Prospective, Randomized Evaluation of Optimal Implant Position of Gamma3 and PFNA for the Treatment of AO/OTA 31-A2 Fractures: Is Central Positioning Always the Best?

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Background/Purpose: Parker et al have reported on lag screw positioning during dynamic hip screw (DHS) implantation in the treatment of proximal femur fractures. They found significant differences in screw cut-out when positioned superior on the AP radiograph and posterior on the lateral. Our goal was to determine ideal positioning of prospectively randomized screw or helical blade placement during intramedullary nail fixation of AO/OTA 31-A2 fractures, in order to minimize the reoperation rate.

Methods: A prospective, randomized controlled study was initiated for the treatment of AO/OTA 31-A2 fractures with either a third-generation Gamma nail (Gamma3, Stryker) or proximal femoral nail antirotation (PFNA, Synthes). 200 patients from 2007 to 2010 with an average age of 81.1 years were randomized in a 1:1 ratio. Intraoperative AP and lateral radiographs were reviewed to calculate Parker's ratio and tip-apex-distance (TAD). Incidences of reoperation were categorized based on Parker's ratios and TAD, and logistic regression and receiver operator characteristic (ROC) curves were used for predictive modeling of reoperation. Significant values were set at $P < 0.05$.

Results: 177 patients (Gamma3: 91; PFNA: 86) met all study criteria. Both implants showed a predilection for a central position on the AP radiograph with 83/91 (91.2%) for Gamma3 and 81/86 (94.2%) for the PFNA group. In the Gamma3 group, there were significantly higher reoperation rates for Parker's ratio values less than 34 (inferior position) on the AP radiograph compared to values between 34 and 66 (central position; $P = 0.035$); this was not seen in the PFNA group. There was a significant association between implant type and reoperation, with Gamma3 having 11/91 (12.1%) reoperations and PFNA having 0/86 (0%) reoperations ($P = 0.001$). Predictive modeling of reoperation for Gamma3 was maximized when both TAD and Parker's ratios from AP radiography were incorporated into the model. With Parker's ratios subdivided into thirds (0-33, 34-66, 67-100), TAD categorized as <20 and ≥20 generated an ROC curve with area under the curve (AUC) of 0.700 ($P = 0.032$) while TAD categorized as ≤25 and >25 generated an ROC curve with AUC of 0.612 ($P = 0.226$). Although a higher risk for reoperation in the Gamma3 group was evident in cases with a lower-third Parker's ratio, these criteria were not predictive of cut-out. There were no significant differences between the Gamma3 and PFNA in terms of Parker's ratios and TAD.

Conclusion: For the Gamma3 device, central position on AP radiographs resulted in significantly fewer reoperations compared to an inferior position. ROC analysis indicates that the combination of Parker's ratio and TAD is a significant predictor of reoperation rate in Gamma3. It also indicates that TAD <20 mm is a better predictor of reoperation compared to 25 mm. The same criteria predicted reoperation, but not cut-out. If using a Gamma3

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system it is important to achieve central positioning of the lag screw on the AP radiograph and TAD <20 mm to minimize the risk of reoperation. In this study the PFNA nail did not fail and was more tolerant of outliers of position.

Rates for reoperation and cut-out subdivided by Parker's ratio for Gamma3 and PFNA: Inferior positioning on AP radiography had a significantly higher reoperation rate. P values, odds ratios, and 95% confidence intervals (CIs) could not be calculated for PFNA because the absence of complications resulted in indistinguishable groups.

Rates for Reoperation and Cut-Out Subdivided by Implant Type and Parker's Ratio

Implant Type	X-Ray View	Outcome	Parker's Ratio			*P* Value*	Odds Ratio*	95% CI*
			<33	34-66	67-100			
Gamma3	AP	Reoperation n/total (%)	3/8 (37.5)	8/83 (9.6)	0/0 (0)	0.035	5.63	1.13-28.04
		Cut-out n/total (%)	1/8 (12.5)	4/83 (4.8)	0/0 (0)	0.382	2.82	0.28-28.14
	Lateral	Reoperation n/total (%)	0/1 (0)	11/85 (12.9)	0/5 (0)	0.536	0.395	0.02-7.52
		Cut-out n/total (%)	0/1 (0)	5/85 (5.9)	0/5 (0)	0.683	0.424	0.01-25.92
PFNA	AP	Reoperation n/total (%)	0/6 (0)	0/80 (0)	0/0 (0)	N/A	N/A	N/A
		Cut-out n/total (%)	0/6 (0)	0/80 (0)	0/0 (0)	N/A	N/A	N/A
	Lateral	Reoperation n/total (%)	0/0 (0)	0/81 (0)	0/5 (0)	N/A	N/A	N/A
		Cut-out n/total (%)	0/0 (0)	0/81 (0)	0/5 (0)	N/A	N/A	N/A

Gamma3 = third-generation Gamma nail, PFNA = proximal femoral nail antirotation, N/A = not available. *Calculated using binary logistic regression.

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Incidence, Magnitude, and Predictors of Shortening in Young Femoral Neck Fractures

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Purpose: Fracture shortening following internal fixation of nongeriatric femoral neck fractures remains poorly described. Recent evidence suggests femoral neck fracture shortening of >5 mm is associated with clinically significant decreases in functional outcome. The purpose of this study is to describe the incidence and magnitude of shortening following internal fixation of young adult femoral neck fractures. Secondary objectives are to identify variables associated with femoral neck shortening. We hypothesized that a small magnitude of fracture shortening would be common in this population, but severe shortening would be relatively rare.

Methods: Young femoral neck fracture patients (ages <60 years) from 2003-2013 were identified from our prospective trauma database. Only subjects treated with cannulated screws or a sliding hip screw (SHS) were included. Patient demographics and operative data were obtained from the prospective database and retrospectively from the chart when necessary. Femoral neck shortening was measured radiographically along the long axis of the neck. All measurements were adjusted for magnification. Univariate analysis was performed to identify potential predictors of shortening, followed by a multivariable regression model to independently adjust for significant variables.

Results: 65 patients with a median age of 51 years (interquartile range [IQR]: 43-56 years) were included. 71% were male and 33% of injuries were from high-energy mechanisms. 75% of the fractures were displaced. The distribution of the fractures within the Pauwel classification was 6% Type I, 58% Type II, and 36% Type III. A closed reduction was performed in 85% of the cases. The median amount of radiographic femoral neck shortening was 6 mm (IQR: 0-12 mm) at a median of 222 days postfixation (IQR: 101-399 days). 54% of patients had ^{3}5 mm of femoral neck shortening (22% between ^{3}5 mm and <10 mm; 32% ^{3}10 mm). Initially displaced fractures shortened more than undisplaced fractures (mean 8.1 mm vs. 2.2mm, $P < 0.001$), and fractures treated with a SHS + derotation screw shortened more than fractures fixed with cannulated screws alone (10.7 mm vs. 5.5 mm, $P = 0.03$). There was no association between fixation type used and fracture displacement, Pauwel angle, Pauwel classification, Garden classification, or level of fracture. Regression analysis confirmed the independent associations of initial fracture displacement and fixation type on femoral neck shortening ($P = 0.001$). When adjusting for initial fracture displacement, fractures treated with a SHS + derotation screw shortened an average of 2.3 mm more than fractures treated with screws alone ($P = 0.03$).

Conclusion: There was a 54% incidence of femoral neck shortening ^{3}5 mm in our young femoral neck fracture population. Furthermore, 32% of the entire cohort experienced severe shortening >1 cm. Although the clinical significance of this shortening is unknown in our series, an association between ^{3}5 mm of shortening and poor functional outcomes

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appears to be emerging in the literature. Finally, irrespective of fracture displacement, fixation with a SHS + derotation screw was associated with more shortening than fixation with screws alone. This adds further controversy to the debate of the optimum fixation method for young femoral neck fractures.

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Cephalomedullary Nail Fixation of Intertrochanteric Fractures: Are Two Proximal Screws Better than One?

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Purpose: This study was conducted to analyze radiographic changes in intertrochanteric fracture alignment after treatment with either a one or a two (integrated)-screw cephalomedullary nail construct.

Methods: 1004 OTA 31-A, 31-B2.1 fractures (1002 patients) treated with either a single-screw cephalomedullary nail (Gamma 3, Stryker), or a two integrated screw cephalomedullary nail (InterTAN, Smith & Nephew) between February 1, 2005 and June 30, 2013 were identified at our institution and reviewed retrospectively. Patients younger than 50 years, follow-up (f/u) less than 3 months, a tip-apex distance >25 mm, inaccurate lag screw placement, pathologic fractures, and revisions were excluded. Fracture stability was based on the Evans classification. Radiographic review included: fracture pattern (stable vs. unstable), postoperative (postop) fracture reduction, differences in the neck shaft angle (NSA), and femoral neck shortening (FNS) at 3, 6, and 12 months postop. Measurements of implant size, NSA, and FNS were normalized using known lag screw dimensions that were digitally corrected for magnification. Rotational discrepancies between radiographs were controlled using a ratio of known to measured dimensions. NSA and FNS were compared at each time interval for all fractures, to measure changes occurring with each device. The Mann-Whitney *U* test was used for statistical analysis.

Results: 372 patients died and 219 were lost to f/u, leaving 413 patients (413 fractures) with more than 3 months f/u. Mean age was 76 years (range, 51-103 years). 67% were female. Of 413 fractures, 130 were treated with a single-screw device (79 stable, 51 unstable), and 283 with a two integrated screw device (155 stable, 128 unstable). At 6-month f/u, there were 64 fractures treated with the single-screw device (33 stable, 31 unstable) and 107 with the two integrated screw device (51 stable, 56 unstable). At 12-month f/u there were 54 fractures treated with the single-screw device (32 stable, 22 unstable) and 54 with the two integrated screw device (23 stable, 31 unstable). Table 1 illustrates the changes between postop and the 12-months f/u films.

Table 1	NSA Changes at 12-Month f/u (degrees)		Shortening (FNS) at 12-Month f/u (mm)	
	Single	Two Integrated	Single	Two Integrated
All Fractures	4.56	1.81*	5.10 (0-13.36)	2.36 (0-7.84)*
Stable	4.19	1.24*	4.91 (0-11.62)	2.35 (0-6.50)*
Unstable	5.08	2.24*	5.37 (0-13.36)	2.38 (0-7.84)*

*Differences statistically significant ($P < 0.001$)

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The single-screw device resulted in 2.5 times greater varus collapse (NSA) and 2 times more femoral neck shortening over 1 year than the two integrated screw device, regardless of fracture stability ($P < 0.001$). NSA and FNS changes were greater for both devices in an unstable fracture pattern as compared to stable fractures, but significantly less movement occurred with the two integrated screw device.

Conclusion: A cephalomedullary nail with two integrated proximal screws appears to maintain initial fracture reduction and subsequent position over time (FNS), with less varus collapse (NSA) than a cephalomedullary nail with a single proximal screw. This was true for both stable and unstable fractures. These data indicate that the two integrated screw device resulted in fewer intertrochanteric malunions, which may be clinically important when considering long-term functional outcomes in patients with these fractures.

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Management and Outcomes of Femoral Head Fractures

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Purpose: The purpose of this study was to evaluate the incidence, treatment, and outcomes of femoral head fractures at a high-volume academic Level I trauma center. Previous studies have reported small series of patients with these injuries but information from larger study populations is lacking.

Methods: This study was approved by the IRB at our institution. A retrospective chart review of a prospectively collected trauma database was performed at a single regional Level I trauma center between January 1, 2000 and January 1, 2013. All AO/OTA 31C fractures of the femoral head were identified for review. All fractures were classified by the Pipkin system. Patients with clinical and radiographic follow-up greater than 6 months were included in our evaluation. Patients treated operatively and nonoperatively were included. For patients treated operatively, approach and fixation techniques were recorded. Follow-up patient radiographs were evaluated for failure of fixation (if performed), development of heterotopic ossification, and the development of osteonecrosis or posttraumatic degenerative joint disease at latest follow-up.

Results: We identified 164 fractures in 163 patients. 17 patients were excluded because of incomplete records or radiographs, leaving 147 fractures available for review. The overall distribution in classification was as follows: Pipkin I: 40 (27.2%), II: 62 (42.2%), III: 7 (4.8%), IV: 23 (15.6%); 15 (10.2%) fractures did not fit within the Pipkin classification system. 78 patients (53.4%) were treated with open reduction and internal fixation (ORIF), 37 (25.3%) with fragment excision, 28 (19.2%) patients were treated nonoperatively, and 3 (2%) with hemiarthroplasty. An anterior approach, rectus tenotomy and mini-fragment screws were used in the majority of patients treated with ORIF. 69 fractures in 68 patients had clinical and radiographic follow-up greater than 6 months (mean follow-up 12.4 months). 62 fractures (89.9%) proceeded to union without radiographic signs of failure. All patients were full weight bearing by 3 months. All Pipkin III fractures failed operative fixation. At last follow-up, 6 patients developed radiographic signs of osteonecrosis, and 7 patients went on to hip arthroplasty. Heterotopic ossification developed in 28 (40.6%) patients. Classification was Brooker I in the majority of patients (60.1%).

Conclusion: Fractures of the femoral head are rare injuries. Over a 13-year period, 147 fractures were treated at our institution. The majority of these fractures can be reliably treated with ORIF using mini-fragment screws through an anterior approach. If fragment fixation is not possible, excision can be performed. Pipkin III fractures represent severe injuries that may not be amenable to successful fixation strategies. Nonbridging heterotopic ossification is

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common following operative intervention. Few patients progress to osteonecrosis or joint degeneration that requires later arthroplasty.

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The Clinical Study of the Treatment of Femoral Shaft Nonunions After Nailing with Augmentation Plating Versus Exchange Nailing

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Purpose: The purpose of this study was to compare the results between augmentation plating versus exchange nailing for femoral shaft nonunion after nailing. We hypothesized that augmentation plating group would have a similar clinical results versus exchange nailing.

Methods: From May 2003 to June 2011, 104 cases of femoral shaft nonunions after nailing were treated. 83 patients were treated with augmentation plating leaving the nail in situ and autogenous bone grafting. 21 patients were treated with exchange nailing without autogenous bone grafting. The main outcome measures included operation time, volume of intraoperative blood loss, volume of intraoperative autogenous blood refused, volume of postoperative drainage, length of hospital stay, cost of hospitalization, and time to radiographic union. The *t'*-test was performed to compare results.

Results: There were no significant differences between the two groups in age, gender, volume of postoperative drainage, and length of hospital stay. There were significant differences in operation time, volume of intraoperative blood loss, volume of intraoperative autogenous blood reinfused, cost of hospitalization, and time to radiographic union (Table).

Conclusion: Augmentation plating leaving the nail in situ with autogenous bone grafting is a better option than exchange nailing for femoral shaft nonunions.

Table. Results of Augmentation Plating Compared With Exchange Nailing

	Augmentation Plating Group	Exchange Nailing Group	*P*
Operation time (min)	99.3 ± 27.8	176.5 ± 46.0	$t' = 7.359$, $P < 0.001$
Volume of blood loss (mL)	494.9 ± 281.3	1157 ± 815.7	$t' = 3.666$, $P = 0.001$
Volume of blood reinfused (mL)	344.6 ± 173.2	665 ± 306.1	$t' = 3.005$, $P = 0.014$
Volume of drainage (mL)	332.0 ± 220.7	315.0 ± 257.1	$t' = -0.305$, $P = 0.761$
Hospital time (day)	13.9 ± 6.1	17.0 ± 5.4	$t' = 1.778$, $P = 0.078$
Cost of hospital (RMB)	28862.5 ± 8547.1	40998.0 ± 14068.3	$t' = 4.083$, $P < 0.001$
Union time (month)	5.2 ± 2.8	8.5 ± 5.5	$t' = 3.175$, $P = 0.002$

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The Results of a Systematic Approach to Exchange Nailing for the Treatment of Aseptic Femoral Nonunions

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Purpose: This study evaluated the effectiveness of a systematic approach to exchange nailing for the treatment of aseptic femoral nonunions previously treated with an intramedullary nail.

Methods: 50 aseptic femoral nonunions in 49 patients who presented with an intramedullary nail in situ an average of 25 months after the initial fracture nailing were evaluated. Our systematic approach includes inserting an exchange nail at least 2 mm larger in diameter than the in situ nail, using a different manufacturer's nail to facilitate placement of interlocking screws in different locations or trajectories or both, static interlocking, correction of any metabolic and endocrine abnormalities, and secondary nail dynamization in cases showing slow progression toward healing. In addition, we do not utilize closed exchange nailing in patients with partial segmental defects of the femur comprising greater than 50% of the cross-sectional cortical contact surface area. The outcome measures were radiographic and clinical evidence of nonunion healing and time to union.

Results: All 50 femoral nonunions (100%) healed following this systematic approach to exchange nailing. The average time to achieve union was 7 months (range, 3-26 months). Fourteen (28%) nonunions healed but had undergone nail dynamization performed between 3 and 9 months following exchange nailing due to concerns about slow progression to healing on radiographs. In 6 patients who had either a subtrochanteric nonunion initially treated with a retrograde nail or a distal femur nonunion initially treated with an anterograde nail, an exchange nail in the opposite direction was utilized to achieve greater stability in the shorter segment. Time to bony union did not vary by patient age ($P = 0.464$), gender ($P = 0.754$), fracture pattern ($P = 0.579$), soft tissues at the time of original injury (closed vs. open) ($P = 0.777$), nonunion location ($P = 0.907$), nonunion type ($P = 0.656$), nonunion duration ($P = 0.852$), history of prior failed dynamization of the in situ nail at presentation ($P = 0.783$), and increase in nail diameter with exchange nailing ($P = 0.649$).

Conclusion: Utilization of our systematic approach of exchange nailing for treatment of aseptic femoral nonunions resulted in a 100% healing rate. The systematic approach includes careful patient selection, increasing nail diameter by at least 2 mm, selecting a different nail manufacturer for the exchange nail, static interlocking, dynamization after 3 months if necessary, and screening for and treating metabolic, endocrine, and other medical problems.

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Working Length and Proximal Screw Constructs in Plate Osteosynthesis of Distal Femur Fractures

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Purpose: This work was undertaken to evaluate the working length, proximal screw density, and diaphyseal fixation mode and the correlation to fracture union after locking plate osteosynthesis of distal femoral fractures using bridge-plating technique.

Methods: In this retrospective medical record review, patients undergoing operative fixation of distal femur fractures with a distal femoral locking plate utilizing bridge-plating technique for the metadiaphyseal region were included. Primary variables included fracture union, secondary surgery for union, plate working length, and diaphyseal screw technique and configuration. Secondary variables included patient demographics, patient comorbidities (tobacco use and diabetes mellitus), injury mechanism, plate metallurgy, OTA fracture type, Gustilo type for open fractures, periprosthetic fracture, and coronal plane fracture alignment.

Results: 99 patients with distal femur fractures with a mean age 60 years (36 male and 63 female) met inclusion criteria. Mean follow-up was 576 days with 89% follow-up until declared union or 1 year and overall 63% 1-year follow-up. None of the clinical parameters (patient demographics, comorbidities, fracture type, mechanism of injury) were statistically significant indicators of union. Plate metallurgy (50 stainless steel and 49 titanium) was not a statistically significant indicator of union. The mean working length (distance between the first screw on either side of the fracture) was 90.5 mm and it was not statistically significant for fracture union. Screw density (number of screws proximal to fracture divided by length of plate proximal to fracture), number of proximal screws, and screw cortices were not significantly related to fracture union. Diaphyseal screw technique did show statistical significance (1 non-locking, 45 locking, 53 hybrid). Hybrid technique had a statistically significant higher chance of union when compared to locking ($P = 0.03$). All proximal locking screw constructs were 2.7 times more likely to lead to nonunion.

Conclusion: Stiffer plating constructs when using bridge-plating techniques in distal femur locking plates was associated with a 2.7× higher likelihood of nonunion. Surgeons should consider avoiding the use of all locking screws for diaphyseal fixation in distal femoral locking plates. However, other factors associated with more flexible fixation constructs such as increased working length, decreased proximal screw number, and decreased proximal screw density were not significantly associated with union in this study. Larger prospective studies are necessary to determine plate type, length, and screw construct to promote the ideal stress-strain environment for fracture healing in distal femur fractures.

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Construct Characteristics Predisposing to Nonunion After Locked Lateral Plating of Distal Femur Fractures

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Background/Purpose: Nonunion rates after lateral locked plating (LLP) of a distal femur fracture range from 0% to 21%. Previous studies have examined patient and injury parameters such as obesity, age, diabetes, fracture type, etc, as possible predictors of nonunion. We now seek to identify discrete construct characteristics related to construct stiffness that may be independent predictors of nonunion risk after LLP fixation of distal femur fractures.

Methods: This is a retrospective review of 271 distal femoral fractures treated with LLP at three Level I academic centers. Nonunion was defined as the occurrence of any secondary procedure to manage poor healing. Construct variables recorded were: (1) plate material, (2) plate length, (3) number of screws proximal to the fracture, (4) ratio of filled screw holes to total plate holes, (5) presence of a screw crossing the main fracture plane, and (6) an overall stiffness score (range, 0 [low stiffness] to 5 [high stiffness]) incorporating the above variables in an equally weighted manner. Stiffness score was calculated by awarding 1 point for each of the following: if the construct was stainless steel, if it had >4 screws proximally, if the plate was <10 holes in length, if the ratio of filled to unfilled holes was >0.65, and if a screw crossed the main fracture plane. Multivariable analysis was performed using logistic regression to control for confounding in order to identify independent risk factors for nonunion.

Results: The overall nonunion rate was 13.3% (n = 36). There was a significant association between plate material and nonunion with rates of 9.6% for titanium and 40.6% for stainless steel ($P < 0.001$). Fixation crossing the fracture was associated with a higher rate of nonunion but did not reach statistical significance ($P = 0.13$). No significant univariate differences with respect to number of proximal screws ($P = 0.34$), plate length ($P = 0.14$), or ratio of filled to total holes ($P = 0.56$) were observed between healed fractures and those with nonunion. Stiffness score did reach significance ($P = 0.025$) but likely reflects the overbearing effect of plate material. Results of the multivariate analysis confirm that the primary significant independent predictor of nonunion is use of stainless steel material showing an odds ratio >6 times higher for nonunion compared to titanium use (odds ratio = 6.4, 95% confidence interval: 2.8-14.7, $P < 0.001$).

Conclusion: When treating distal femur fractures with LLP, plate material has a highly significant and overbearing influence on the risk of nonunion independent of any other construct variable, including an overall stiffness score that weights suspect construct char-

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