OTA HIGHLIGHT PAPER

Treatment Failure in Femoral Neck Fractures in Adults Less Than 50 Years of Age: Analysis of 492 Patients Repaired at 26 North American Trauma Centers

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Objectives: To assess the operative results of femoral neck fractures (FNFs) in young adults in a large multicenter series, specifically focusing on risk factors for treatment failure.

Design: Large multicenter retrospective cohort series.

Setting: Twenty-six North American Level 1 trauma centers.

Patients: Skeletally mature patients younger than 50 years with displaced and nondisplaced FNFs treated between 2005 and 2017.

Intervention: Operative repair of FNF.

Main outcome measurements: The main outcome measure is treatment failure: nonunion and/or failed fixation, osteonecrosis, malunion, and need for subsequent major reconstructive surgery (arthroplasty or proximal femoral osteotomy). Logistic regression models were conducted to examine factors associated with treatment failure.

Results: Of 492 patients with FNFs studied, a major complication and/or subsequent major reconstructive surgery occurred in 45% (52% of 377 displaced fractures and 21% of 115 nondisplaced fractures). Overall, 23% of patients had nonunion/failure of fixation, 12% osteonecrosis type 2b or worse, 15% malunion (>10 mm), and 32% required major reconstructive surgery. Odds of failure were increased with fair-to-poor reduction [odds ratio (OR) = 5.29, 95% confidence interval (CI) = 2.41–13.31], chronic alcohol misuse (OR = 3.08, 95% CI = 1.59–6.38), comminution (OR = 2.63, 95% CI = 1.69–4.13), multiple screw constructs (vs. fixed-angle devices, OR = 1.95, 95% CI = 1.30–2.95), metabolic bone disease (OR = 1.77, 95% CI = 1.17–2.67), and increasing age (OR = 1.03, 95% CI = 1.01–1.06). Women (OR = 0.57, 95% CI = 0.37–0.88), Pauwels angle ≤50 degrees (type 1 or 2; OR = 0.64, 95% CI = 0.41–0.98), or associated femoral shaft fracture (OR = 0.19, 95% CI = 0.10–0.33) had lower odds of failure.

Conclusions: FNFs in adults <50 years old remain a difficult clinical and surgical problem, with 45% of patients experiencing major complications and 32% undergoing subsequent major reconstructive surgery. Risk factors for complications after treatment of displaced FNFs were numerous.

Key Words: young, femoral neck, fracture, fractures, vertical, Pauwels, <50, young adult, failed fixation, treatment failure, treatment failure

Level of Evidence: Therapeutic Level III. See Instructions for Authors for a complete description of levels of evidence.

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INTRODUCTION

Femoral neck fractures (FNFs) in young adults (ie, <50 years old) are well recognized for their risk of complications and poor clinical outcomes.[1–8] The incidence of treatment failure, including fixation failure, nonunion, symptomatic malunion, and osteonecrosis, has been reported between 5% and 90%.[1–9] The management and associated complications of FNFs in young adults are inherently different than in the geriatric population.[9,10] Although arthroplasty is often considered first-line treatment for older patients, operative repair is typically performed in the younger population, which may introduce a significant amount of variability in treatment and outcomes. Moreover, clinical studies to date on the subject are limited by small sample size, heterogeneous populations, treatment variability, poor follow-up, and unclear outcomes.[1–9] The goals of this study were to evaluate the incidence, characteristics, and risk factors for treatment failure in a large cohort of young patients with FNFs (with and without ipsilateral shaft fractures) treated with internal fixation at North American Level 1 trauma centers.

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METHODS

Inclusion Criteria and Data Collection

Patients from 26 North American Level 1 Trauma Centers with FNFs (Orthopaedic Trauma Association [OTA/AO] type 31B fractures)[11] were evaluated. Patients' age ranged from skeletal maturity to 49 years, and all patients were treated with surgical repair between January 1, 2005 and December 31, 2017. Institutional Review Board approval was obtained from each center. Databases were searched for Current Procedural Terminology codes 27235 (femoral neck cannulated screw fixation) and 27236 (ORIF hip fracture and hemiarthroplasty).[12]

Exclusion criteria included the following:

1. Follow-up less than 6 months (unless treatment failed)
2. Lack of adequate records or radiographic images
3. Initial treatment with arthroplasty or fixed-angle locked plate
4. Skeletally immature
5. Stress fractures
6. Patients without a native contralateral hip
7. Ballistic injuries
8. Associated acetabular, femoral head, or peritrochanteric fractures or hip dislocations.

Medical record review was performed, and data collection included patient and injury factors, and details of clinical outcomes. Medical conditions associated with diminished bone metabolism and fracture healing were identified,[13,14] including smoking, diabetes mellitus type 1, chronic alcohol misuse, chronic steroid use, end-stage renal disease, and other metabolic diseases (includes chronic liver, bone metabolism, or autoimmune diseases). Each available radiograph of the hip, pelvis, and femur from before ("injury"), during ("intra-operative"), and after surgery including follow-up was evaluated by 2 fellowship-trained orthopaedic trauma surgeons; disagreements were adjudicated by a third orthopaedic trauma surgeon. Injury factors assessed included initial displacement (modified Garden classification[15]), modified Pauwels classification,[14,16] and the OTA/AO fracture classification).[11] Surgery details included approach (open vs. closed reduction), reduction quality, and implant(s) type. The quality of fracture reduction[5] was graded as excellent (<2 mm of displacement and <5 degrees of angulation in any plane on any view), good (2–5 mm of displacement and/or 5–10 degrees of angulation), fair (>5–10 mm of displacement and/or >10–20 degrees of angulation), or poor (>10 mm of displacement and/or > 20 degrees of angulation or any varus). The greatest absolute value defined "shortening" using 2 methods as shown in Fig. 1. All measurements were estimated by comparing established implant geometry (ie, screw head or sliding hip screw–barrel diameter) and radiographic implant measures to control for magnification. First, a modified overlay method was used to measure the degree of vertical shortening compared with an outline of the uninjured, contralateral hip[17–20]: an outline of the contralateral femoral head, neck, and trochanter was created as a reference and then superimposed onto the radiograph being evaluated for femoral neck shortening. Second, the magnitude of implant shortening was measured via screw protuberance from the lateral cortex or changes in the sliding hip screw–barrel relationship.[21–23]

Treatment failure was the primary clinical outcome and was subdivided into the following categories:

1. Nonunion and/or failed fixation was defined as lack of healing at >6 months and/or loss of the implants' mechanical integrity.[5,6]
2. Osteonecrosis was defined and stratified according to the modified Ficat system.[24] Types 2b and greater were defined as clinical failures.
3. Malunion was defined as vertical or femoral neck shortening of ≥10 mm.[17,21–23] As no absolute benchmark for clinically important shortening exists in younger patients and the desire to maintain the native hip is variable across patients in this cohort, we also calculated the incidence of shortening with a threshold of ≥15 mm and without consideration of deformity.
4. Subsequent major reconstructive surgery was defined as secondary conversion to hip arthroplasty, proximal femoral osteotomy, or early revision of fixation.

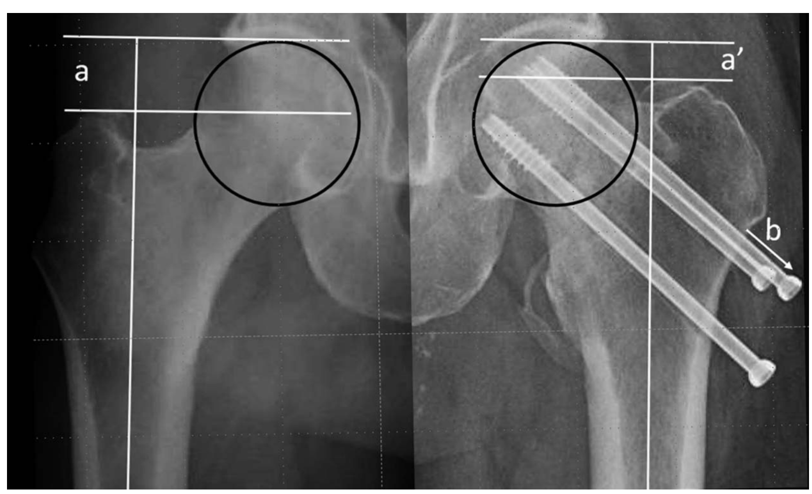

FIGURE 1. Example of 2 methods for measuring for radiographic shortening: the greater absolute value of the 2 methods defined shortening used for analysis. (1) An overlay method using the well contralateral hip measured the magnification-controlled distance between 2 parallel lines at the cranial aspect of the femoral head and the tip of the greater trochanter (a). This created overlay was then used over the injured hip and the like landmarks measured (a'). Shortening was calculated as [a minus a']. (2) The degree of femoral neck shortening was estimated from the amount of implant prominence laterally (b).

Statistics

All analyses were conducted using R 3.6.3 and R studio version 1.2.5001 except for initial reporting of patient and fracture characteristics (Tables 1–3). Descriptive statistics of frequency and percent for categorical variables and mean ± SD were reported for patient, injury, and treatment/clinical results variables, overall and for displaced and nondisplaced fractures separately. Exploratory univariable and multivariable logistic regression models were conducted to examine the association between each factor and failure, separately by displaced and nondisplaced groups. Significance was set at $P < 0.05$.

RESULTS

The study group comprised 492 FNFs (377 displaced and 115 nondisplaced). Mean duration of follow-up was 22.4 months [range, 2 weeks (early failure) to 141 months]. Sixty-five percent of patients were male and 98% of FNF were Pauwels type II or III (mean Pauwels angle was 53.2 ± 11.4 degrees). Patient, injury, and treatment characteristics are shown in Table 1.

Overall, treatment failure occurred in 44.5% of young patients with FNFs. Displaced fractures failed more frequently (51.7% vs. 18.3%, $P < 0.001$) and had 4.80 higher odds of failure (95% confidence interval [CI] = 2.92–8.20) than nondisplaced fractures. Details of failure are presented in Table 2. Treatment failures included 23% nonunion and/or failed fixation, 12% osteonecrosis, and 15% malunion (defined as ≥10 mm shortening compared with their normal contralateral side). All complications evaluated were increased in displaced fractures compared to non-displaced fractures. The results of the univariate logistic regression

TABLE 1. Patient, Injury, and Treatment Characteristics in all Fractures, Nondisplaced and Displaced Fractures.[13]

Variable	Entire Cohort	Nondisplaced Fractures	Displaced Fractures	P
Number of patients (n)	492	115	377	N/A
Mean age (y)	36.8 ± 8.8	37.9 ± 9.0	36.5 ± 8.7	0.160
Female gender	172 (35%)	51 (44%)	121 (32%)	0.023
Mean body mass index (BMI) ± SD	27.1 ± 6.9	27.0 ± 7.7	27.2 ± 6.7	0.823
Metabolic bone conditions, total	236 (48%)	47 (41%)	189 (50%)	0.092
Current smoker	165	13	152	
Diabetes mellitus	25	9	16	
Current alcohol misuse	50	3	47	
Current steroid use	21	11	10	
End stage renal disease	24	18	6	
Mean modified Pauwels angle[14]	N/A	N/A	53.2 ± 11.4	NA
Pauwels classification				
Type I (<30 degrees)	N/A	N/A	6 (1.6%)	NA
Type II (30°–50 degrees)			122 (32.4%)	
Type III (>50 degrees)			243 (64.5%)	
OTA/AO classification (Type 31B_._)[15]				
1.1	66 (13.4%)	66 (57.4%)	—	NA
1.2	42 (8.5%)	42 (36.5%)	—	
1.3	38 (7.7%)	—	38 (10.7%)	
2.1	29 (5.9%)	—	29 (7.6%)	
2.2	120 (24.4%)	—	120 (31.8%)	
2.3	162 (32.9%)	—	116 (30.8%)	
3	35 (7.1%)	—	35 (9.3%)	
Fracture comminution	N/A	N/A	254 (67.4%)	NA
Associated femoral shaft fracture	97 (19.8%)	15 (13.0%)	82 (21.8%)	0.059
Reduction method				
Closed	243 (49.4%)	115 (100%)	128 (34.0%)	<0.001
Open	249 (50.6%)	0 (0%)	249 (66.0%)	
Reduction quality[5]				
Excellent	N/A	N/A	99 (26.2%)	NA
Good			197 (52.3%)	
Fair			68 (18.0%)	
Poor			13 (2.7%)	
Construct type				
Fixed-angle device	206 (41.9%)	31 (27.0%)	175 (46.4%)	<0.001
Sliding hip screw	179	22	157	
Cephalomedullary nail	27	9	18	
Multiple cannulated screws	286 (58.1%)	84 (73.0%)	202 (53.6%)	

TABLE 2. Clinical Results and Complications in *All* Fractures

	Entire Cohort	Nondisplaced Fractures	Displaced Fractures	*P*
Number of patients (n)	492	115	377	
"Treatment failure": hips with major complications and/or major subsequent reconstructive surgery, malunion defined as ≥10 mm	219 (44.5%)	24 (20.9%)	195 (51.7%)	<0.001
Failures, if malunion was defined as ≥15 mm	157 (31.9%)	21 (18.3%)	136 (36.1%)	
Failures, if malunion was not considered failure	118 (23.9%)	21 (18.3%)	97 (25.7%)	
Nonunion, failed fixation, or both	112 (22.8%)	7 (6.1%)	105 (27.8%)	<0.01
Osteonecrosis (stage [27])				
None	411 (84.6%)	101 (87.8%)	310 (82.2%)	
Type 1	1 (0.2%)	0	1 (0.3%)	
Type 2a	23 (4.7%)	0	23 (3.1%)	
"Severe" osteonecrosis, total	57 (11.6%)	7 (6.1%)	50 (16.1%)	<0.01
Type 2b	3 (0.6%)	1 (0.9%)	2 (0.5%)	
Type 3	12 (2.4%)	3 (0.3%)	9 (2.4%)	
Type 4	42 (8.5%)	3 (0.3%)	39 (10.0%)	
"Malunion"				
Defined as ≥10 mm	74 (15.0%)	6 (5.2%)	68 (18.0%)	<0.001
If, malunion defined as ≥15 mm	39 (7.9%)	0 (0.0%)	39 (10.3%)	<0.001
Patients having secondary surgeries*	207 (42.1%)	17 (14.8%)	190 (50.4%)	<0.001
Patients having "major reconstructive surgery"	158 (32.1%)	12 (10.4%)	146 (38.8%)	<0.001
Hip arthroplasty	100 (20.3%)	11 (9.6%)	89 (23.6%)	
Proximal femoral osteotomy	46 (9.3%)	1 (1.0%)	45 (11.9%)	
Early revision of fixation†	12 (2.5%)	0	12 (3.2%)	
Patients having "minor" secondary surgery	74 (15.0%)	12 (10.4%%)	62 (16.4%)	0.260
Late implant removal	54 (11.0%)	12 (10.4%)	44 (11.7%)	
Excision of heterotopic bone	8 (1.6%)	0	8 (2.1%)	
Debridement for infection	6 (1.2%)	0	6 (1.6%)	
Hip arthroscopy	4 (0.8%)	0	4 (1.0%)	

*Many patients had "minor" surgery (eg, screw exchange), followed by "major" reconstructive surgery.
†Does not include early simple screw exchange.

models for displaced and nondisplaced fracture patients are reported in Tables 3 and 4, respectively.

Patients with displaced fractures who had treatment failure were more likely to be characterized by the following: fair or poor fracture reduction [odds ratio (OR) = 5.29, 95% CI = 2.41–13.31], chronic alcohol misuse (OR = 3.08, 95% CI = 1.59–6.38), fracture comminution (OR = 2.63, 95% CI = 1.69–4.13), use of a multiple screw construct (as opposed to fixed-angle device, OR = 1.95, 95% CI = 1.30–2.95), any metabolic bone disease (OR = 1.77, 95% CI = 1.17–2.67), and increasing age (OR = 1.03, 95% CI = 1.01–1.06). Patients who were female (OR = 0.57, 95% CI = 0.37–0.88), had a fracture with a Pauwels angle ≤50 degrees (type 1 or 2; OR = 0.64, 95% CI = 0.41–0.98), or had an associated femoral shaft fracture (OR = 0.19, 95% CI = 0.10–0.33) had lower odds of failure (Table 3). The multivariable regression model indicated that femoral neck comminution [adjusted OR (AOR) = 2.16, 95% CI = 1.30–3.61, $P = 0.003$], lack of associated femoral shaft (AOR = 0.24, 95% CI = 0.12–0.44, $P < 0.001$), fair or poor fracture reduction (AOR = 3.98, 95% CI = 1.73–10.49, $P = 0.002$), and repair with a multiple screw (not fixed-angle) construct (AOR = 1.95, 95% CI = 1.30–2.95, $P = 0.001$) were significantly associated with failure. Age, sex, and presence of any metabolic bone disease, and open or closed reduction method were not significant in the multivariable regression model.

For the 24 patients with nondisplaced fractures who experienced failure (of 115 total, 21%), there were no differences observed by patient or surgical factors (Table 4). Age and associated femoral shaft fracture were included in a multivariable regression model, but neither was significantly associated with failure.

DISCUSSION

We identified a treatment failure rate of 45% in this large multicenter study of 492 young adult patients with FNFs managed with operative repair at 26 North American trauma centers. Forty-two percent of all injured hips ultimately underwent at least one additional surgery after initial repair,

TABLE 3. Descriptive and Regression Statistics in Patients With 377 *Displaced* Fractures: Including Demographics, Preexisting Health, Injury, and Surgical Characteristics

	Clinical Results		Univariate Regression Modelling			
Variables	Hips With Failure	Hips Without Failure	Odds Ratio	*P*	Lower Control Limit	Upper Control Limit
Number of patients (n)	195	182	—	—	—	—
Mean age (y)	37.7 ± 8.7	35.3 ± 8.6	1.03	0.008	1.01	1.06
Female gender (% female)	51 (26.2%)	70 (38.5%)	0.57	0.011	0.37	0.88
Mean body metabolic index	26.7 ± 5.6	27.6 ± 7.7	0.98	0.234	0.95	1.01
Metabolic bone conditions	111 (56.9%)	78 (42.9%)	1.77	0.006	1.17	2.67
Current smoker	86 (44.1%)	66 (36.3%)	1.35	0.156	0.89	2.05
Diabetes mellitus	8 (4.1%)	8 (2.2%)	0.93	0.879	0.33	2.57
Current alcohol misuse	35 (17.9%)	12 (6.6%)	3.08	0.001	1.59	6.38
Current steroid use	8 (4.1%)	2 (1.1%)	3.83	0.092	0.94	25.60
End stage renal disease	5 (2.6%)	1 (0.5%)	4.74	0.158	0.75	91.22
Others	22 (11.3%)	15 (8.2%)	1.42	0.324	0.72	2.87
Mean modified Pauwels angle ± SD (degrees) (14)	60.9 11.1	63.9 ± 11.5	0.98	0.013	0.96	0.99
Pauwels classification						
Types 1 & 2 (≤50 degrees)	76 (39.2%)	52 (28.6%)	0.64	0.040	0.41	0.98
Type 3 (>50 degrees)	117 (60.0%)	126 (69.2%)				
Fracture comminution	151 (77.4%)	103 (56.6%)	2.63	<0.001	1.69	4.13
Segmental medial comminution present	26 (13.3%)	23 (12.6%)	1.06	0.857	0.58	1.94
Associated femoral shaft fracture	18 (9.2%)	64 (35.2%)	0.19	<0.001	0.10	0.33
Periprosthetic fracture	12 (6.2%)	8 (4.4%)	1.43	0.442	0.58	3.74
Open reduction method	125 (64.1%)	124 (68.1%)	0.84	0.409	0.54	1.28
Reduction grade						
Excellent and good	145 (75%)	151 (83.0%)	5.29	<0.001	2.41	13.31
Fair and poor	50 (25.6%)	31 (17.0%)				
Construct type						
Fixed-angle device	73 (37.4%)	101 (55.5%)	0.48	0.001	0.32	0.73
Multiple cannulated screws	120 (61.5%)	82 (45.1%)	1.95	0.001	1.30	2.95

and 32% of the entire cohort required subsequent major reconstructive surgery (100 total hip arthroplasties, 45 proximal femoral osteotomies, and 12 early revisions of fixation). Factors including displaced fractures, comminution, poor reduction quality, use of a multiple screw construct, and lack of an associated femoral shaft fracture were shown to predict failure in our multivariate model.

Previous reports on FNFs in young adult patients are characterized by small and heterogeneous populations, single-center settings, variable modalities, inconsistent reporting of results, and widely variable outcomes. Seminal study by Protzman and Burkhalter[1] documented poor results in 22 US military personnel 20–40 years old who underwent operative fixation for acute FNFs. Nonunion and osteonecrosis occurred in 59% and 86% of these hips, respectively. Subsequent results with protocolized, contemporary treatments[4,10,25–28] have shown improved but still broadly variable results for fixation in the young adult population. More than a decade ago, Damany et al[29] reported overall rates of nonunion at 8.9% and osteonecrosis at 23.0% for FNFs in 15- to 50-year-old patients in a meta-analysis, including 18 studies and 564 patients. More recently, Slobogean et al[7] pooled results from 42 previous studies comprising over 1500 patients <60 years old with FNFs treated with repair. They found a nonunion in 8%, implant failures in 9%, osteonecrosis in 13%, malunion in 6%, and a reoperation rate in 16% of hips. This analysis, however, was limited by unclear treatment and failure definitions in the included studies and a relatively older patient population. Clinical results (ie, an analysis of treatment failures) have not been previously reported in any well-defined large single study. Most importantly, the risk factors for treatment failure have not been adequately evaluated in this at-risk population.

Of the 377 displaced fractures evaluated in our study, 52% resulted in treatment failure, including 28% with nonunion and/or fixation failure, 16% with type 2b or greater osteonecrosis, and 18% with malunion (defined as shortening ≥10 mm). Additionally, 50% of these failures underwent at least one secondary surgery, with 39% requiring subsequent major reconstructive surgery (89 hip replacements, 45 proximal femur osteotomies, and 12 early revision of repairs). Notably, all 12 early revisions of fixation subsequently failed and underwent hip arthroplasty[11] or proximal femoral osteotomy.[1] For displaced fractures, the predictive factors for treatment failure included fair or poor reduction (OR = 5.3), chronic alcohol misuse (OR = 3.1), femoral neck

TABLE 4. Descriptive and Regression Statistics in Patients With 115 *Nondisplaced* Fractures: Including Demographics, Preexisting Health, Injury, and Surgical Characteristics

	Clinical Results		Univariate Regression Modelling			
Variables	**Hips With Failure**	**Hips Without Failure**	**Odds Ratio**	***P***	**Lower Control Limit**	**Upper Control Limit**
Number of patients (n)	24 (18.3%)	91 (81.7%)				
Mean age ± SD (y)	40.53 (8.72)	37.27 (8.95)	1.05	0.136	0.99	1.11
Gender (% female)	8 (33.3%)	43 (47.3%)	0.57	0.265	0.20	1.50
Mean body mass index ± SD	25.10 (6.98)	27.40 (7.80)	0.95	0.257	0.8	1.03
Metabolic bone conditions (any)	8 (38.1%)	39 (41.5%)	0.87	0.775	0.32	2.26
Current smoker	0 (0.0%)	13 (13.8%)				
Diabetes mellitus	1 (4.8%)	8 (8.5%)	0.54	0.569	0.03	3.18
Current alcohol misuse	2 (9.5%)	1 (1.1%)				
Current steroid use	3 (14.3%)	8 (8.5%)	1.79	0.421	0.37	6.90
End stage renal disease	4 (19.0%)	14 (14.9%)	1.34	0.637	0.35	4.31
OTA/AO classification (Type 31_._)15						
1.1 (“valgus impacted”)	18 (85.8%)	52 (55.3%)				
1.2 (“nondisplaced)	3 (14.3%)	42 (44.7%)				
Associated femoral shaft fracture	6 (28.6%)	9 (9.6%)	3.73	0.027	1.11	11.99
Construct type				0.249	0.64	4.81
Fixed-angle device	8 (38.1%)	24 (25.5%)				
Sliding hip screw	4 (19.0%)	18 (19.1%)				
Cephalomedullary nail	3 (14.3%)	6 (6.4%)	1.79			
Multiple cannulated screws	13 (61.9%)	71 (75.5%)	0.53	0.208	0.20	1.47

comminution obvious on plain radiographs (OR = 2.6), multiple cannulated screw construct (compared with fixed-angle devices; OR = 2.0), any metabolic bone disease (OR = 1.7), and age (OR = 1.02). Associated femoral shaft fractures (OR = 0.20), Pauwels type 1 and 2 fractures (Pauwels angle ≤50 degrees) (OR = 0.64), and female gender (OR = 0.57) seemed to be protective.

Among the 115 nondisplaced fractures, 21% experienced treatment failure, including 6% with nonunion and/or fixation failure, 6% with osteonecrosis, and 5% with malunion ≥10 mm deformity. Of these patients, 10% (11/115) required a subsequent major reconstructive surgery. Ten of the 11 patients underwent hip replacement. There were no patients or surgical factors that were predictive of failure in the univariate logistic regression models for nondisplaced fractures.

This study found that patients with *displaced* FNFs experience treatment failure more than 4 times than those with nondisplaced fractures. All categories of treatment failure evaluated in this study occurred more frequently in the displaced group compared with the nondisplaced group (Table 2). These findings are rendered even more vital because the ratio of displaced to nondisplaced FNFs seen at our centers was greater than 3:1. Because previous clinical studies have been too small to clearly define the effect of displacement on complications and outcomes, ours is the first clinical study to address the impact of fracture displacement on results. The recent meta-analysis for young FNFs[7] compared displaced and nondisplaced fractures, noting “while implant failure could not be reliably calculated due to difficulties in reporting,” there were differences in nonunion (10% vs. 5.2%), osteonecrosis (14.7 vs. 6.4%) and (any) reoperation (17.8 vs. 6.9%). Our current study found that compared with patients with nondisplaced fractures, those with displaced injuries were more frequently male, experienced different fracture pattern (by definition), were more often treated with a fixed-angle device, and trended toward increased association with ipsilateral femoral shaft fractures. Displaced FNFs in young healthy patients with no evidence of diminished bone metabolism are presumed to indicate a greater energy of impact, mechanical instability, and presumably damage to the local biology compared with nondisplaced fractures[4] and may explain their increased risks for nonunion, fixation failure, and osteonecrosis.[7,29]

Our study found equal failure rates in FNFs treated with closed and open reductions, contrary to the findings of Patterson et al,[30] who recently suggested that nonunion rates were increased by open reduction. Fair or poor reduction was identified as a powerful predictor of failure in our multicenter cohort of displaced FNFs (OR 5.29). Previous studies have shown trending effect of reduction quality on outcomes,[5,6,8] but never with the power of these results. The ostensible benefits of a high-quality reduction are to regain inherent bony stability[4–6] and potentially to restore blood flow to the femoral head.[4] The former benefit has been highlighted in several recent studies on fracture morphology of the medial fracture segment, which is often broad-based cortical bone up to 5 mm thick or more at the calcar.[31–33] Thus, if the FNF can be anatomically reduced, “overreduced” into an incarcerated position (Gottfried reduction),[34–36] or held with a medial buttress plate,[27,37–40] an innately more stable construct might be achieved. When assessing the impact of open or closed reduction in this cohort, the failure rates were equal. Notably, the quality of reduction correlated with the reduction method: for example, good or excellent reductions were seen more frequently with open reductions compared with closed reductions (91% vs. 84%, respectively).

Beyond displacement and fracture reduction, implant choice and bone quality also seem to be important factors in the outcomes of displaced young FNFs. These findings should not be surprising because both factors could be expected to affect fixation strength. Fixed-angle devices were successfully used much more frequently in displaced FNFs compared with multiple cannulated screws (62% vs. 37%; OR = 0.48). This benefit does not seem to apply to nondisplaced FNFs, and lower failure rates were seen in these stable fractures using both implant types. Although numerous mechanical testing studies have shown clear advantage to the fixed-angle implants in a young patient model,[39–42] clinical data have been less conclusive.[5,6,8,43,44] A recent expert survey of OTA members showed an even 50:50 split in support of a fixed-angle device or multiple cannulated screws in treating young patients' vertical FNFs. Remarkably, more than 70% of surgeons surveyed claimed mechanical superiority of their preferred method.[45]

Bone quality substantially affects the implant's ability to maintain mechanical integrity of fractures, as seen in FNFs where fixation of the head–neck segment is limited by local anatomy and regional architecture. Our data showed that nearly half of our young FNF patients had a condition(s) likely to affect bone quality or its ability to heal and thus may not allow enough stability to achieve union. For example, patients with displaced FNFs, where stable fixation is presumably vital, showed OR for treatment failure with "current alcohol misuse" at 3.08 and "any metabolic bone disease" at 1.77. This is the first study to identify bone metabolism problems as risks for treatment failure in this population. Lund et al[46] recently showed that low Hounsfield unit measurements in the femoral head and neck on perioperative computed tomography scans were associated with increased incidence of poor outcomes with femoral neck fixation and femoral neck shortening. Considering these findings might be particularly important for decisions such as "arthroplasty versus repair" or for preoperative planning for surgical repair and might suggest that a more comprehensive assessment including these variables may help to optimize treatment.

There are several key points elucidated here that may guide the management of young patients with FNFs. First, providing individualized care may reduce the high risk of failure in these patients. Risk stratification should become more routine when making decisions between repair and arthroplasty. For example, if a patient approaching middle age with a displaced fracture has factors placing them at risk for failure, increased consideration might be given toward hip arthroplasty. Alternatively, young patients with a displaced fracture, healthy bone, and few risk factors should be reasonably treated with a well-planned and executed surgical repair. Second, it is clear that a quality reduction and the use of a fixed-angle implant are beneficial in treating displaced fractures. Although closed versus open reduction in displaced fractures did not affect outcomes specifically, a fair or poor-quality reduction had a 5.3 times higher OR of failure when compared with a high-quality reduction. Orthopaedic surgeons play a key role in reducing risks for failure in patients with this at-risk diagnosis: this includes the thoughtful gathering of relevant information on the patient (eg, history) and injury pattern (eg, radiology), thereby allowing for comprehensive decision making on the method of treatment and a preoperative plan. Increasing the success rate of surgical repairs in young patients FNFs also demands improving technical execution of surgery such as quality reduction (as reported here) and proper usage of the implants used for fixation.[47–49]

Our study is not without limitations. Innate biases are inherent in this retrospective study because our population of injured patients was selected for repair as opposed to arthroplasty. Criteria for making this treatment decision cannot be well defined in our study. Treatment at our Level 1 trauma centers may also not directly extrapolate well to lower-acuity hospitals where surgical assistant availability and surgical volume is different. Also, although average follow-up was almost 2 years, minimum follow-up for inclusion was limited to only 6 months. Although short-term follow-up may provide for the analysis of healing and stability of implant constructs, it limits the analysis of osteonecrosis, which may take 2 or more years to manifest. We also strictly defined osteonecrosis as that which affects clinical outcomes, that is, Ficat type 2b or greater.[24] Although one could make the case that this parameter is the most clinically relevant, our criterion may also underestimate the true rate of osteonecrosis. Finally, we have defined malunion as ≥10 mm of deformity (mostly shortening), although ≥15 mm has occasionally been used and may be an acceptable amount of deformity in younger patients.[28–32] We may therefore be somewhat overreporting treatment failures and potentially affecting our secondary analyses. However, no studies have shown that one amount of clinical shortening is more important than another. This study has several strengths as well. First, we studied a large number of FNFs in a representative young population treated at a variety of major trauma centers across North America. Our mean age was 36.8 years and 98% of fractures were Pauwels type 2 or 3. Both variables are typically seen in high-energy mechanisms. Second, treatment strategies were subjectively consistent across centers, with no apparent outliers in their methodologies. Third, we have strictly defined our modes of treatment failure and tried to use clinically important end points for those categorizations. Finally, we have identified several risk factors for failure of treatment, some of which may ultimately allow for better decision making in patients with FNFs who fall into the treatment gap between arthroplasty and repair.

In summary, FNFs in young adults undergoing repair remain a difficult clinical problem for patients and surgeons. This large, multicenter study has demonstrated that almost half of patients experience treatment failure, such as nonunion and/or failed fixation, osteonecrosis, or malunion, most of which require secondary reconstructive surgeries. Numerous risk factors for these complications have been identified, including patient demographics and comorbidities, injury patterns, and treatment modalities. The results of this study draw attention to pitfalls in treatment, potentially allowing orthopaedic surgeons to allow better decisions and execution of surgical repairs in young adults with FNFs.

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