical variables, univariate 2-group comparisons were performed using chi-square tests when expected cell counts were >5, and Fisher exact tests when expected cell counts were <5.

ASA = American Society of Anesthesiologists, BMI = body mass index, OTA/AO = Orthopaedic Trauma Association/Arbeitsgemeinschaft für Osteosynthesefragen, SD = standard deviation.

medial cortex due to the location of the entry point and nail geometry. Thus, the distal aspect of the nail can drift laterally into varus with loading of the nail.[8,20]

We found that increased nail toggle was associated with a smaller nail/canal ratio. As less of the nail fills the canal, increased migration of the nail tip into varus is allowed. None of the patients with a nail/canal ratio >0.74 on the AP view or >0.6 averaged between the AP and lateral views, sustained >4 degrees of nail toggle. Notably, Dorr C femoral canals were found to be associated with increased nail toggle on univariate analysis but not on multivariate analysis. This finding was likely not significant on multivariate analysis due to a smaller nail/canal ratio being the primary reason for increased nail toggle in these patients.

Previous studies have found an increased nail/canal ratio to be associated with a decreased risk of nonunion in femoral and tibial shaft fractures which they attributed to the increased stability provided by increased nail fill of the canal.[25,26] Similarly in our study, we believe that increased nail fill of the canal improves the stability of the construct and thus decreases the risk of nail toggle and loss of reduction. A potential concern with increased nail fill is peri-implant fracture at the distal tip of the nail, although we did not encounter this in our study as all the peri-implant fractures occurred in the distal supracondylar region. Another potential concern with increased nail fill is thigh pain, which we were not able to study.

Engagement of the lateral cortex by the end of the lag screw/helical blade was found to be protective against nail toggle on univariate analysis but it was not significant on multivariate analysis. If the end of the lag screw/helical blade engages an intact lateral cortex, this provides an additional point of fixation, which may help prevent nail toggle. The importance of the lag screw engaging the lateral cortex was seen in a study by Abram et al, in which the end of the lag screw being short of the lateral cortex was found to be the most significant predictor of nail failure.[27]

Shorter TAD was also associated with increased nail toggle, which we did not initially expect to find. Prior studies have shown that a shorter TAD is associated with decreased screw cutout and risk of failure.[4,28,29] However, with a shorter TAD, the construct is better secured in the femoral head, which may make it more likely for the entire construct to toggle in the canal distally rather than cut-out of the femoral head proximally. Notably, most patients in our study had a TAD <25 mm and we still recommend aiming for this to decrease the risk of screw cutout.

Another possible contributor to nail toggle is the size and shape of the distal interlocking screw hole. In the short lengths of the TFN-A and InterTAN, the single distal screw hole is oblong and thus does not provide tight circumferential fit around the screw even when placed in static mode. This allows the nail to toggle around the distal interlocking screw in the coronal plane until either the bottom of the screw hole hits the interlocking screw or the nail tip hits the lateral cortex (Fig. 5). In long lengths of the TFN-A and InterTAN at least one of the distal interlocking holes is round providing tight fit around the interlocking screw and thus theoretically preventing coronal toggle of the nail (Fig. 6).

The importance of the size and shape of the distal interlocking screw hole in preventing nail toggle was demonstrated in a recent biomechanical sawbones study that studied short nail failure in femurs with wide medullary canals.[30] The authors of the study found that short 11 mm nails placed into 18 mm femoral canals toggled into varus with loading. When long nails were tested, they were not found to toggle despite having the same nail-canal mismatch as the short nails. When the distal interlocking screw from the round hole was removed in long nails leaving only the distal interlocking screw in the oblong hole, the long nails were found to move easily in the canal similar to the short nails. In addition, when an additional screw was inserted in the oblong

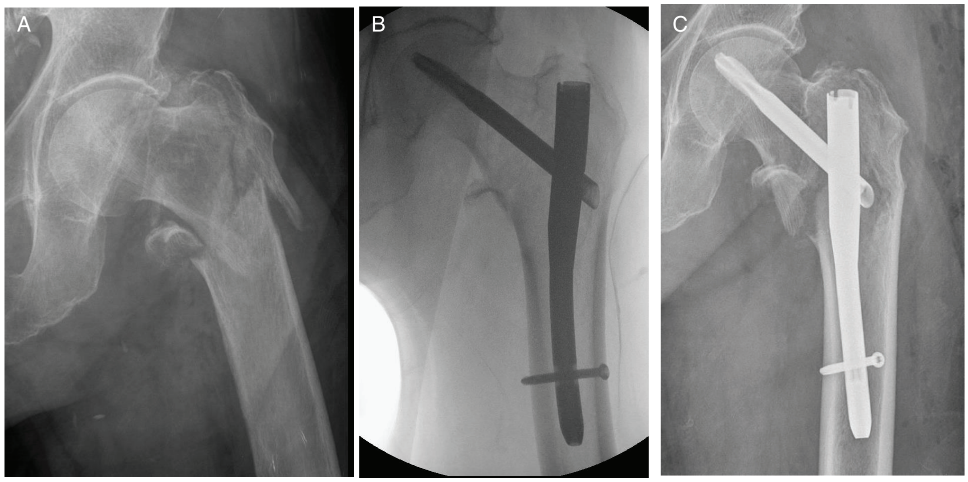

Figure 3. (A) Injury film, (B) Intraoperative AP fluoroscopy, (C) post-anesthesia care unit AP radiograph.

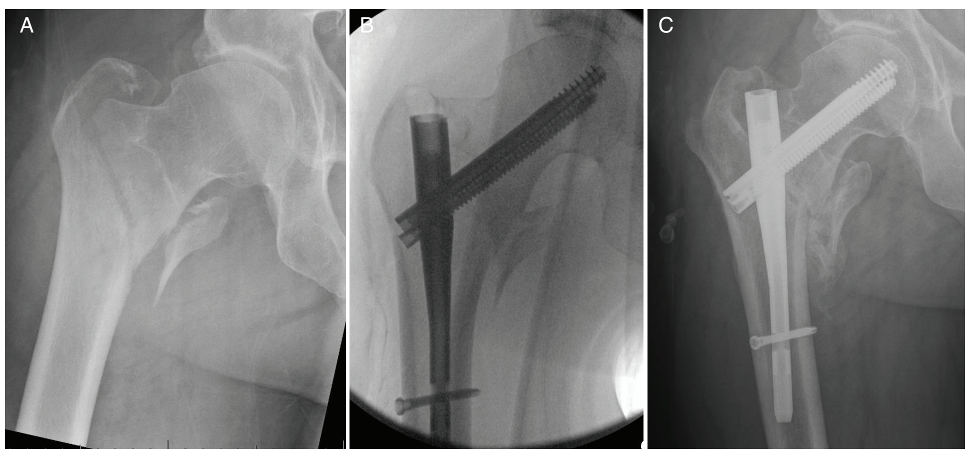

Figure 4. (A) Injury film, (B) Intraoperative AP fluoroscopy (C) AP radiograph, 15 weeks post-op.

Figure 5. These images show how the oblong shaped distal interlocking hole allows the nail to rotate around the distal interlocking screw a significant amount in the coronal plane until the bottom of the screw hole contacts the interlocking screw.

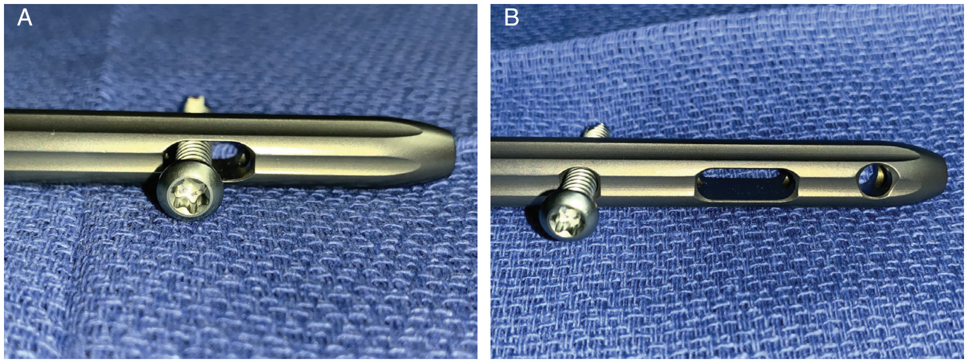

Figure 6. (A) Oblong distal interlocking hole in short TFN-A, which allows for significant toggling of the nail around the screw before the bottom of the screw hole hits the screw, (B) Round distal interlocking hole in long TFN-A, which provides tight circumferential fit around the screw, preventing significant toggling of the nail around the screw.

distal interlocking hole of the short nails to provide tight fit, the end of the nail was able to maintain its position in the canal with loading.

Patients in our cohort with increased nail toggle had increased varus collapse. This occurs because, as the nail toggles into varus, the firmly attached head/neck fragment can lose reduction and collapse into varus despite an excellent initial reduction as seen in our 2 failures. This is important, as previous studies have shown that increased varus collapse is associated with worse functional outcomes.[31] There was a trend towards higher reoperation rate in patients with increased nail toggle, although this was not statistically significant.

This study has several limitations. This was a retrospective study, and there may be confounding variables which were not examined. Nail length was determined by surgeon preference and thus there may be selection bias. In addition to toggle in the coronal plane, the nail can rotate around the distal interlocking screw in the sagittal plane. This study was likely underpowered to detect an association between nail toggle and reoperation rate due to the low number of total reoperations in our study. Future studies should look at a larger sample size and also investigate the association between increased nail toggle and functional and patient reported outcomes.

5. Conclusions

In patients with wide femoral canals, an undersized short CMN may not provide adequate stability, leading to toggling of the nail around the distal interlocking screw and subsequent loss of reduction. Lower percentage nail fill of the canal and shorter TAD are risk factors for increased nail toggle. Increased nail toggle was found to be associated with increased varus collapse. Potential solutions to prevent short nail toggle and associated loss of reduction in patients with wide femoral canals are to maximize construct stability by choosing a nail width that sufficiently fills the canal or to use a long nail.

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