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Fixation Strategies for the Displaced Femoral Neck Fracture in Patients Ages 18-59: Which Strategy is Superior?

A Mechanical Approach to Clinical Decision Making

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Abstract

Research Question: In young to middle-aged patients (18-59 years old) undergoing surgical repair for a displaced femoral neck fracture, is there a superior surgical fixation device, or combinations of devices that significantly affects clinical outcomes?

Background, Significance, and Rationale for the Question:

Femoral neck fractures vary according to a variety of factors including age and mechanism of injury. In older patients (>60 years old), lower energy fractures such as a ground level fall are far more common due to high relative incidence of bone degeneration and disease. Poor bone quality, the inability to limit weight bearing, along with comorbidities where secondary surgeries may not be tolerated, often limits the utility of fracture repair in favor of replacement.

Mechanism of femoral neck fractures in the cohort of young to middle-aged patients (18-59 years old) is highly variable. These fractures can be high energy leading to atypical fracture angles and comminution. Additionally, bone quality and comorbidity impact become more variable. Regardless, these patients are usually treated with operative repair as outcomes of arthroplasty in young to middle-aged patients are not well-defined and early revision surgery is expected due to implant wear over time. Highly impactful decisions are made regarding the hardware and methodology used for augmentation and there is great need to for identification of the superior internal fixation strategies that promises better results.

Materials and Methods: This is a retrospective study of patients 18 to 59 years old with a displaced femoral neck fracture treated with surgical repair between 2005 and 2017 at 26 Level 1 trauma centers in North America. A database including approximately 1500 patients was

evaluated for injury mechanism, internal fixation method implemented, and success of that intervention, in addition to a variety of patient demographics.

Results: 808 of 1500 individuals met study criteria with 552 individuals having a displaced femoral neck fracture that qualified for analysis. Amongst the entire cohort the two most used constructs included SHS+AR (34%) and CS Alone (44%) of which SHS+AR was statistically less likely to fail (p=<0.001). Overall, 251 individuals received some form of a FA device. 302 individuals underwent fixation via CS. All FA devices demonstrated a significantly greater rate of fixation success in comparison to the CS group (p=<0.001). Amongst FA construct devices the CN demonstrated the lowest incidence of failure (38%) (p=0.305).

Conclusions: This study served to demonstrate the clear statistical superiority of the fixed-angle device amongst the general population, with sliding hip screws paired with anti-rotation screws promising best results in a number of subdivided patient groups including, both males and females, both younger and older cohorts, those with fracture comminution, and those without associated femoral shaft fractures. The cephalic nail, while less frequently implemented also posed the lowest incidence of failure with significant advantages in all ages, females, and those without alcohol use, metabolic disease or fracture comminution. Overall, with consideration given to patient demographic and co-morbidity, FA constructs should represent the internal fixation standard of care in patients aged 18-59.

Research Questions:

In young to middle-aged patients (18-59 years old) undergoing surgical repair for a displaced femoral neck fracture, is there a superior surgical fixation device, or combinations of devices that significantly affects clinical outcomes? Can we optimize the methodology of repair and its correlation with patient demographics and comorbidities such that internal fixation may be predictably better than it has been in the past?

Hypothesis: Our null hypothesis will be that there will be no differences in fixation success amongst all variations in internal fixation strategies for patients 18-59 years old. Additionally, no individual patient demographic will impact the success of any given fixation strategy.

Introduction, Significance and Rationale:

Multiple surgical modalities are considered when addressing displaced femoral neck fractures. These include total hip arthroplasty (THA), hemiarthroplasty (HA), and variations of repair strategies usually relying on internal fixation.[2] These strategies are broadly grouped into the categories of fixed-angle devices and screws, with a broad spectrum of variability involving screw types, plates, anti-rotations screws, and cephalo-medullary nails. Displaced femoral neck fractures in elderly patients (e.g.>60 years old) are typically treated with either THA or HA as replacement has predictable results with high patient satisfaction.[3] Additionally, failure rates of surgical repair are high in this patient population.[4]

Young adult patients (e.g.<50 years old) are usually treated with operative repair as outcomes of arthroplasty in the young are not well defined[1] and revision surgery is expected due to implant wear over time.[5] Success of repair in younger populations have proved highly variable and frequently unsuccessful due to the higher impact mechanism of injury often complicated by comminution. This poses a challenge to reduction and compression that has attempted to be surgically addressed in a variety of ways, including various screw types and screw-plate combinations. This confounded variability in both mechanism of injury and choice of fixation strategies only serves to obscure a proposed guideline for fixation success. It is currently understood that patients under 50 years old that have Pauwels type III (<50^{o}) fractures experience much higher incidences of fixation failure, avascular necrosis, malunion and nonunion. This is largely due to the biomechanically less favorable sheering forces present. Internal fixation to address these issues varies greatly with use of fixed angle sliding hip screws alongside anti-rotation screws appearing to address the more complicated Pauwels type III fractures most effectively.[1]

In the middle-aged group of 50-59-year-old patients' injury mechanisms, bone quality and comorbidity burden are more variable and decisions between replacement and repair becomes less clear.[2] While outcomes of repair have generally remained less than ideal and highly variable depending on the specific mechanism of injury and repair,[6] arthroplasty still poses the same problem faced by the young cohort as there is strong potential for revision surgery due to part longevity. While revision surgery does not directly impact survivorship, there is an increased likelihood of wound complications, superficial infections, and additional reoperation.[7] More discretionary action is placed in the hands of the physician and their patients, while statistically informed outcomes are lacking synthesis and clarity.

The overall goal of this research is to identify specific surgical fixation strategies performed in correlation to fracture mechanism and patient demographics among individuals 18-59 years old with displaced femoral neck fractures that make them statistically more likely to succeed without complication or revision. This study's primary specific aim is to delineate specific fracture grading aspects and surgically based characteristics among individuals 18-59 years old that directly correlates to successful surgical repair via the method of internal fixation of a displaced femoral neck fracture. We set out with the expectation that patients lacking comorbidities with less complicated factures and with repairs utilizing a locking plate system, sliding hip screws with anti-rotation screws, or spring-loaded cancellous screw triangulation, to experience the lowest incidence of fixation failure, neck shortening and nonunion.

Identifying how patient demographics, co-morbidities, injury mechanism, and surgical treatment characteristics are associated with the best possible surgical outcomes will provide confidence in both patient and clinician centered decisions. This particular project was accomplished in conjunction with the efforts of fellow students as it pertains to assembly of the

patient database. While she attempted to address the overall incidence of failure in this group through a comprehensive statistical analysis of the relative risk factors for failure, this particular project aimed to take an in depth focus into the fracture and repair mechanics and how specifically those more focused factors relate to outcomes.

Materials and Methods Approach:

This is a retrospective, comparative study of young to middle-aged patients (18 to 59 years old) with a femoral neck fracture treated with surgical repair between 2005 and 2017 at 26 different Level 1 trauma centers in North America. A database including approximately 1500 deidentified patient electronic medical records were specifically evaluated and compared on the basis of demographics, injury mechanism and pattern, and specifics of the surgical treatment methods in relation to outcomes and incidence of revision surgeries. Medical records were assessed for demographic related data and detailed measurements were taken, using interval radiographs to study the injury and patient factors, details of fixation performed, post-injury complications and any associated secondary revision surgeries.

A number of aspects of each individual electronic medical record will be evaluated throughout the course of this study including:

- Demographics: This includes sex, age, and race of the patient
- Relevant co-morbidities: This includes body mass index (BMI), smoking, diabetes, steroid use, alcoholism, end stage renal disease (ESRD), and metabolic disorders
- Description of Injury and Repair: This included facture severity, angle, comminution, associated shaft fractures and impact of the injury utilizing measurements acquired from interval radiography.
- "Success" of Surgery: This was qualified on the basis of time to union, level of alignment and minimization of femoral neck shortening in addition to a lack of avascular necrosis, nonunion, or need for revision surgery.

Interval Radiography:

Data from the interval radiography provided a precise measurement of change in hip structure

and location both pre and post injury. Each facture was evaluated for the mechanism and severity of injury, being categorized based on:

1. Modified Garden's classification: accounts for completion and level of displacement for each fracture [8, 9]
2. Modified Pauwels' classification: grades femoral neck fractures by accounting for orientation of the fracture line in degrees.[10]
3. Arlet and Ficat classification: grades the level of severity of avascular necrosis to the hip joint.[11, 12]
4. Orthopedic Trauma Association system classification: standardized medical coding of various fracture types [13]
5. Evidence of fracture nonunion: defined as significant loss of the reduction and fixation of the fracture, or persistence of the fracture for longer than 6 months, or requirement of revision surgery
6. Time required to reach facture union
7. Level of malunion: analyzed using the opposite femoral neck for reference and standardizing measurements using known implant hardware size and adjusting according to imaging magnification.[14-17]
8. Evidence of hip shortening: shortening measured $\geq$15mm equates to failure on the basis that it has been statistically shown to impact gait and function [15-16]
9. Presence of a "shelf sign" fracture: defined by a horizontally oriented fracture line >6mm in length that accommodates load-bearing in a manner that reduces the typical sheer forces present by providing a shelf of sorts to the proximal portion of the femoral neck.

Radiograph magnification controlled for using known implant sizes and scaling subsequent measurements in relationship to those parts (i.e. screw head width or sliding hip screw barrel width).

Surgical Methods and quality:

Fracture reduction and characteristics of fixation were recorded for use of the following hardware components:

1. Fixed-angle devices (FA), this included sliding hip screws (SHS) and cephalo-medullary nails (CN)
    a. Additions of supplemental anti-rotations screws (AR) either partially (PT) or fully (FT) threaded, and/or medial plates (mdpl) were also noted
2. Cortical/cancellous screws (CS) utilizing any variation of partially vs fully threaded cortical vs cancellous combination
    a. Additions of supplemental Pauwels screws (Pau) and/or medial plates (mdpl) were also noted

Quality of surgical repair was also evaluated via examination for evidence of surgical error. Factors such as the quality of fracture realignment (*aka* reduction), decisions on implant types, and their application were assessed according to historical benchmarks. Given that there is generally no accepted method for grading the quality of surgical reduction, fracture reduction was quantified according to the 4-tiered reduction quality grading as defined by Dr. George Haidukewych in the journal of bone and joint surgery.[18] Excellent (reduction score of 1) is defined as <2mm of displacement and <5^{o} of angulation. Good (reduction score of 2) is defined as 2-5mm of displacement and/or 5-10^{o} of angulation. Fair (reduction score of 3) is defined as >5-10mm and/or >10-20^{o} of angulation. Poor (reduction score of 4) is defined as >10mm and/or

>20^{o} of angulation.[18] Fixation failure was defined by a number of data points collected. This included, nonunion at 6 months, need for revision surgery within 1 year, or malunion as indicated by >15mm of femoral neck shortening.

Additional measurements were also collected based on any surgical revision data and radiographs available for those to whom it applied. This includes all the above in addition to method, level of revision (major vs minor), and time to revision surgery. Revision surgery is defined as early re-fixation of femoral neck fractures via valgus intertrochanteric osteotomy, Girdlestone procedure or total and hemi arthroplasty conversions; screw exchange being excluded.

Data Analysis:

Student's t-test was used for analysis of the differences in continuous variables while Chi-square and Fischer's exact were used for differences in proportions for the categorical variables. Proportions were reported as percentage, parametric continuous variables reported as mean± standard deviation, and non-parametric continuous variables reported as the mean with range. The level of statistical significance accepted for all analyses was an alpha = 0.05.

Expert Panel Review:

All interval radiography, and surgical methods and quality was reviewed and verified by a 3-physician panel of orthopedic trauma surgeons following the conclusion of the student's initial completion of data collection to ensure consistency and accuracy in reporting.

Results:

Of the approximately 1500 individual patient charts reviewed amongst patients age 18-59 years, 808 individuals met overall study criteria for further analysis. Of these 808 individuals, 552 individuals had a displaced femoral neck fracture that qualified for analysis of the fixation quality and intervention strategy.

Table 1: General fixation constructs: Comparison of generalized femoral neck fixation strategies across all study participants.

Constructs Compared		Construct 1 (n)	Failure (%)	Construct 2 (n)	Failure (%)	p-value
Construct 1	Construct 2					
All FA	All CS	251	49%	302	65%	**<0.001**
All SHS	All CS	229	50%	302	65%	**<0.001**
CN	All CS	21	38%	302	65%	**0.014**
All SHS	CN	229	50%	21	38%	0.305

Legend: Bolded text indicates statistical significance

Table one demonstrates overall comparison of the entire patient cohort categorized by the most general constructs of fixed angle devices and cortical/cancellous screws. 251 individuals received some form of a FA device, whether an SHS or CN. 302 individuals underwent fixation via CS. FA devices demonstrated a significantly greater rate of fixation success in comparison to the CS group. All SHS and CN constructs individually demonstrated similar significantly less incidence of failure compared to the CS group. When comparing the two most generalized FA construct devices no significance was identified between the two with CN demonstrating a lower incidence of failure at 38%.

Table 2: Fixed-angle constructs: Comparison of all fixated angle device variations for femoral neck fixation across all study participants.

Constructs Compared		Construct 1 (n)	Failure (%)	Construct 2 (n)	Failure (%)	p-value
Construct 1	Construct 2					
SHS alone	CN	36	64%	21	38%	0.059
SHS alone	SHS+AR	36	64%	190	47%	0.061
SHS alone	SHS+mdpl	36	64%	17	59%	0.723
SHS alone	SHS+AR+mdpl	36	64%	12	50%	0.394

SHS+AR	SHS+mdpl	190	47%	17	59%	0.343
SHS+ARPT	SHS+ARFT	148	47%	28	43%	0.714

Legend: Bolded text indicates statistical significance

Table 2 compared variations amongst the FA devices. The most common FA construct implemented was the SHS+AR, representing 190 out of 251 (76%). No significantly superior FA device was identified, with SHS+ARFT and CN having the lowest incidence of failure at 43% and 38% failure respectively.

Table 3: Cannulated Screw Constructs: Comparison of variations in screw fixation for femoral neck fixation across all study participants.

Constructs Compared		Construct 1 (n)	Failure (%)	Construct 2 (n)	Failure (%)	p-value
Construct 1	Construct 2					
CS Alone	CS+mdpl	244	65%	22	77%	0.236
CS Alone	CS+Pau	244	65%	29	62%	0.775
CS Alone	CS+Pau+mdpl	244	65%	3	100%	~
CS+Pau	CS+mdpl	29	62%	22	77%	0.246

Legend: Bolded text indicates statistical significance, ~ indicates unable to perform statistical analysis

Table 3 compares variations amongst the CS constructs. No significantly superior CS construct was identified, with CS+Pau demonstrating the lowest failure incidence of 62%. Of note CS+Pau+mdpl construct analysis was unable to be performed with 100% failure rate amongst the small group of 3 individuals who received this construct.

Table 4: Subgroup constructs compared: FA vs CS groups

Constructs Compared		Construct 1 (n)	Failure (%)	Construct 2 (n)	Failure (%)	p-value
Construct 1	Construct 2					
CS+mdpl	SHS+AR	22	77%	190	47%	**0.007**
CS+Pau	SHS+AR	29	62%	190	47%	0.127
CS+Pau+mdpl	SHS+AR	3	100%	190	47%	~
CS Alone	SHS+AR	244	65%	190	47%	**<0.001**
CS+mdpl	SHS+mdpl	22	77%	17	58%	0.216
CS+Pau	SHS+mdpl	29	62%	17	58%	0.828
CS+Pau+mdpl	SHS+mdpl	3	100%	17	58%	~
CS Alone	SHS+mdpl	244	65%	17	58%	0.621
CS+mdpl	SHS+AR+mdpl	22	77%	12	50%	0.104
CS+Pau	SHS+AR+mdpl	29	62%	12	50%	0.475

CS+Pau+mdpl	SHS+AR+mdpl	3	100%	12	50%	~
CS Alone	SHS+AR+mdpl	244	65%	12	50%	0.298
CS+mdpl	CN	22	77%	21	38%	**0.009**
CS+Pau	CN	29	62%	21	38%	0.094
CS+Pau+mdpl	CN	3	100%	21	38%	~
CS Alone	CN	244	65%	21	38%	**0.015**
CS+mdpl	SHS+ARPT	22	77%	148	47%	**0.007**
CS+Pau	SHS+ARPT	29	62%	148	47%	0.129
CS+Pau+mdpl	SHS+ARPT	3	100%	148	47%	~
CS Alone	SHS+ARPT	244	65%	148	47%	**<0.001**
CS+mdpl	SHS+ARFT	22	77%	28	43%	**0.014**
CS+Pau	SHS+ARFT	29	62%	28	43%	0.146
CS+Pau+mdpl	SHS+ARFT	3	100%	28	43%	~
CS Alone	SHS+ARFT	244	65%	28	43%	**0.027**
CS+mdpl	SHS Alone	22	77%	36	64%	0.285
CS+Pau	SHS Alone	29	62%	36	64%	0.919
CS+Pau+mdpl	SHS Alone	3	100%	36	64%	~
CS Alone	SHS Alone	244	65%	36	64%	0.802

Legend: Bolded text indicates statistical significance, ~ indicates unable to performed statistical analysis

Table 4 compares all subgroup constructs of table 2 to those of table 3 in attempt to identify the superior subconstruct overall. SHS+AR, whether partially or fully threaded and CN constructs demonstrated significantly less incidence of failure in comparison to the CS Alone and CS+mdpl group. CS+Pau+mdpl was once again insufficient data for analysis. Of note the CS+Pau construct success was insignificantly different from all SHS+AR (PT or FT) and CN constructs. SHS Alone, without additional hardware failed to demonstrate significance to any of the CS subconstructs with a 64% failure rate.

Table 5: General fixation constructs compared by: patient age

Age ≤44						
Constructs Compared		Construct 1 (n)	Failure (%)	Construct 2 (n)	Failure (%)	p-value
Construct 1	Construct 2					
All FA	All CS	140	39%	142	56%	**0.003**
All SHS	All CS	123	39%	142	56%	**0.005**
CN	All CS	17	35%	142	56%	**0.010**
All SHS	CN	123	39%	17	35%	0.767
*SHS+AR	All CS	106	37%	142	56%	**0.002**

Age >44						
Constructs Compared		Construct 1 (n)	Failure (%)	Construct 2 (n)	Failure (%)	p-value
Construct 1	Construct 2					
All FA	All CS	110	62%	160	73%	0.064
All SHS	All CS	105	62%	160	73%	0.070
CN	All CS	4	50%	160	73%	0.322
All SHS	CN	105	62%	4	50%	0.631
*SHS+AR	All CS	84	59%	160	73%	**0.039**

Legend: Bolded text indicates statistical significance, * indicates subgroup constructs included of clinical and statistical significance

In tables 5-14 fixation constructs were subsequently compared in relation to patient demographic and comorbid identifiers. Of note data analysis from tables 1-4 was performed in the same manner on all these subdivided data sets, however data beyond the general constructs of FA, SHS, CN and CS groups compared was only reported if a particular subgroup construct demonstrated a statistical significance that varied from the tables 1-4.

In table 5, all fixation devices were compared amongst individuals divided by the median age of the study population. In a similar manner to the overall population in table 1, the cohort ≤44 years old showed that FA devices demonstrated a significantly greater rate of fixation success in comparison to the CS group. In opposition the cohort >44 years did not demonstrate a significant difference in incidence of fixation success between the FA, SHS, and CN constructs. Of note however, amongst the subconstructs analyzed, SHS+AR demonstrated the statistically significantly less incidence of fixation failure when compared to All CS.

In comparing the younger to older cohorts, incidence of fixation failure was lower in the younger cohort, with All CS failing 56% vs 73% in the older cohort, and All FA failing 39% in the younger cohort vs 62% in the older cohort.

Table 6: General fixation constructs compared by: patient sex

Female						
Constructs Compared		Construct 1 (n)	Failure (%)	Construct 2 (n)	Failure (%)	p-value
Construct 1	Construct 2					

All FA	All CS	85	40%	109	66%	**<0.001**
All SHS	All CS	79	41%	109	66%	**<0.001**
CN	All CS	5	20%	109	66%	**0.036**
All SHS	CN	79	41%	5	20%	0.363
*SHS+AR	All CS	68	37%	109	66%	**<0.001**
Male						
Constructs Compared		Construct 1 (n)	Failure (%)	Construct 2 (n)	Failure (%)	p-value
Construct 1	Construct 2					
All FA	All CS	164	53%	189	64%	**0.037**
All SHS	All CS	148	54%	189	64%	0.064
CN	All CS	16	44%	189	64%	0.108
All SHS	CN	148	54%	16	44%	0.433
*SHS+AR	All CS	122	52%	189	64%	**0.043**

Legend: Bolded text indicates statistical significance, * indicates subgroup constructs included of clinical and statistical significance

In table 6, all fixation devices were compared amongst individuals divided by sex. In a similar manner to the overall population in table 1, the female cohort also demonstrated a significantly greater rate of fixation success in the FA group compared to the CS group. The male group still demonstrated lower incidence of failure amongst FA devices compared to CS but saw higher incidence of failures amongst all general constructs and did not demonstrate significant differences between all SHS and all CS groups. Of note, with both male and female cohorts, SHS+AR demonstrated statically less failure compared to the all CS group.

Table 7: General fixation constructs compared by: patient BMI

BMI ≤25						
Constructs Compared		Construct 1 (n)	Failure (%)	Construct 2 (n)	Failure (%)	p-value
Construct 1	Construct 2					
All FA	All CS	113	51%	121	56%	0.455
All SHS	All CS	105	52%	121	56%	0.565
CN	All CS	7	29%	121	56%	0.153
All SHS	CN	105	52%	7	29%	0.222
*SHS Alone	CS+pau	13	77%	10	30%	**0.024**
*SHS Alone	Nail	13	77%	7	29%	**0.035**
BMI >25						
Constructs Compared		Construct 1 (n)	Failure (%)	Construct 2 (n)	Failure (%)	p-value
Construct 1	Construct 2					
All FA	All CS	120	48%	145	68%	**<0.001**

All SHS	All CS	107	48%	145	68%	**<0.001**
CN	All CS	13	46%	145	68%	0.106
All SHS	CN	107	48%	13	46%	0.918

Legend: Bolded text indicates statistical significance, * indicates subgroup constructs included of clinical and statistical significance

In table 7, all fixation devices were compared amongst individuals divided by median BMI of the study population. In a similar manner to the overall population in table 1, the BMI >25 cohort, FA devices demonstrated a significantly greater rate of fixation success in comparison to the CS group. However, unlike the combined cohort from table 1, CN failed to demonstrate statistical advantage in comparison to All CS constructs. In the BMI $\leq$25 cohort, % failure amongst FA devices was slightly increased from 48% to 51%, however All CS constructs were more successful with a 56% incidence of failure compared to 68% failure in the BMI >25 cohort. This resulted in an insignificant difference between FA and CS failure incidence. When comparing subconstructs within the BMI $\leq$25 cohort, CS+Pau and CN both demonstrated substantial success with only 30% and 29% failure respectively and were statistically significantly less likely to fail than SHS Alone.

Table 8: General fixation constructs compared by: fixation reduction quality

Good reduction (quality score 1-2)						
Constructs Compared		Construct 1 (n)	Failure (%)	Construct 2 (n)	Failure (%)	p-value
Construct 1	Construct 2					
All FA	All CS	214	43%	255	62%	**<0.001**
All SHS	All CS	199	44%	255	62%	**<0.001**
CN	All CS	15	33%	255	62%	**0.028**
All SHS	CN	199	44%	15	33%	0.412
Poor reduction (quality score 3-4)						
Constructs Compared		Construct 1 (n)	Failure (%)	Construct 2 (n)	Failure (%)	p-value
Construct 1	Construct 2					
All FA	All CS	36	81%	47	81%	0.973
All SHS	All CS	29	86%	47	81%	0.547
CN	All CS	6	50%	47	81%	0.089
All SHS	CN	29	86%	6	50%	**0.044**

Legend: Bolded text indicates statistical significance, * indicates subgroup constructs included of clinical and statistical significance

In table 8, all fixation devices were compared amongst individuals divided by good (Haidukewych reduction quality scores 1-2) and poor reduction (Haidukewych reduction quality scores 3-4). Notably, the vast majority of study participants received initially appropriate fracture reduction (469 of 552 participants; 90%), with an overall fixation failure of 53%. Once again FA constructs demonstrated statistically significantly less incidence of fixation failure. No singular fixation device was statistically less likely to fail compared to another FA construct or subconstruct.

Individuals who had poor reduction quality only represented 10% of the study population (83 individuals). They did experience a significant increase in failure of fixation at 81% overall failure (p=<0.001). FA devices did not prove superior to CS, however CN constructs did demonstrate statistically less failure incidence than SHS.

Table 9: General fixation constructs compared by: presence of any metabolic disease

Any metabolic disease						
Constructs Compared		Construct 1 (n)	Failure (%)	Construct 2 (n)	Failure (%)	p-value
Construct 1	Construct 2					
All FA	All CS	96	50%	113	67%	**0.011**
All SHS	All CS	81	49%	113	67%	**0.012**
CN	All CS	14	50%	113	67%	0.201
All SHS	CN	81	49%	14	50%	0.966
No metabolic disease						
Constructs Compared		Construct 1 (n)	Failure (%)	Construct 2 (n)	Failure (%)	p-value
Construct 1	Construct 2					
All FA	All CS	154	48%	188	63%	**0.005**
All SHS	All CS	147	50%	188	63%	**0.012**
CN	All CS	7	14%	188	63%	**0.009**
All SHS	CN	147	50%	7	14%	0.067

Legend: Bolded text indicates statistical significance, * indicates subgroup constructs included of clinical and statistical significance

In table 9, all fixation devices were compared amongst individuals divided by presence of any metabolic disease. This included any individuals with history of smoking, diabetes, alcoholism,

steroid use or end stage renal disease (ESRD). Metabolic diseases were quite prevalent in this study population consisting of 209 individuals. Compared to tables 1-4, individuals regardless of the presence of metabolic disease demonstrated similar results of FA devices resulting in less incidence of failure when compared to All CS devices. The singular statical difference between groups was related to CN constructs which showed significantly less failure in those without any metabolic disease when compared to All CS constructs.

Table 10: General fixation constructs compared by: patient alcohol use

Alcohol use						
Constructs Compared		Construct 1 (n)	Failure (%)	Construct 2 (n)	Failure (%)	p-value
Construct 1	Construct 2					
All FA	All CS	27	74%	41	80%	0.533
All SHS	All CS	23	69%	41	80%	0.322
CN	All CS	4	100%	41	80%	0.323
All SHS	CN	23	69%	4	100%	0.200
No alcohol use						
Constructs Compared		Construct 1 (n)	Failure (%)	Construct 2 (n)	Failure (%)	p-value
Construct 1	Construct 2					
All FA	All CS	223	46%	261	62%	**<0.001**
All SHS	All CS	205	47%	261	62%	**0.001**
CN	All CS	17	24%	261	62%	**<0.001**
All SHS	CN	205	47%	17	24%	0.058
*CS+Pau	CN	26	62%	17	24%	**0.015**

Legend: Bolded text indicates statistical significance, * indicates subgroup constructs included of clinical and statistical significance

In table 10, all fixation devices were compared amongst individuals divided by alcohol use status alone in attempt to delineate if any particular metabolic disease state changed results. This was additionally performed individually on all other contributing metabolic diseases with other disease states providing non-contributory results. Overall incidence of failure amongst those with alcohol use disorder was higher (78% failure) than those without history of alcohol use (55% failure) (p= <0.001). No particular fixation construct was superior amongst the alcohol use cohort. In those without history of alcohol use, similar significance was demonstrated as to what

was demonstrated in tables 1-4. Of note, CS+Pau construct was not statistically inferior to any of the FA constructs, excluding the CN construct.

Table 11: General fixation constructs compared by: presence of fracture comminution

Fracture comminution						
Constructs Compared		Construct 1 (n)	Failure (%)	Construct 2 (n)	Failure (%)	p-value
Construct 1	Construct 2					
All FA	All CS	156	53%	183	68%	**0.006**
All SHS	All CS	142	54%	183	68%	**0.009**
CN	All CS	14	50%	183	68%	0.175
All SHS	CN	142	54%	14	50%	0.801
*SHS Alone	SHS+AR	20	85%	121	48%	**0.002**
*SHS Alone	SHS+AR+mdpl	20	85%	9	44%	**0.024**
No fracture comminution						
Constructs Compared		Construct 1 (n)	Failure (%)	Construct 2 (n)	Failure (%)	p-value
Construct 1	Construct 2					
All FA	All CS	82	41%	107	63%	**0.004**
All SHS	All CS	75	43%	107	63%	**0.008**
CN	All CS	6	17%	107	63%	**0.025**
All SHS	CN	75	43%	6	17%	0.212

Legend: Bolded text indicates statistical significance, * indicates subgroup constructs included of clinical and statistical significance

In table 11, all fixation devices were compared amongst individuals divided by presence of fracture comminution. Fracture comminution was a common finding of radiography with 339 incidences occurring. Amongst those without comminution similar results to tables 1-4 were demonstrated with the FA devices showing significantly less failure compared to CS, but no statistically superior FA device was identified. In those with fracture comminution, while still demonstrating all FA device success compared to CS, SHS alone had statistically higher rates of failure while the other subconstructs of SHS+AR and SHS+AR+mdpl were significantly less likely to fail by comparison.

Table 12: General fixation constructs compared by: presence of associated femoral shaft fracture

Femoral shaft fracture						
Constructs Compared		Construct 1 (n)	Failure (%)	Construct 2 (n)	Failure (%)	p-value
Construct 1	Construct 2					
All FA	All CS	54	19%	37	38%	**0.040**
All SHS	All CS	45	18%	37	38%	**0.041**
CN	All CS	9	17%	37	38%	0.378
All SHS	CN	45	18%	9	17%	0.754
No femoral shaft fracture						
Constructs Compared		Construct 1 (n)	Failure (%)	Construct 2 (n)	Failure (%)	p-value
Construct 1	Construct 2					
All FA	All CS	196	57%	265	69%	**0.011**
All SHS	All CS	183	57%	265	69%	**0.014**
CN	All CS	12	50%	265	69%	0.175
All SHS	CN	183	57%	12	50%	0.617
*SHS Alone	SHS+AR	27	78%	154	54%	**0.021**

Legend: Bolded text indicates statistical significance, * indicates subgroup constructs included of clinical and statistical significance

In table 12, all fixation devices were compared amongst individuals divided by presence of an associated femoral shaft fracture. The median age of individuals with associated femoral shaft fractures was 33 years old. Both cohorts with and without femoral shaft fractures demonstrated similar general construct results to those described in table 1. The notable differences being that in both cohorts CN constructs failed to demonstrate significantly less incidence of failure compared to All CS cohorts. In those without associated femoral shaft fractures a unique subconstruct finding was identified in which SHS+AR demonstrated significantly less incidence of failure compared to the use of SHS Alone.

Table 13: General fixation constructs compared by: presence of shelf sign

Shelf sign						
Constructs Compared		Construct 1 (n)	Failure (%)	Construct 2 (n)	Failure (%)	p-value
Construct 1	Construct 2					
All FA	All CS	60	27%	36	52%	**0.010**
All SHS	All CS	53	28%	36	52%	**0.020**
CN	All CS	7	14%	36	52%	0.062
All SHS	CN	53	28%	7	14%	0.431
No shelf sign						
Constructs Compared			Failure (%)	Construct 2		p-value

Construct 1	Construct 2	Construct 1 (n)		(n)	Failure (%)	
All FA	All CS	184	57%	258	68%	**0.021**
All SHS	All CS	169	57%	258	68%	**0.028**
CN	All CS	14	50%	258	68%	0.167
All SHS	CN	169	57%	14	50%	0.591

Legend: Bolded text indicates statistical significance, * indicates subgroup constructs included of clinical and statistical significance

In table 13, all fixation devices were compared amongst individuals divided by presence of a shelf sign on interval radiography. Incidence of failure amongst all individuals with the shelf sign was 36% compared to 63% incidence of failure amongst those without the presence of a shelf sign. Both cohorts with and without presence of the shelf sign demonstrated statistically similar results to the general constructs described in table 1. The notable differences being that in both cohorts CN constructs failed to demonstrate significantly less incidence of failure compared to All CS cohorts.

Discussion and Innovation:

When comparing the general constructs of FA devices and CS constructs our data has made clear that in the general patient population, in addition to most all subdivided patient populations of individuals 18-59 with displaced femoral neck fractures, FA devices are the statistically superior internal fixation device of choice for achieving successful fixation.

Amongst the FA devices used, SHS+AR was by far the most used construct. While no particular FA device was statistically superior to another this may have been limited by the relatively low incidences of alternative FA constructs, leaving the comparison groups much smaller and less likely to demonstrate these statistical differences. Regardless, SHS+AR demonstrated quite a low incidence of failure (47%) second only to the CN (38%), which was far less commonly implemented. Notably, the SHS Alone group demonstrated a much higher incidence of failure (64%), suggesting the impactful addition of anti-rotation screws that warrants further examination especially given the alpha of 0.061 when comparing SHS+AR to SHS Alone. When comparing AR screws on the basis of partially threaded (PT) vs fully threaded (FT), ARFT demonstrated 43% failure compared to ARPT's 47% failure, again suggesting possible impact of anti-rotation screw choice. A larger sample size of ARFT may have led to statistical significance and warrants further investigation.

In a similar fashion to the FA constructs, the CS constructs also failed to demonstrate a statistically superior choice in hardware amongst the grouping. CS+Pau resulted in the lowest incidence of failure at 62% but CS Alone was not far behind at 65% failure. Of note, while all CS+Pau+mdpl failed, sample size was very limited with only 3 individuals receiving this construct. Subsequently no analysis was able to be performed in comparing this construct to the

others and thus conclusions are not able to be made as to its success or lack thereof in comparison to the alternative interventions.

When subconstructs of both the FA and CS classes were compared amongst each other, CN and SHS+AR demonstrated superior success to CS Alone and CS+Mdpl but the CS+Pau construct was insignificantly different from all SHS+AR whether PT or FT and CN constructs suggesting not all variations of CS constructs can be ruled out as viable fixation options, given that it remains at the least statistically non-inferior. When SHS Alone was analyzed in comparison to CS subconstructs, its failure to demonstrate any significant difference in success, once again highlights the impactful nature of additional hardware, the anti-rotation screw in particular.

While overall demographic and co-morbidity impact of fixation success is the purpose and aim of another study utilizing the same database of patients, impact of these patient related factors needs comparison based on the construct used as well. Amongst the cohort >44 years there failed to be a significant difference between the FA, SHS, and CN constructs. However, amongst the subconstructs analyzed, SHS+AR demonstrated the statistically significantly less incidence of fixation failure when compared to All CS, making it appear to be the most desirable intervention in those age 44-59. Unsurprisingly the young population had much greatest fixation success likely related to a myriad of factors including, better bone quality, ability to participate fully in recovery, and decreased incidence of comorbidity.

While incidence of failure amongst CS devices was similar between sexes, females demonstrated better fixation success with FA devices that played out as statistically superior as well. Both sexes showcased the unique advantages of the SHS+AR construct compared to CS. Males failure to demonstrate the superiority of the FA construct in general was unique and

unexpected. The male group had higher incidence of failure, which may impact this but further investigation would be require to delineate the sources of these failures, whether it be higher impact and complicated injuries or anatomic variabilities in sheer force load between sexes.

Increased BMI showcased advantages in an FA device in particular while lower BMI individuals were able to tolerate CS fixation just as well. This likely pertains to the shearing forces at play in this fracture with CS constructs being limited in their ability to withstand these sheering forces particularly in overweight to obese individuals.

As expected, reduction quality greatly impacts success and our analysis served to highlight how the skill of a surgeon in their ability to reduce a fracture to as near anatomical as possible will impact overall outcome. This is clearly seen through the differences in fixation failure of 53% overall in good fixation vs 81% in poor fixation ($p=<0.001$). FA devices remained superior in those with good fixation but no clear winner was demonstrated in poor fixation, likely related to the mechanical disadvantages presented by errors or limitations in part placement. The only construct to demonstrate significant advantage to any other constructs was the CN in comparison to All SHS. Presumably its ability to maintain substantially more shear force load compared to other FA devices might contribute to its improved success regardless of the reduction quality.

Metabolic disease was quite prevalent in the study population. This was expected on the basis that the incidence of displaced FNF fractures is higher in those with some component of bone disease often caused by these metabolic disorders. The presence of any metabolic disease, however, did not statistically influence the success of fixation constructs and the FA construct remained superior in a similar manner to the overall population. Some variation in CN success

was seen when compared to the general population, likely clinically irrelevant as sample size of the CN population was quite limited with this analysis.

As expected, and as historically documented throughout medical literature, alcohol use causes suppression of bone marrow and limited healing abilities.[19] This population demonstrated this as well and in doing so failed to demonstrate significance amongst any constructs with overall failure of 78% vs 53% in those without alcohol use ($p = <0.001$).

As it related to complicating features of the FNF injury, comminution highlighted the limited success of SHS alone and the benefits of additional components like plates and anti-rotation screws amongst the FA constructs. When the cohort was divided by the presence of associated femoral shaft fractures, know to complicate femoral neck fracture repair, limited differences in device success were observed in comparison to the overall population. That said a unique observation was made in that those with associated shaft fractures appeared much less likely to fail. This might be able to be explained logically as the median age of individuals with associated shaft fractures is 33 years, 11 years younger than overall population which may explain decreased rates of fixation failure as was showcased in table 5. Limited sample size may also contribute to this unique variation. Of note those without shaft fractures appeared to have significantly better success with SHS+AR compared to SHS Alone. Concerning the presence of a shelf-sign, the presence of this fracture type appeared to have limited impact on choosing the best fixation strategy with FA still proving superior, however the notable decrease in failure to achieve fixation showcases the physical advantages of decreased shear forces being present on successful fixation.

Future Directions:

The end goal of this project was to provide a fundamental body of evidence which would better enable the choice surgical interventions for displaced femoral neck fractures repair in young to middle aged individuals. This evidence-based approach should minimize femoral neck shortening, nonunion, malunion, incidence of avascular necrosis, and need for revision surgery.[7] While compelling evidence has already been showcased in favor of the general FA device, the future of this research hopes to provide the grounds to creating a more easily implemented clinical and radiographically based evaluation process that streamlines care and recommends the most appropriate surgical approach in a more nuanced fashion beyond that of the generalized construct, which our current study is in some regards limited to. Ability of a clinical tool to make specific subconstruct recommendations based on patient demographics and co-morbidities would provide the most powerful impact to patient success.

Conclusions:

This study served to demonstrate the clear statistical superiority of the fixed-angle device amongst the general population, with sliding hip screws paired with anti-rotation screws promising best results in a number of subdivided patient groups including, both males and females, both younger and older cohorts, those with fracture comminution, and those without associated femoral shaft fractures. The cephalic nail, while less frequently implemented also posed the lowest incidence of failure with significant advantages in all ages, females, and those without alcohol use, metabolic disease or fracture comminution. Overall, with consideration given to patient demographic and co-morbidity, FA constructs should represent the internal fixation standard of care in patients aged 18-59. In only limited circumstances should CS constructs specifically with the addition of Pauwels screws be considered.

Surgical repair is commonly implemented in the younger group and arthroplasty is preferred in the older age group.[8] Clinical practice paradigms for the younger group have historically failed to promise reasonable chances of success and this needed to be addressed. While many physicians, per the guidelines of the American Academy of Orthopedic Surgeons, are already taking into consideration the important impact that current health and future lifestyle has on their surgical intervention of choice,[2] physicians are having to rely on largely anecdotal evidence. Through this study, we have been able to provide the initial foundation to this evidence-based research, and now know that physicians can move forward with confidence that the FA is clearly superior throughout a majority of this population.

Compliance:

The project required and received IRB approval but no IACUC approval given the retrospective and de-identified nature of the project from The University of Texas Southwestern Medical Center IRB# STU-2020-0748. I have completed the required CITI training in order to participate in this research. De-identified patient charts have been collected from 26 level 1 trauma centers across the country. Deidentified information includes patient electronic medical records along with pre and post operation x-ray imaging. Review of x-ray findings and surgical methodology and quality standards within study were analyzed and confirmed by a non-biased 3rd party panel of 3 orthopedic surgeons to eliminated concerns for bias or inconsistency in data extraction.

List of Abbreviations

CN: Cephalic Nail

CS: Cortical screw

CS Alone: Cortical screw without additional hardware used for fixation

CS+mdpl: Cortical screw with medial buttress plate use

CS+Pau: Cortical screw with Pauwels screw used

CS+Pau+mdpl: Cortical screw with Pauwels screw and medial buttress plate used

FA: Fixed angle device

SHS: Sliding hip screw

SHS+AR: Sliding hip screw with additional anti-rotation screw(s) used

SHS+ARPT: Sliding hip screw with additional partially threaded anti-rotation screw(s) used

SHS+ARFT: Sliding hip screw with additional fully threaded anti-rotation screw(s) used

SHS+mdpl: Sliding hip screw with medial buttress plate use

SHS+AR+mdpl: Sliding hip screw with anti-rotation screw(s) and medial buttress plate used

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