Advances in Orthopedics

Hip Fracture Evaluation and Management

Lead Guest Editor: Nabil Ebraheim
Guest Editors: Sumon Nandi, Paul Dougherty, and Gary Gruen

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Contents

HIP Fracture Evaluation and Management
Sumon Nandi, Paul Dougherty, Gary Gruen, and Nabil Ebraheim
Editorial (2 pages), Article ID 2717518, Volume 2019 (2019)

Total Hip Arthroplasty for Bilateral Femoral Neck Stress Fracture: A Case Report and Review of the Literature
Kevin Moerenhout, Georgios Gkagkalis, G.-Yves Laflamme, Dominique M. Rouleau, Stéphane Leduc, and Benoit Benoit
Review Article (8 pages), Article ID 2720736, Volume 2019 (2019)

Hip Fracture Nonunions: Diagnosis, Treatment, and Special Considerations in Elderly Patients
Sharon Babcock and James F. Kellam
Review Article (11 pages), Article ID 1912762, Volume 2018 (2018)

Predicting Discharge Location among Low-Energy Hip Fracture Patients Using the Score for Trauma Triage in the Geriatric and Middle-Aged (STTGMA)
Sanjit R. Konda, Hesham Saleh, Ariana Lott, and Kenneth A. Egol
Research Article (6 pages), Article ID 9793435, Volume 2018 (2018)

Management of Subtrochanteric Proximal Femur Fractures: A Review of Recent Literature
Christopher Jackson, Mina Tanios, and Nabil Ebraheim
Review Article (7 pages), Article ID 1326701, Volume 2018 (2018)

Standardised Warfarin Reversal Expedites Time to Theatre for Fractured Neck of Femur Surgery and Improves Mortality Rates: A Matched Cohort Study
Thomas S. Moores, Benjamin D. Chatterton, Matthew J. Walker, and Phillip J. Roberts
Research Article (8 pages), Article ID 4791214, Volume 2018 (2018)

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Volume 2019, Article ID 2717518, 2 pages
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Editorial

HIP Fracture Evaluation and Management

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Hip fracture incidence is over 250,000 per year in the United States and is expected to grow to 850,000 by the year 2040 [1]. The severity of a hip fracture is underscored by the mortality rate of 20 to 30% in the year following injury [1, 2]. Most hip fractures occur in those older than 50, a demographic in which there is a higher prevalence of comorbidities [3]. As a result, minimizing perioperative adverse events while maximizing postoperative function and reoperation-free survival is essential in hip fracture patients. These aims not only seek to optimize quality of care in a large patient population, but also control cost as hip fractures comprise the majority of orthopaedic trauma-associated health care expenditures [4].

In this issue, investigators discuss preoperative optimization, intraoperative surgical technique, discharge planning, and management of postoperative complications in hip fracture patients. By offering guidance to surgeons throughout the entire episode of care, from hospital admission to follow-up, we hope to provide a broad-based overview of hip fracture evaluation and management.

T. S. Moores and colleagues describe an effective protocol for reversing the effect of warfarin in hip fracture patients that decreases time to the operating room (OR) following presentation. Morbidity and mortality following hip fracture are mitigated by decreasing time to OR following injury, so Moores' findings are impactful.

Subtrochanteric femur fractures pose a clinical challenge, not only due to the technical difficulty of reduction and fixation, but also the high rate of nonunion. C. Jackson et al.'s text offers technical pearls within the framework of an anatomic and biomechanical discussion that is helpful to surgeons as they strive to minimize these issues.

S. R. Konda and his coauthors present use of a validated risk assessment tool to predict discharge disposition and readmission among hip fracture patients. Strategies for optimization of discharge planning are offered to minimize costs associated with the hip fracture episode of care.

Nonunion following hip fracture fixation in the elderly is highly consequential as revision surgery may be required in this medically frail and functionally compromised patient population. J. F. Kellam et al. provide a discussion of optimal methods for hip fracture fixation to prevent nonunion, a rubric for determining the cause of nonunion, and revision surgery techniques to treat nonunion.

Nearly all orthopaedic surgeons care for hip fracture patients. In the issue to follow, we aim to present papers that are immediately applicable to the clinical practices of our broad audience.

Conflicts of Interest

The editors declare that there are no relevant conflicts of interest.

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Gary Gruen
Nabil Ebraheim

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Review Article

Total Hip Arthroplasty for Bilateral Femoral Neck Stress Fracture: A Case Report and Review of the Literature

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Femoral neck stress fractures (FNSFs) can be treated conservatively or surgically, depending on initial displacement and patient condition. Surgical treatment options include internal fixation, with or without valgus osteotomy or hip arthroplasty, either hemi or total. The latter is mainly considered when initial treatment fails. A review of the literature shows that total hip arthroplasty (THA) is only considered as primary treatment in displaced fractures (type 3) in low-demand patients. We present a case of successive bilateral FNSF in a young active patient, where a THA was performed on one side, after failed internal fixation, and where it was chosen as primary treatment on the other side after failed conservative treatment.

1. Introduction

Stress fractures are infrequent lesions due to overloading and/or repetitive overuse and can occur at several sites, with the more common being the metatarsals, femoral/tibial shaft, and femoral neck. They can be subcategorized into insufficiency fractures when an abnormal bone fractures under normal stresses and into fatigue fractures when a normal bone fractures under abnormal stresses [1]. The physiopathologic substrate is the combination of an imbalance between bone remodeling capacity and repetitive stress. Endocrine, metabolic, and pharmacologic causes have been described.

Femoral neck stress fractures (FNSFs) represent 5% of all stress fractures in the general population and are encountered more often, up to 15%, in athletes [1]. More specifically, it is seen in long-distance runners and can be associated with the "female athlete triad" [2, 3]. In nondisplaced incomplete femoral stress fractures, treatment is nonoperative with non-weight-bearing and activity cessation. In complete fractures, or when conservative treatment fails, internal fixation by percutaneous screw fixation or dynamic hip screw (DHS) is applied. Other treatment possibilities are intertrochanteric osteotomy or hip arthroplasty, either hemi or total (THA). The latter is mainly reserved as a salvage option in cases where previous surgical treatment has failed. We present the case of a young patient who presented with femoral neck stress fractures on both sides within a two-year span. THA has been chosen as a salvage procedure after nonunion following internal fixation on one side and as the primary surgical treatment on the other side.

2. Case Report

A 46-year-old female patient, who used to run three times a week (20 km/week), presented to our outpatient clinic in 2016 with right groin pain, which had begun a few days before without trauma. She was under treatment for multiple sclerosis since 2002, taking teriflunomide daily. Initial X-rays

(a) (b)

Figure 1: (a) AP pelvic X-ray showing a stress fracture of the right femoral neck. (b) Frontal view on CT scan of the right hip confirming the femoral neck fracture.

(a) (b)

Figure 2: (a) AP pelvic X-ray and (b) lateral view of the right hip after dynamic hip screw (DHS), 6 weeks after surgery. The implant is in good position.

Figure 3: Right hip X-ray showing mobility around the DHS (arrows) and a fracture line on the compression side.

showed a dense line in the femoral neck, with lateral cortex disruption on the tension side. A stress fracture was suspected and confirmed on CT scan (Figures 1(a) and 1(b)). The patient underwent internal fixation by DHS with a good radiographic result (Figure 2). However, groin pain was still present after 1 year, disabling all sports activity. X-rays were taken, showing radiolucency around the cervicocephalic screw, probably due to interfragmentary mobility, and signs of nonunion, mainly on the compression side (Figure 3). A THA using a cementless stem and a press-fit cup (AMIS/Versafit, Medacta®, Switzerland) with ceramic on ceramic bearing was performed (Figure 4), without complications. Pathological exam of the retrieved femoral head showed avascular necrosis.

Two years later, aged 48 years, the patient returned because of pain in her left groin, with no traumatic event

Figure 4: AP pelvic X-ray 6 weeks after right noncemented THA.

present in the previous days. Initial X-rays and CT scan were normal. Due to the history of the patient, non-weight-bearing was applied and an MRI was taken. This MRI showed bone marrow edema of the left hip on the compression side. Follow-up X-rays showed a minimally displaced femoral neck fracture of the left hip (Figure 5).

Blood samples and metabolic analysis (vitamin D, Ca, P, TSH, PTH, and VIH) were normal. Body mass index was normal, and "female athlete triad" syndrome was excluded as there were no menstrual abnormalities. Osteoporosis was excluded by DEXA scan. Four months of nonoperative treatment with non-weight-bearing protocol found the patient still in pain. X-rays confirmed a nondisplaced complete fracture of the femoral neck. After discussion with the patient, we opted for primary THA (Figure 6). The same combination of implants as the contralateral side was used. The patient was discharged from hospital one day after surgery with no adverse events, with a Harris Hip Score (HHS) of 94 and a Hip disability and Osteoarthritis Outcome Score (HOOS) of 85.6 for her left hip at 5 months postoperatively. HHS and HOOS were, respectively, 99.9 and 94.6 for her right hip at two years after surgery. The patient regained walking activity without support four weeks after surgery but has yet to regain all previous sports activity.

3. Review of the Literature

A medical literature search was performed in MEDLINE (PubMed) database. The keywords used were bilateral, femoral, neck, stress, fatigue, and fractures. Only papers published in English were considered. Radiology papers as well as papers with fractures due to trauma or located elsewhere than the femoral neck were rejected. Three case series and 36 case reports matched the search criteria and were retained for review.

Bilateral FNSFs are only described in case reports or minor case series, with various management and failure rates (Table 1). Miller has reported the first documented case of bilateral FNSF in the literature in 1950 [4]. Cases of bilateral femoral neck fractures, even simultaneous, have been reported in healthy military recruits [5–9] as well as in healthy nonathletes [10, 11]. Insufficiency or fatigue bilateral fractures of the femoral neck have been described in various conditions such as pregnancy [12]; bone metabolic diseases, caused by osteomalacia associated with coxa vara [13] or by celiac disease [14]; vitamin D deficiency [15]; and rare genetic syndromes like Marfan [16] and autosomal dominant osteopetrosis [17]. Other more common risk factors, such as steroid treatment [18, 19] and anorexia nervosa [20], have also been involved in cases of bilateral insufficiency femoral neck fractures. Bilateral FNSF has also been described as a very rare complication following simultaneous bilateral total knee arthroplasty [21].

Among the 46 patients with bilateral FNSF found in the literature, 23 were male and 23 were female, with a mean age of 35 years. Fifty-six percent were on compression, 18% were on the tensile side, and 26% were displaced. Twenty-three percent were treated conservatively; 56% were treated by internal fixation; 12% had an osteotomy; and eight (9%) out of 92 patients had a prosthetic implant, among them only two had a total hip replacement. Failure rate for internal fixation was 11.5%. Internal fixation methods used in those cases were screws in four patients and gamma nails in one patient, bilaterally. Two (10%) of the 21 patients with conservative treatment were eventually operated, with screws in one case and hemiarthroplasty in the other. One patient went on being treated conservatively using bisphosphonates, although the femoral neck fracture on one side was still visible in the X-rays at 24 months of follow-up postinternal fixation [22]. Failure rate for conservative treatment was three (14%) out of 21 patients.

No complications were recorded with the osteotomy treatment in those series nor with the prosthetic implants. Follow-up was inconsistent, ranging from 2 weeks to 15 years. No quality of life questionnaire or other outcome measuring score was reported in any of the case reports.

4. Discussion

Different classifications exist regarding FNSF. Fullerton and Snowdy proposed a classification of FNSF in three types, based on biomechanics and degree of displacement: type 1 is a compression-sided fracture; type 2 is a tension-sided fracture; and type 3 is a displaced fracture [23]. If fracture lines are less than 50% of the neck, treatment of femoral neck stress fractures is nonoperative, consisting of non-weight-bearing and activity cessation. If compression or tension-sided fractures have fracture lines greater than 50% of the neck, percutaneous screw fixation must be strongly considered [23]. Type 2 stress fractures, as found in the right hip of our patient, often heal poorly and therefore require treatment that is more aggressive in order to avoid malunion, nonunion, or osteonecrosis, leading to hip osteoarthritis [24]. After nonunion following DHS on the right hip, we opted for THA. Other treatment options, such as valgus intertrochanteric osteotomy with DHS or blade plate fixation in order to compress and stabilize the stress fracture by converting shear forces to compressive ones, have been described with variable failure rates [25, 26]. Valgus intertrochanteric osteotomy permits a more horizontal

(a) (b) (c)

Figure 5: (a) Pelvic MRI showing bone marrow edema of the left hip on the compression side. (b) AP and (c) profile follow-up X-ray of the left hip showing a minimally displaced complete femoral neck fracture (arrow).

Figure 6: Postoperative pelvic X-ray after left total hip arthroplasty and three years after right total hip arthroplasty. Implants are in good position.

reorientation of the stress fracture line by subtracting a wedge on the lateral femur (Figure 7). THA has given good results and more predictable failure rates.

We opted for primary THA on the patient's left hip once conservative treatment failed. This treatment option can be disputed. As the second femoral neck stress fracture was on the compression side, it would have had more healing potential than the contralateral tension-sided stress fracture. These two fractures are therefore not comparable in outcome. Although valgus intertrochanteric osteotomy was a valid therapeutic option age wise, we believed it presented a potential failure risk, resulting from avascular necrosis of the femoral head, given that this was the pathological finding on the contralateral side. In such a case, we would have been confronted with a more complicated primary THA requiring the extraction of material and a hip with altered biomechanics from the valgus orientation of the proximal femur. This was explained to the patient, but she refused to go through the same process with the risk of a potential failed internal fixation and preferred the option of THA. Another reason for her decision is that, as an independent worker, she needed to get rapidly back to work. Taking a longer leave of absence from work was no longer an option for her.

This case highlights the potential of primary THA in femoral neck stress fractures. We found only one case of bilateral femoral neck stress fractures treated by THA in the literature, but this case reported on a debilitated cerebral palsy patient [27]. To the best of our knowledge, this case is the first to report on a young active patient treated by THA for bilateral femoral neck stress fractures. Although this

Table 1: Case series of bilateral femoral neck fractures with their treatment, failure rates, and follow-up duration.

Author	Tensile/ compressive	Treatment	Failure/ treatment	Follow-up	Patient age/sex
Naik et al.					
Case 1	L: n.a.; R: 1	L: OS screw; R: OT	L: HA	28 m	38 M
Case 2	L: 1; R: 3	L: OS screw; R: OT	No	12 m	38 F
Case 3	L: 3; R: 1	L: OT; R: OT	No	6 m	48 F
Case 4	L: 2; R: 3	L: OT; R: OT	No	7 y	40 F
Selek et al.					
Case 1	L: n.a.; R: n.a.	L: OS screws; R: OS screws	No	4 y	30 F
Case 2	L: n.a.; R: n.a.	L: OS screws; R: OS screws	No	28 m	35 F
Case 3	L: n.a.; R: n.a.	L: OS screws; R: OS screws	No	2 y	30 F
Moo et al.					
Case 1	L: 2; R: 1	L: OS screws; R: cons	No	28 m	19 M
Case 2	L: 1; R: 3	L: cons; R: OS screws	No	4 m	18 M
Case 3	L: n.a.; R: 2	L: OS screws; R: OS screws	No	24 m	20 M
Cakmak et al.	L: 2; R: 3	L: OS screws; R: HA	No	18 m	82 F
Nagao et al.	L: 2; R: 3	L: OS screws; R: cons	L: HA; R: HA	24 m	36 M
Hernigou et al.	L: 1; R: 1	L: OS DHS; R: OS DHS	No	2 w	38 F
Vaishya et al.	L: 1; R: 1	L: OS screws; R: OS screws	No data	No data	50 M
Santoso et al.	L: 1; R: 1	L: cons; R: cons	No	5 m	37 M
Oliveira et al.	L: 1; R: 1	L: OS; R: OS	No data	No data	43 M
Sariyilmaz et al.	L: 1; R: 1	L: VOT (blpl); R: VOT (blpl)	No	2 y	26 F
Baki et al.	L: 1; R: 1	L: OS screws; R: OS screws	No	6 m	22 F
Nemoto et al.	L: 1; R: 1	L: OS screws; R: OS screws	No	2 y	24 M
Webber et al.	L: 1; R: 1	L: OS screws; R: OS screws	No	No data	23 M
Wright et al.	L: 3; R: 3	L: OS screws; R: OS screws	No access to full article	No access	24 M
Bouchoucha et al.	L: 3; R: 2	L: VOT (blpl) R: OS (DHS)	No data	No data	15 F
Naranje et al.	L: 3; R: 2	L: OS screws; R: OS screws	No	12 m	34 M
Carpintero et al.	L: 2 ; R: 3	L: OS gamma; R: OS gamma	R: AVN L: AVN/THA	No data	32 M
Khadabadi et al.	L: n.a.; R: n.a.	L: OS DHS; R: OS DHS	No	12 m	25 M
Romero et al.	L: 2; R: 1	L: OS screws; R: OS screws	No	6 m	19 M
Chameseddine et al.	L: 3; R: 3	L: HA; R: HA	No	6 m	71 F
Pankaj et al.	L: 2; R: 3	R: HA; R: OS screws	No	±5 y	58 M
Haddad et al.	L: 3; R: n.a.	L: OS screws; R: OS screws	L: delayed union/conservative	4 m	56 F
Mariani et al.	L: 3; R: 3	L: THA; R: THA	No	24 m	24 M
Eberle et al.	L: 2; R: 1	L: cervical nail ("three-flanged nail"); R: cons	No	40 m	54 F
Zuckerman et al.	L: 1; R: 1	L: OS DHS; R: OS DHS	No	24 m	46 F
Voss et al.	L: 1; R: 1	L: cons; R: OS screws	R/L: nonunion	24 m	30 F
Bailie et al.	L: 1; R: 1	L: cons; R: cons	No	2m	15 M
Annan et al.	L: n.a.; R: n.a.	L: DHS + VOTR: DHS + VOT	No	6 m	29 F
Ichikawa et al.	L: 2; R: 2	L: OS screws; R: OS screws			61 F
Chouhan et al.	L: 1; R: 1	L: cons; R: cons	No	6 m	32 M
Hootkani et al.	L: 3; R: 3	L: HA; R: HA	No	24 m	28 M
Scheerlinck et al.	L: 1; R: 1	L: cons; R: cons	L: displaced fracture after accidental fall/ OS by 2 screws	14 w	8 F
Kharazzi et al.	n.a.	L: OS pins; R: OS pins	No	15 y	22 M
Rengman	n.a.	L: cons; R: cons	No	No data	21 M
Vento et al.	n.a.	L: OS pins; R: OS pins & DHS	No data	No data	53 M
Miller	L: 1; R: 1	L: cons; R: cons	No	8 m	36 F
Slipman et al.	L: 1; R: 1	L: cons; R: cons	No data	No data	36 F
Kalaci et al.	L: 1; R: 1	L: OS screws; R: OS screws	No	6 w	18 F
Gurdezi et al.	L: 1; R: 1	L: cons; R: cons	No	12 m	61 F

Table 1: Continued.

Author	Tensile/ compressive	Treatment	Failure/ treatment	Follow-up	Patient age/sex
N total	Type 1: 41 (56%) Type 2: 13 (18%) Type 3: 19 (26%) Total known: 73 Total unknown: 21	% of prosthesis Cons: 21 (23%) OS: 52 (56%) OT: 11 (12%) Arthroplasty (6HA, 2THA): 8 (9%) Total known: 92 Total unknown: 2	% of failure 2 screws: HA 1 screw: delayed union 1 screw: nonunion 1 cons: nonunion 1 cons: HA 1 cons: OS 1 nail: AVN 1 nail: THA	Mean: 23, 4 m	Mean: 35 y Mean M: 30 y Mean F: 40 y

L: left hip; R: right hip; OS: osteosynthesis; HA: hemiarthroplasty; OT: osteotomy; cons: conservative treatment; DHS: dynamic hip screw; VOT: valgus osteotomy; blpl: blade plate; THA: total hip arthroplasty; NS: no score; AVN: avascular necrosis; Type 1: compression fracture; type 2: tension fracture; type 3: displaced fracture; n.a.: not available.

Figure 7: Valgus intertrochanteric osteotomy: by subtracting a 30° wedge on the lateral femur (black hatched), the vertical stress fracture (red hatched) on the left becomes 30° more horizontal on the right.

should not be the gold standard, it should be considered as a treatment option, especially in young high-demand patients who want to quickly regain unrestricted and painless mobility of their hips. Failure rate following internal fixation of femoral neck fractures in the nonelderly population has been reported as high as 59% [28]. Complications associated with treatment by internal fixation, such as avascular necrosis (12–86%), nonunion (10–59%), as well as early-onset hip osteoarthrosis, are avoided with the THA option [29]. Although all the risk factors associated with traumatic femoral neck fractures are well described in the literature, data about the incidence of these complications in femoral neck stress fractures are lacking. The incidence is dependent on the situation (tensile versus compression side), fracture line (complete versus partial), and initial displacement of the fracture. Potential complications associated with THA, such as infection or dislocation, must be considered and clearly explained to the patient. The incidence of infection and dislocation following THA for femoral neck fractures are probably the same as those in the general population, but we do not have the data to back this assumption. However, salvage THA after failed internal fixation of the neck fracture is associated with higher complication rates [30–32].

In cases of uni- or bilateral neck stress fractures, a metabolic and systemic assessment is mandatory in order to rule out a metabolic cause favoring the stress fracture. Menstrual abnormalities and eating disorders must always be investigated when femoral neck stress fractures are present. In the present case, blood and metabolic workup were normal. The patient had no risk factor other than running three times a week, for a total of 20 km/week. Her treatment for multiple sclerosis is not known to be associated with bone metabolism and thus cannot be held responsible for playing a role in the pathogenesis of her stress fractures. Bazelier et al. found that multiple sclerosis itself is associated with an increased risk of osteoporotic fractures—especially hip fractures—mainly resulting from an increased risk of falls, particularly when taking glucocorticoids or antidepressants [33]. However, in our case, the patient sustained no fall, had a normal osteoporotic workup, and took no glucocorticoid or antidepressant medication.

5. Conclusion

Although internal fixation remains the gold standard in nondisplaced femoral neck stress fractures, femoral osteotomy and THA must be part of the treatment options. Total hip arthroplasty, especially with the advances in material technology, tribology, and surgical technique, has excellent clinical outcomes and high patient satisfaction rates, making it now a more interesting avenue for young and active patients. Thus, when it comes to femoral neck stress fractures, it should be considered in cases of failed internal fixation or in those cases not responding to conservative treatment.

Conflicts of Interest

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Review Article

Hip Fracture Nonunions: Diagnosis, Treatment, and Special Considerations in Elderly Patients

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In the United States, more than 300,000 hip fractures occur annually in the elderly population with associated significant morbidity and mortality. Both intracapsular and extracapsular hip fractures have inherent treatment challenges and therefore are at risk of nonunion complications. A systematic assessment including radiographic, metabolic, and infectious evaluations should be completed for all patients suspected of nonunion. Failed internal fixation of intracapsular hip fractures is typically treated with arthroplasty, while extracapsular proximal femur nonunions may be amenable to revision internal fixation or arthroplasty. While not a classic hip fracture, bisphosphate associated subtrochanteric femur fractures affect a similar patient population and are historically difficult to treat. Atypical subtrochanteric femur fractures are at increased risk of nonunion given the altered biologic environment secondary to bisphosphonate use; therefore adjuvant therapies may be beneficial in setting of revision fixation. Having a thorough understanding of nonunion risks, recognition, evaluation, and treatment is necessary for appropriate patient care.

1. Introduction

Hip fractures in the elderly occur in significant numbers, with 1.6 million fractures worldwide annually and a projected increase to over 6 million hip fractures yearly by 2050 [1, 2]. Hip fractures can be broken down into two generic categories: intracapsular and extracapsular, depending on where the fracture occurs about the proximal femur. Femoral neck fractures are classified as intracapsular, while extracapsular hip fractures can be further broken down into intertrochanteric and peritrochanteric, with possible subtrochanteric extension depending on the fracture line exit point about the greater and lesser trochanters. An accepted terminology to encompass all extracapsular hip fractures is peritrochanteric femur fracture, with the fracture occurring about the greater and lesser trochanter and not extending greater than 5cm from the lesser trochanter. Pure subtrochanteric femur fractures do not involve the area about the trochanters, instead involving the proximal third femoral shaft. This fracture type is fraught with its own reduction and treatment challenges and is not included within the group of fractures classically considered "hip fractures." In contrast, atypical femur fractures (AFFs), otherwise known as subtrochanteric femur fractures associated with prolonged bisphosphonate, occur in a similar patient population as hip fractures and therefore were included for this review.

In a study reviewing the United States 2008 Nationwide Emergency Department Sample emergency room visits, it was found that more than 90% of 341,000 hip fractures occurred in patients over the age of 60 and that overall the rate of peritrochanteric femur fractures compared to femoral neck fractures was 2:1 [3]. It is well accepted that hip fractures, whether peritrochanteric or femoral neck in morphology, generally necessitate surgical treatment if the patient is medically stable to survive the operation and will benefit from pain relief and improved mobility provided by the surgical intervention. Typically peritrochanteric femur fractures are treated with internal fixation, while femoral neck fractures are treated with either internal fixation or arthroplasty, but controversy exists regarding which treatment is better [4, 5]. The morbidity and mortality, along with the socioeconomic impact of hip fractures, are substantial, and complications of

fracture nonunion and fixation failure only compound these effects.

All hip fractures treated operatively with internal fixation or treated nonoperatively have the potential to go onto nonunion. Those fractures treated with a type of arthroplasty are not at risk for nonunion, as the proximal portion of the fractured femur is discarded to allow for implantation of the arthroplasty replacement. The US Food and Drug Administration (FDA) defines a nonunion as a fracture 9 months from injury that shows no visible progressive healing for 3 months, yet this is not always a practical definition. Therefore, additional accepted definitions for nonunion are the following: a fracture that in the opinion of treating physician has no possibility of healing without further intervention [6] or a fracture that has shown no radiographic progression over 3 consecutive images in a patient who has clinical symptoms consistent with nonunion. The causes of nonunion are commonly multifactorial, consisting of biological, mechanical, injury, and patient factors that all contribute to putting a fracture at risk of nonunion [7]. Basic biological requirements for fracture healing are a combination of mechanical stability from appropriate fixation, adequate bony vascularity, and osteoprogenitor and growth factor cells, as well as bone-to-bone contact of the fracture fragments [8]. When a combination of these requirements is not met, nonunion may occur. Classically, hypertrophic nonunions occur when there is adequate vascularity but inadequate fracture stability, and this results in abundant nonbridging callus formation at the fracture site. Atrophic nonunions lack adequate blood supply at the fracture site, which may have been injured at the time of trauma or have been iatrogenic secondary to poor soft tissue handling at the time of surgery. These nonunions show no callus at the fracture site and evidence of bone resorption. Oligotrophic nonunions, also known as the "surgeon's nonunion," are characterized by a diastasis at the fracture site, minimal callus, and variable vascularity and mechanical stability [6].

Femur nonunions result in decreased mental and physical health, along with debilitating impacts on activities of daily living [9]; therefore when treating hip fracture patients, it is imperative to monitor for adequate healing postoperatively and begin an appropriate nonunion evaluation for those patients who meet the previously quoted definitions. Failure to recognize a nonunion could result in the catastrophic complication of fixation failure and need for revision surgery in an emergency setting [10], compared to intervention or revision surgery on a planned timeline if the problem is recognized earlier.

2. Nonunion Evaluation

Hip fracture nonunion should be suspected in patients who continue to have groin or thigh pain with ambulation, sitting, or transfers that cannot be explained by other etiologies. Radiographs should be closely evaluated for signs of hardware loosening with presence of a surrounding "halo" about implants, as well as fracture shortening, or lack of expected callus formation or bridging of fracture fragments [10, 11]. Radiographs of the entire limb should be obtained to evaluate overall limb alignment. Computed tomography (CT) scan is typically indicated to better characterize the nonunion, estimate the cross sectional area of bridging callus, and evaluate for rotational deformities [6]. Infection must be ruled out, as indolent infection can contribute to fracture nonunion. White blood cell (WBC) count, C-reactive protein (CRP), and erythrocyte sedimentation rate (ESR) should be obtained, and their elevation, especially when combined, is a strong predictor of infection [7]. Additionally, intraoperative cultures should be obtained at the time of revision surgery even if there are no clinical signs of infection, as 20% of patients in a large multicenter series were shown to have positive cultures, with only 9% felt to be contaminants [12]. If infection is confirmed in the initial laboratory evaluation and surgical intervention is deemed necessary and safe, multiple treatment options exist. Removal of hardware and culture-specific antibiotics should be considered in all operative candidates. Resection arthroplasty, staged debridement with revision internal fixation, staged debridement with arthroplasty, and single stage revision arthroplasty are all viable options. While staged debridement with antibiotic spacer placement followed by arthroplasty after eradication of infection is a reliable treatment option [13, 14], it is important to be aware of the risks associated with revision arthroplasty surgery. Ford et al. evaluated 80 patients with an average age of 64 who began the process for two-stage exchange arthroplasty in setting of infection. 30% had a serious complication, including 3 perioperative deaths, 30% required an additional operation, 18% never underwent reimplantation, and 27% became reinfected [15].

In addition to ruling out infection, a metabolic and endocrine assessment should be completed in the setting of nonunion. Abnormalities within vitamin D and calcium processing pathways, thyroid function, and other hormonal interactions have all been associated with delayed fracture healing and may be present in those patients presenting with nonunion [16, 17]. We recommend an initial evaluation including the laboratory tests listed in Table 1. Based on the results of these screening tests, if a more specific evaluation is required, we recommend referral to an endocrinologist. There, further testing can be performed to evaluate levels of estrogen, testosterone, cortisol, and additional specific labs depending on the associated patient complaints and symptoms [7, 10].

Adequate treatment of any metabolic abnormalities recognized during this evaluation is recommended, with some nonunions healing without any additional surgical intervention following the metabolic correction [16]. For example, it was shown that hypoalbuminemia and lymphocytopenia are both independent predictors of fixation failure in nondisplaced femoral neck fractures [18]; therefore correction of such laboratory values may theoretically decrease failure and therefore reoperation and nonunion rates. Even for those patients without vitamin D deficiency, vitamin D supplementation has been shown to decrease the risk of hip fractures and increase proximal femur bone density [19], and a recent study has shown the cost effectiveness in calcium and vitamin D supplementation in fracture patients while attempting to reduce the nonunion rate [20].

Table 1: Recommendation for initial metabolic laboratory evaluation in the setting of fracture nonunion, with associated common abnormalities and underlying disease processes. We recommend CBC, CMP, 25-hydroxyvitamin D, iPTH, and TSH, as well as CRP and ESR to rule out infection. Additional tests may be required and obtained by a treating endocrinologist depending on the initial laboratory screening results.

Laboratory Test	Important Values	Common Nonunion Abnormalities	Associated Diseases or Causes for Abnormal Values
Complete blood count (CBC)	White blood cell (WBC)	Elevated	Infection
		Decreased	Immunosufficiency
Sedimentation rate	(ESR)	Elevated	Infection
C-reactive protein	(CRP)	Elevated	Infection
Comprehensive metabolic panel (CMP)	Calcium (Ca)	Decreased	Hypoparathyroidism
			Vitamin D deficiency
			Renal osteodystrophy
	Alkaline phosphatase (ALP)	Elevated	Vitamin D deficiency
			Calcium deficiency
			Chronic renal failure
	Albumin (Alb)	Decreased	Protein deficiency
	Glucose (Glu)	Elevated	Diabetes mellitus
Thyroid function panel	Thyroid stimulating hormone (TSH)	Elevated	Hypothyroidism (Low T3, T4)
		Decreased	Hyperthyroidism (High T3, T4)
	Free T4	Decreased	Hypothyroidism (Low T3, T4)
		Elevated	Hyperthyroidism (High T3, T4)
	Free T3	Decreased	Hypothyroidism (Low T3, T4)
		Elevated	Hyperthyroidism (High T3, T4)
Intact parathyroid hormone (iPTH)	(iPTH)	Elevated	Primary hyperparathyroidism: pituitary adenoma
			Secondary hyperparathyroidism: Vitamin D deficiency, Vitamin D resistance
			Renal osteodystrophy
25-hydroxyvitamin D	(Vit D 25(OH))	Decreased	Vitamin D deficiency
			Malabsorption/Liver disease
			Anticonvulsant medication

Therefore, while completing a thorough metabolic workup in the setting of nonunion is crucial, correcting any preexisting abnormalities and deficiencies at the time of the index fracture may have an overall positive effect on fracture healing.

3. Femoral Neck Fracture Nonunion

The optimal treatment for elderly intracapsular femoral neck fractures continues to remain controversial. It is generally taught that nondisplaced femoral neck fractures (Garden

types I and II) undergo internal fixation with a cannulated screw construct, while displaced femoral neck fractures (Garden types III and IV) are treated with arthroplasty [21–23]. While internal fixation affords the advantage of maintaining the patient's own femoral head, less surgical trauma, and, in very frail patients, a slight decrease in overall morbidity and mortality [24], there are high rates of complications for those undergoing fixation, including avascular necrosis, delayed union, nonunion, fracture shortening, and increased rate of reoperation [4, 25]. A recent meta-analysis of 34 articles comparing THA, hemiarthroplasty, and osteosynthesis for displaced femoral neck fractures in patients over the age of 60 showed high revision rates for fractures treated with internal fixation compared to both THA and hemiarthroplasty [5]. This echoed a previous meta-analysis of 106 studies, which showed a reoperation rate of 20-36% within two years [25]. The international, multicenter, randomized FAITH trial showed that, for all types, low energy femoral neck fractures in patients over 50 years of age, whether treated with sliding hip screw or cannulated screws, there was a 21% reoperation rate, with an average of 15% undergoing revision to either total hip arthroplasty or hemiarthroplasty. Only 67% of all fractures healed by 24 months, and, of those that healed, nearly 30% had fracture shortening of more than 5mm [26]. A subsequent study determined that female sex, higher body mass index (BMI), displaced fracture, prominence of screws at the lateral femoral cortex, screw penetration, high placement of lag screw on immediate postoperative images, and smokers treated with cannulated screws were at increased rate of revision surgery [27]. Similarly, Yang et al. found a significantly increased odds ratio of 2.93 for nonunion in displaced femoral neck fractures compared to nondisplaced fractures in a study of 202 patients with an average age of 64.5. Additional risk factors for nonunion were less than anatomic reduction and traditional triangle compared to inverted triangle configuration of cannulated screws [28]. A decrease in contralateral hip bone mineral density (BMD) has also been shown to increase the risk of nonunion in displaced femoral neck fractures treated with cannulated screws [29]. It is important to remember these risk factors for complications and nonunion in elderly femoral neck fractures treated with internal fixation and to pursue appropriate interventions if necessary.

Usually femoral neck nonunions in physiologically young patients are treated with methods to salvage and maintain the patient's own native femoral head, and typically this is accomplished with a valgus intertrochanteric osteotomy. This procedure improves the mechanical environment of the nonunion, creating compressive rather than shear forces across the nonunion [11, 23, 30, 31]. In elderly patients with femoral neck nonunions, the accepted revision treatment method is arthroplasty given the reliability of outcomes, potentially decreased surgical insult, and ability for immediate weight bearing (Figure 1) [4, 11, 23, 32]. There is debate regarding the decision between total hip arthroplasty (THA) and hemiarthroplasty, but if the articular cartilage of the femoral head or acetabulum has been damaged, total hip arthroplasty is recommended [11]. Mabry et al. evaluated 84 patients who underwent Charnley cemented THA for nonunion from 1970 to 1997 with an average follow-up of 12 years. There was a 93% survival free revision rate at 10 years and 76% at 20 years, with 96% of the 72 who never underwent revision having no or mild hip pain, indicating THA as a reliable long-term treatment option for femoral neck nonunions [32]. There is documented increased risk of dislocation following THA for failed osteosynthesis of femoral neck fractures compared to primary THA [32, 33]; therefore it is recommended that the patient undergo conversion arthroplasty surgery by a surgeon who is trained in revision arthroplasty.

4. Peritrochanteric Femur Fracture Nonunion

Peritrochanteric femur fractures typically occur in a physiologically older population than femoral neck fractures, account for about 50% of hip fractures, and include all proximal femur fractures that occur from the extracapsular femoral neck area to below the lesser trochanter within 5cm [34]. Stable 2-part intertrochanteric femur fractures with an intact lateral cortex and typical fracture obliquity were classically treated with a sliding hip screw (SHS). Instable 3- or 4-part peritrochanteric femur fractures or those with a reverse obliquity fracture pattern (fracture from the proximal medial cortex exiting distally on the lateral femoral cortex) are treated with cephalomedullary nail (CMN). Overall, there has been an increased use of CMNs for all peritrochanteric femur fractures, independent of the perceived stability [35, 36]. The results of a recent randomized controlled trial confirmed this treatment algorithm, showing greater healing complication, revision procedures, femoral shaft medicalization, and associated pain for multifragmentary intertrochanteric femur fractures treated with SHS compared to intramedullary nail [37]. Similarly, Chehade et al. saw an increased rate of reoperation, as well as increased mortality, in unstable peritrochanteric femur fractures, especially those treated with the Australian Austofix intramedullary nail secondary to Z-effect phenomenon [38]. Baldwin et al. summarized current treatment controversies for cephalomedullary nailing of intertrochanteric femur fractures, stating that there is no difference in fixation failure or need for revision surgery when comparing short versus long CMNs, helical blade versus lag screw, or locked versus unlocked nail in the setting of a stable fracture pattern. Tip apex distance <25mm continues to be the most important factor to decrease implant cutout, regardless of blade or screw type. Unstable peritrochanteric femur fractures are recommended to be treated with distal interlocking screws for improved biomechanical properties, including torsional resistance [35]. Fracture reduction continues to be imperative for overall outcome, as fractures with "poor" reduction (varus malalignment on AP image, >20 degrees angulation on lateral image, or >4mm displacement) had significantly shorter time to failure than those with "adequate" or "good" reduction [39]. While choosing the correct implant specific to fracture morphology and obtaining a good reduction improve likelihood of fracture union, nonunions of peritrochanteric hip fractures unfortunately occur and various treatment options exist.

(a) (b) (c) (d)

Figure 1: (a) A 61-year-old female sustained a syncopal fall at home resulting in a displaced left transcervical femoral neck fracture. She has a history of multiple medical comorbidities including end-stage renal disease on hemodialysis, diabetes mellitus, and hypertension. She subsequently went into PEA arrest twice during transport to the hospital. She was intubated and sedated on arrival. She remained critically injured in the Intensive Care Unit and was deemed an extremely high risk for surgery; therefore surgical intervention was delayed until the patient was medically stable. On hospital day 8, the patient was cleared by the medical service for surgical intervention of her displaced femoral neck fracture, and after extensive conversation with the patient and her family, consent was obtained and surgery was pursued with the plan for hemiarthroplasty given her fracture displacement and delayed presentation to the OR. After induction of anesthesia, the patient was deemed too instable to undergo a hemiarthroplasty, so conversion to closed reduction with percutaneous cannulated screws was chosen, aware of the chance of failure, but choosing this given her medical instability and high risk (b). She was followed in the clinic and over the following 7 months continued to have groin pain with ambulation and radiographic signs of hardware failure and nonunion (c). During this time, she had extensive medical optimization in anticipation of revision surgery. When deemed medically optimized and cleared for surgery, after discussion with the patient and her family, she was brought back to the OR for hardware removal and left hip hemiarthroplasty (d). She tolerated the procedure without complications and is ambulating with minimal pain postoperatively.

If nonunion or implant failure results following internal fixation of a peritrochanteric femur fracture, there are a number of factors to consider, which will assist in determining the appropriate revision treatment for the patient. First, patient's functional level, goals of care, and life expectancy must be evaluated. If revision surgery is desired, then, as with all nonunions, metabolic and infectious evaluations are begun. Next, evaluating proximal femoral bone stock and integrity of the articular cartilage will help determine if revision internal fixation is possible or if conversion to arthroplasty is the appropriate treatment.

Screw cutout is the common mode of failure, commonly resulting in cartilage damage and necessitating conversion to THA. Additionally, if there is evidence of hip arthritis, THA is advocated [10, 11]. Depending on the amount of proximal femur bone stock remaining and prior stress risers along the shaft created by the previous fixation implant, a calcar-replacing implant, long stem implant, or a megaprosthesis (proximal femur replacement) may be required (Figure 2) [11, 39–41]. The majority of patients treated with calcar-replacing prostheses for intertrochanteric nonunion had significant reduction in pain and the returned ability to

Figure 2: (a) A 85-year-old active female sustained a fall from standing height onto her right hip resulting in an unstable displaced intertrochanteric femur fracture. (b) She underwent locked cephalomedullary nailing within 24 hours of the injury at an outside institution. The neck-shaft angle measures 119 degrees with a 130-degree implant. Note the cranial endpoint for the compression screw. (c) She was referred to an arthroplasty specialist 7 months later with catastrophic failure, screw cutout, and associated acetabular defect. (d) After a long discussion with the patient and her desire for pain relief and ability to ambulate, the decision was made for removal of hardware with femoral head resection and obtainment of cultures. (e) Two days later, cultures were negative for infection, and she was brought back to the operating room for total hip arthroplasty implantation with acetabular augment to correct defect created by the compression screw cutout. A long diaphyseal-fitting stem was used given the poor proximal bone stock, and a cable was placed to support the lateral cortex from lag screw stress riser. The patient is ambulating without pain or assist device 10 months postoperatively.

ambulate [40, 41]. If adequate proximal femoral bone stock is present and hip joint integrity is maintained, revision operative fixation should be considered. Correction of fracture malreduction, improving fracture stability, and increasing biology to the fracture may all be necessary depending on the contributing factors to nonunion. Thorough debridement of the nonunion site should be completed prior to revision fixation, with the option for bone grafting at the nonunion site if deemed necessary [6, 10]. In a study of 1360 peritrochanteric femur fractures treated with CMN, 20 patients underwent revision for nail fatigue failure. 40% were treated with revision CMN, 30% were treated with arthroplasty

or megaprosthesis, and the remaining underwent revision fixation with a proximal femur locking plate. Overall, there was a higher rate of rerevision in the proximal femur locking plate group and a longer time to radiographic union. Regardless of revision treatment modality, 1-year mortality rate following revision fixation was 30% [39]. Ultimately, one must take the entire patient into account when choosing the appropriate intervention for peritrochanteric femoral nonunion, as the mortality rate is similar to that of the index hip fracture, and postoperative rehabilitation may vary depending on treatment modality and weight bearing restrictions.

5. Atypical Subtrochanteric Femur Fracture Nonunion

Although not classically included in the encompassing category of "hip fracture," atypical subtrochanteric femur fractures related to long-term bisphosphonate use affect a similar patient population and can be fraught with the same healing challenges of femoral neck and peritrochanteric femur fractures. Atypical femur fractures (AFFs) are located between the lesser trochanter and the supracondylar flare of the femur, although they are most commonly located in the subtrochanteric region. They must have 4 of 5 major criteria as defined by the American Society for Bone and Mineral Research (ASBMR): (1) pathologic or low energy injury, (2) fracture line starting at lateral cortex and being transverse or short oblique in orientation, (3) no or minimal comminution, (4) complete fractures extending through both cortices and may create a medial spike, while incomplete fractures involve only the lateral cortex, and (5) lateral cortical beaking being present and indicative of local periosteal thickening [42]. Al-Ashqar et al. summarize the underlying pathogenesis of AFFs secondary to prolonged bisphosphonate use causing reduced osteoblast and osteoclast activity resulting in "severely suppressed bone turnover," accumulation of microdamage without the normal reparative process, and unregulated mineralization, leading to increased brittleness [43]. Odvina et al. first described severely suppressed bone turnover in 2005, noted in patients on long-term alendronate therapy with spontaneous nonspinal fractures, whose cancellous bone showed low osteoblastic and osteoclastic activity [44]. Therefore bisphosphonate usage should cease immediately at the time of fracture.

The risk of fracture is associated with increased duration of bisphosphonate use, and Asian ethnicities are at increased risk secondary to increased femoral bowing and increased lateral cortical stresses [43]. Because of the altered bone physiology, multiple studies have shown delayed healing, with increased nonunion rates of around 30% [44–47], so performing a well-done index procedure is critical. Cephalomedullary nailing has been shown to have better outcomes than plate fixation, with plate failure averaging 30% [46, 48]. Reduction continues to be critical to outcomes (Figure 3). For subtrochanteric femur fractures, neutralizing the typical deformity of flexion, abduction, and external rotation of the proximal fragment is necessary, and AFF transverse or short oblique morphology results in an inherently unstable pattern with decreased bony contact. Cho et al. evaluated 48 fractures in 42 patients and found an overall primary healing rate of 68.7%, with 15 cases of failure. Fractures fixed in 5 degrees or more of malreduction in any plane had a significantly higher likelihood of healing failure, with a neck-shaft angle of at least 125.6 degrees, 4.4 degrees less than varus angulation compared to the uninjured contralateral hip, and 5.5 degrees less than sagittal angulation [45].

Average time to union for atypical subtrochanteric femur fracture ranges from 7.3 to 10.7 months [45, 47, 48], and intervention in the setting of delayed union prior to implant failure should be considered. In the setting of atrophic nonunion without malreduction, autologous bone grafting has been successful in obtaining union without hardware revision [45]. Correcting malreduction, even inducing a slight amount of valgus, will improve mechanical properties across the fracture site to aid in healing (Figure 4). Improving the biologic environment is also possible with teriparatide, an anabolic osteoporosis medication that stimulates bone formation and promotes growth factor production for fracture healing. A meta-analysis of 251 patients with osteoporosis treated with teriparatide suggested faster fracture healing times and improved functional outcomes [49], with the possibility that starting treatment immediately at the time of fracture is more effective than waiting 6 months [50]. Similar to adding biology with autologous bone graft in delayed union, a case report illustrates an atypical subtrochanteric femur fracture healing without surgical intervention and only the addition of teriparatide treatment [51]. Conversely, a more contemporary study evaluating 24 months of teriparatide treatment in patients with atypical femur fractures showed no difference in fracture healing, hip bone mineral density, or trabecular bone score, but there was active bone formation on histomorphometry [52]. More research is needed for clear recommendations of teriparatide's use in AFFs, both acutely and in the setting of delayed union, but what is clear is that all patients should stop bisphosphonate use and continue calcium and Vitamin D supplementation [42, 48]. Due to their inherent risk of delayed union secondary to alterations in normal bone healing physiology, treating atypical subtrochanteric femur fractures with cephalomedullary nailing, anatomic or slight valgus alignment, and maximizing the metabolic and mechanical environments will increase a patient's likelihood of fracture union.

6. Summary

Elderly hip fractures are projected to continue to increase in the coming decades, and, with increased fracture treatment, there inherently is the possibility for complications related to fracture healing, including implant failure and nonunion. Recognizing femoral neck, peritrochanteric, and atypical subtrochanteric femur fracture nonunions and having the tools to treat such complications are necessary for improved patient outcomes. A thorough nonunion assessment should always be performed if intervention is desired, consisting of radiographic, infectious, and metabolic evaluation.

Figure 3: (a) Atypical left femur fracture sustained after a fall from standing in a 58-year-old female with history of bisphosphonate use. (b) She underwent closed reduction and cephalomedullary nailing with a slightly medial start point to induce slight valgus alignment with the trochanteric proximal nail bend. (c) At 6 weeks postoperatively, she denies pain and is ambulating without assistance. Fracture alignment is maintained. (d) At 6 months, she has radiographic union and is back to all activities.

When an abnormality is discovered, treating this, whether it is culture specific antibiotics and hardware removal with antibiotic cement implantation in the setting of infection or correction of vitamin D, electrolyte, hormone, or other chemical imbalances or improvement in mechanical forces across the fracture, all must be appropriately addressed to increase rate of successful nonunion surgery. Arthroplasty continues to be a reliable treatment option in the setting of both femoral neck and peritrochanteric femur nonunions, as it gives elderly patients the ability to immediately weight bear and removes the physiologic burden of fracture healing. Ultimately, enough emphasis cannot be placed on the importance of an appropriate, acceptable index surgery, along with maximizing patient bone healing capabilities with nutritional supplementation, vitamin D, and calcium to improve the chances of fracture healing and decreasing risk factors of nonunion. Atypical subtrochanteric femur fractures are at increased risk of delayed healing and nonunion; therefore maximizing the mechanical and physiologic environment for fracture healing is paramount. More research is warranted prior to making strong recommendations regarding the use of teriparatide for nonunions.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

Figure 4: (a) Atypical right subtrochanteric femur fracture created in a 68-year-old male with 8-year history of bisphosphonate use. (b) He underwent open reduction internal fixation with a locked piriformis reconstruction nail within 24 hours of injury. Note anatomic alignment immediately postoperatively. (c) At 8 weeks postoperatively, he had increased pain in his hip and felt a pop. New radiographs reveal hardware failure with nail fracture and varus collapse. (d) Given his adequate proximal femoral bone stock, he underwent revision open reduction internal fixation with removal of hardware, locked cephalomedullary nailing, and augmentative plating with autologous bone grafting of the nonunion site. (e) At 6 months postoperatively, he has radiographic signs of union and is pain-free and returned to all previous activities.

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Research Article

Predicting Discharge Location among Low-Energy Hip Fracture Patients Using the Score for Trauma Triage in the Geriatric and Middle-Aged (STTGMA)

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Patterns of discharge location may be evident based on the "sickness" profile of the patient. This study sought to evaluate the ability of the STTGMA tool, a validated mortality risk index for middle-aged and geriatric trauma patients, to predict discharge location in a cohort of low-energy elderly hip fracture patients, with successful discharge planning measured by readmission rates. Low-energy hip fracture patients aged 55 years and older were prospectively followed throughout their hospitalization. On initial evaluation in the Emergency Department, each patient's age, comorbidities, injury severity, and functional status were utilized to calculate a STTGMA score. Discharge location was recorded with the primary outcome measure of an unsuccessful discharge being readmission within 30 days. Patients were risk stratified into minimal-, low-, moderate-, and high-risk STTGMA cohorts. A p-value of <0.05 was considered significant for all statistical tests. 408 low-energy hip fractures were enrolled in the study with a mean age of 81.3±10.6 years. There were 214 (52.5%) intertrochanteric fractures, 167 (40.9%) femoral neck fractures, and 27 (6.6%) subtrochanteric femur fractures. There was no difference in readmission rates within STTGMA risk cohorts with respect to discharge location; however, among individual discharge locations there was significant variation in readmission rates when patients were risk stratified. Overall, STTGMA risk cohorts appeared to adequately risk-stratify readmission with 3.5% of minimal-risk patients experiencing readmission compared to 24.5% of moderate-risk patients. Specific cohorts deemed high-risk for readmission were adequately identified. The STTGMA tool allows for prediction of unfavorable discharge location in hip fracture patients. Based on observations made via the STTGMA tool, improvements in discharge planning can be undertaken to increase home discharge and to more closely track "high-risk" discharges to help prevent readmissions.

1. Introduction

According to national projections by the US Census Bureau, the older population of the United States will undergo considerable growth in the upcoming years [1]. Current estimations report that the geriatric population, aged 65 years and older, will increase from 43.1 million in 2012 to 83.7 million in 2050 [1]. It is estimated that they will account for over 20% of the general population [2]. Trauma is currently the fifth leading cause of death in older adults. In 2050, the older population will account for approximately 40% of all trauma cases [3].

Hip fractures are common in the middle-aged and geriatric trauma population. Currently, more than 250,000 hip fractures occur each year in the United States, with that estimate expected to increase to 840,000 by 2040 [4]. Hip fractures are associated with significant morbidity, mortality, and costs [5]. In fact, hip fractures account for 14% of all fractures yet comprise 72% of overall fracture care costs [6]. Given the expected increase in the older population and serious health and financial consequences associated with hip fractures in this population, proper management of these patients is imperative.

Interdisciplinary care, consisting of geriatric consultations, discharge planning, and rehabilitation has been shown to improve functional capacity and reduce mortality after hip fracture surgery [7–9]. In conjunction with a multidisciplinary approach, having defined postacute care pathways reduces costs and utilization of hospital resources [10]. Although patient care involves several

Table 1: Summary of variables utilized to calculate a low-energy STTGMA score.

Injury Status	Health Status	Functional Status
Low Energy	CCI	Ambulatory capacity
GCS		
AIS Head/Neck		
AIS Chest		

important aspects, this study focuses on discharge planning.

Early discharge planning reduces lengths of stay, costs, and utilization of hospital resources, while decreasing patient mortality and improving functional outcomes [11]. Thus, orthopaedic surgeons should identify patients who are candidates for discharge home versus those who will require rehabilitation services or skilled levels of care early in the admission to facilitate discharge planning [12]. Certain factors, such as advanced age, preoperative motor ability, preexisting comorbidities, and cognition have been shown to affect discharge location [12, 13]. However, there are few methodologies that assist orthopaedic surgeons to systematically predict the discharge locations of their patients.

The Score for Trauma Triage in the Geriatric and Middle-Aged (STTGMA) is a novel inpatient mortality risk tool developed and validated in the National Trauma Databank as well as at our institution as a reliable tool for prediction of inpatient mortality [14, 15]. The purpose of this study is to investigate whether STTGMA scores, calculated upon initial admission in the Emergency Department, can be used to predict patients who will require postacute facility care when discharged and can therefore provide a valuable tool to guide discharge planning for patients with low-energy hip fractures with successful discharge planning measured by readmission rates.

2. Materials and Methods

From 10/1/2014 to 9/30/2016, all patients aged 55 years and older who were admitted with a hip fracture AO/OTA fracture classification of 31-A, 31-B, and (32-A(1-3).1, 32-B(1-3).1, 32-C(1-3).1) were enrolled in this IRB-approved study and followed prospectively at 2 level 1 trauma centers and 1 academic tertiary-care center. "Middle-aged" was defined as patients aged 55-64 years old, while "geriatric" as ages ≥ 65 years. Only low-energy mechanisms of injury, defined as ground-level falls up to two levels of stair height, were included [14]. Exclusion criteria were any patients that died within the Emergency Department setting prior to admission.

Upon initial evaluation in the Emergency Department, basic demographics and all STTGMA variables were collected to provide information regarding each patient's injury, health, and functional status. Glasgow Coma Scale (GCS) and Abbreviated Injury Severity (AIS) for the head/neck and chest were utilized for injury status. Charlson Comorbidity Index (CCI) represented the patient's health status. Their ambulatory capability (community, household, nonambulatory) represented their functional status. Note that for ambulatory capacity, patients were considered a community ambulator if they spent ≥ 50% of their time ambulating outside their primary residence, a household ambulatory if they spent ≥ 50% of their time ambulating within their residence, and a nonambulator if they were unable to ambulate without assistance. These variables, summarized in Table 1, were utilized to calculate a STTGMA score, which provides the predicted risk (0-100%) of inpatient mortality during the index hospitalization. All STTGMA variables were collected by junior year orthopaedic surgery residents who had been trained in STTGMA score calculation via a standardized online 20 minute tutorial [16].

Patients were prospectively followed throughout their admission. Discharge location was determined by the admitting physician in consultation with a social worker and case manager, all of whom were blinded to patient's STTGMA score. Discharge locations were collected and included discharge to home, acute inpatient rehabilitation facility, skilled nursing facility (SNF) as well as discharges to hospice, long-term care facilities (LTCF), transfer to another acute hospital, and death during index hospitalization. Readmission data within 30 days from discharge was obtained. To make this tool clinically useful for guiding early discharge planning, patients were divided into minimal-risk (<0.4%), low-risk (0.4-1.5%), moderate-risk (1.5-5.0%), and high-risk (>5% STTGMA score) patients. These risk groups were compared considering a p-value < 0.05 as significant for all statistical tests.

3. Results

A total of 408 consecutive patients with low-energy hip fractures were included in the cohort and prospectively followed throughout their index hospitalization. No patients were lost to follow-up. The mean age at the time of injury was 81.3 ± 10.6 years. Of this cohort, 167 (40.9%) sustained femoral neck fractures (31-B), 214 (52.5%) intertrochanteric fractures (31-A), and 27 (6.6%) subtrochanteric fractures (32-A(1-3).1, 32-B(1-3).1, 32-C(1-3).1). 18 patients (4.4%) patients were managed nonoperatively, and 9 patients (2.2%) died during their index admission. 29 (7.1%) underwent total hip arthroplasty, 77 (18.9%) underwent hemiarthroplasty, and 284 (69.9%) underwent open reduction internal fixation (ORIF) (Table 2).

With regard to injury status, the mean GCS was 14.9 ± 0.8, the mean AIS Head/Neck was 0.04 ± 0.24, and the mean AIS Chest was 0.03 ± 0.19, With regard to health status the mean CCI was 1.4 ± 1.6. With regard to functional status, the mean age was 80.3 ± 10.6 and the majority of patients were either community (290, 71.1%) or household (91, 22.3%) ambulators. Table 3 summarizes these results in

Table 2: Demographics, summary of the injuries sustained (anatomic location and AO/OTA fracture classification), and procedure performed on the cohort of 408 hip fracture patients.

	Total Cohort (n=408 patients)
Age (years) (mean ± SD)	81.3 ± 10.6
Gender (female) (n,%)	286 (70.1%)
Fracture Type:	
Intertrochanteric Fractures (31-A)	214 (52.5%)
Femoral Neck Fractures (31-B)	167 (40.9%)
Subtrochanteric Fractures (32-A(1-3).1, 32-B(1-3).1, 32-C(1-3).1)	27 (6.6%)
Procedure:	
Open Reduction Internal Fixation	284 (69.6%)
Hemiarthroplasty	77 (18.9%)
Total Hip Arthroplasty	29 (7.1%)
Non-operative	18 (4.4%)

Table 3: Summary of the injury, health, and functional status variables utilized to calculate STTGMA scores.

Injury Status			
Glasgow Coma Scale		*AIS Head/Neck*	
GCS 15	380 (93.1%)	AIS 0	394 (96.6%)
GCS 14	17 (4.2%)	AIS 1	12 (2.9%)
GCS 13	5 (1.2%)	AIS 2	1 (0.2%)
GCS 12	2 (0.5%)	AIS 3	1 (0.2%)
GCS 11	2 (0.5%)	Mean ±SD	0.04 ± 0.24
GCS 6	1 (0.2%)		
GCS 5	1 (0.2%)		
Mean ± SD	14.85 ± 0.80		
AIS Chest			
AIS 0	396 (97.1%)		
AIS 1	11 (2.7%)		
AIS 2	1 (0.2%)		
Mean ± SD	0.03 ± 0.19		
Health Status			
Charlson Comorbidity Index		*Age*	
0	146 (35.8%)	55-59	17 (4.2%)
1	108 (26.5%)	60-69	59 (14.5%)
2	80 (19.6%)	70-79	87 (21.3%)
3	36 (8.8%)	80-89	151 (37.0%)
4	15 (3.7%)	90-99	93 (22.8%)
5	4 (1.0%)	>100	1 (0.2%)
6	13 (3.2%)	Mean ± SD	81.3 ± 10.6 years
7	4 (1.0%)		
8	2 (0.5%)		
Mean ± SD	1.42 ± 1.62		
Functional Status			
Ambulatory Status			
Community	290 (71.1%)		
Household	91 (22.3%)		
Non-ambulator	27 (6.6%)		

Table 4: Discharge location patterns for minimal-, low-, moderate-, and high-risk cohorts. Percentages reflect proportion of each respective risk cohort discharged to each location.

Location	*Minimal Risk Cohort (n=226)*	*Low Risk Cohort (n=102)*	*Moderate Risk Cohort (n=53)*	*High Risk Cohort (n=27)*	*Total Cohort (n=408)*
Home	63 (27.9%)	12 (11.8%)	5 (9.4%)	4 (14.8%)	84 (20.6%)
Acute Rehab	41 (18.1%)	15 (14.7%)	3 (5.7%)	2 (7.4%)	61 (15.0%)
Skilled Nursing Facility	118 (52.2%)	72 (70.6%)	41 (77.4%)	14 (51.9%)	245 (60.0%)
Hospice	1 (0.4%)	1 (1.0%)	0 (0.0%)	3 (11.1%)	5 (1.2%)
LTCH	1 (0.4%)	0 (0.0%)	1 (1.9%)	0 (0.0%)	2 (0.5%)
Death	2 (0.9%)	1 (1.0%)	2 (3.8%)	4 (14.8%)	9 (2.2%)
Transfer to Acute Hospital	0 (0.0%)	1 (1.0%)	1 (1.9%)	0 (0.0%)	2 (0.5%)

Table 5: Length of stay and readmission rate for minimal-, low-, moderate-, and high-risk cohorts stratified by discharge location. Percentages reflect proportion of each respective risk cohort readmitted. P-value[a] analyzes differences in readmission rates by discharge location (within a specific risk group); P-value[b] analyzes differences in readmission rates, length of stay, and discharge location among risk groups.

	Minimal Risk Cohort (n=226)	*Low risk Cohort (n=102)*	*Moderate Risk Cohort (n=53)*	*High Risk Cohort (n=27)*	*Total*	*p-value$_b$*
Length of Stay (days) (mean±SD)	7.4 ± 4.5	8.4 ± 6.6	9.0 ± 5.0	8.5±5.2	8.0±5.2	0.128
Readmission rate N (%)	8 (3.5%)	7 (6.9%)	13 (24.5%)	3 (11.1%)	31 (7.6%)	<0.005
Home N (%)	4 (6.3%)	2 (16.7%)	2 (40.0%)	0 (0.0%)	8 (9.5%)	<0.005
Acute Rehab N (%)	1 (2.4%)	2 (13.3%)	1 (33.3%)	1 (50.0%)	5 (8.2%)	<0.005
Skilled Nursing Facility N (%)	3 (2.5%)	3 (4.2%)	10 (24.4%)	2 (14.3%)	18 (7.3%)	<0.005
p-value[a]	0.385	0.174	0.729	0.268	0.814	

more detail. Utilizing these variables, the mean STTGMA score for the entire cohort was 1.7% ± 5.1%. 226 patients (55.4%) were included in the minimal-risk cohort (STTGMA score <0.4%), 102 patients (25.0%) were included in the low-risk cohort (STTGMA score 0.4%-1.5%), 53 patients (13.0%) were included in the moderate-risk cohort (STTGMA score 1.5%-5.0%), and 27 patients (6.6%) were included in the high-risk cohort (STTGMA score >5.0%). There was no difference in mean STTGMA score between the fracture pattern cohorts; however, as expected, there was a significant difference in mean STTGMA score between the procedure-specific cohorts with patients in the total hip arthroplasty group having a lower mean STTGMA score than those in the hemiarthroplasty or ORIF group (0.3±0.6% versus 2.1±5.9% versus 1.1±2.3%; p=0.024).

Of the 408 patients, 84 (20.6%) were discharged to home, 61 (15.0%) to an acute rehabilitation facility and 245 (60.0%) to a skilled nursing facility. There were 9 (2.2%) patients who died during the index hospitalization, 2 (0.5%) patients who was transferred to an outside hospital, 2 (0.5%) patients who were transferred to LTCF, and 5 (1.2%) patients who were transferred to hospice care. There were statistically significant differences in discharge patterns between the risk groups (p<0.005). While 63 patients in the minimal-risk cohort (27.9%) were discharged home, this percentage decreased significantly in the higher risk groups. The percentage of patients discharged to skilled nursing facilities also increased in the higher risk groups with 77.4% of the moderate-risk cohort discharged to SNF compared to 52.2% of the minimal-risk cohort (Table 4).

Overall, STTGMA risk cohorts also appeared to adequately risk-stratify readmission with 3.5% of minimal-risk patients requiring readmission compared to 24.5% of moderate-risk patients. Specific cohorts were deemed high-liability for readmission including low and moderate-risk STTGMA patients discharged home (28.5% and 33.3% readmission rate, respectively); moderate- and high-risk STTGMA patients discharged to SNF (21.9% and 14.3% readmission rate, respectively) and low-, moderate-, and high-risk patients discharged to AR (18.2%, 33.3%, and 50% readmission rates, respectively). However, within each cohort, discharge location (home, SNF, acute rehab) did not have an impact on readmission risk for each risk group (Table 5).

4. Discussion

The Score for Trauma Triage in the Geriatric and Middle-Aged is able to risk-stratify low-energy hip fracture patients with respect to discharge location and risk of readmission within 30 days after discharge. STTGMA can also be used to more closely track "high-risk" discharges to prevent readmissions. This analysis also demonstrates that improvements in discharge planning can be undertaken to encourage more home discharge in hip fracture patients as there were no differences in readmission risk based on discharge location within each risk group.

An important aspect of the STTGMA tool is that it is calculated from variables collected in the Emergency Department upon initial admission. Thus, STTGMA may be utilized as a clinical risk tool by orthopaedic surgeons to better guide patient care early within the hospitalization in preparation of discharge. The results of this study suggest that patients in the higher risk groups have a higher incidence of discharge to SNFs, while patients in the minimal-risk cohort are more likely to be discharged to home or acute inpatient rehabilitation. Based on these results we recommend that orthopaedic surgeons, along with their multidisciplinary team, commence early discharge planning on either hospital day 0 or 1 using the STTGMA tool to guide planning to home, acute inpatient rehabilitation or to SNF based on their STTGMA result. Early discharge planning may decrease patient mortality and improve their functional outcomes [14]. In addition, it will lead to reductions in inpatient lengths of stay, hospital costs, and utilization of hospital resources [14]. Furthermore, hospitals may use the STTGMA tool to more closely track the "high-risk" discharges as we identified in this study to prevent readmission including low- and moderate-risk STTGMA patients discharged home, moderate- and high-risk STTGMA patients discharged to SNF, and low-, moderate-, and high-risk patients discharged to acute rehab.

Our results demonstrated that STTGMA was able to associate patients, based on historical discharge location patterns, into a home, acute inpatient rehabilitation, and SNF category. This ability is important given the current shift in hip fracture reimbursement to a bundled payment model with the goal of improvement in the quality of care of these patients. The average Medicare payment for the initial rehabilitation stay for hip fracture patients is approximately $15,183 [17]. It is estimated that rehabilitation provides an additional 622 days of life. Estimations report that the average Medicare payment for such a patient is approximately $78 per day for two years following hospitalization [13]. Taking this cost information into account, increased savings may be realized if patients can be safely discharged home instead of discharged to acute inpatient rehabilitation or a subacute nursing facility. The use of STTGMA allows for identification of those patients who historically would have been discharged to acute inpatient rehabilitation or a subacute nursing facility but who may be safely discharged home with home-based physical therapy. This is an area open for future study.

There are several limitations to our study. First, although this study included several different types of hospitals, all hospitals are in an urban environment and may not be representative of other institutions throughout the country. Furthermore, our discharge rates to home and to acute inpatient rehabilitation are greater than those typically cited in the hip fracture population [18]. One possible reason for the high rate of home discharge during the study period is that all hospitals included in this study had a policy to encourage home discharge for all patients with acceptable family support. There was no standardized protocol to encourage home discharge, however, and this decision was made via shared decision-making process involving the patient/family and attending physician. With respect to the high rate of acute rehabilitation discharges, one possible explanation is that at two of the hospitals included in the study, there is an acute rehab facility within the hospital making acute rehab discharge often a simpler process than a discharge to a skilled nursing facility or home. Second, information regarding patients' race, socioeconomic status, and education level were not collected; investigating these variables may reveal confounding factors. In future studies, we plan to collect this data to determine its effect on the correlation found between STTGMA score and discharge location.

5. Conclusions

This novel scoring system, the Score for Trauma Triage in the Geriatric and Middle Aged, has the capacity to identify hip fracture patients who are likely to be discharged to a postacute care facility after inpatient hospitalization. Thus, it is a valuable clinical risk tool for orthopaedic surgeons in guiding patient care and early preparation of discharge planning for at-risk patients. Early discharge planning has multiple proven benefits for both the patient and the healthcare system.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

All authors declare that they have no conflicts of interest of interest related to the research or the manuscript. Kenneth Egol, M.D., is a consultant for Exactech and Dr. Sanjit Konda, M.D., is a consultant for Stryker.

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Review Article

Management of Subtrochanteric Proximal Femur Fractures: A Review of Recent Literature

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Subtrochanteric femur fractures are an uncommon injury in orthopedics, but when they are encountered they may present difficulties in management. The purpose of this paper is to examine the recent literature on the epidemiology, classification, initial evaluation, and definitely treatment for these injuries. These will assist the physician to determine the optimal treatment strategy and avoid potential surgical complication.

1. Introduction

Fractures of the proximal femur is a very important topic in the field of orthopedic surgery, but much of that attention is placed on fractures of the femoral neck and intertrochanteric areas. An additional area that must be well understood is the subtrochanteric (ST) region of the femur, which is defined as the proximal femoral shaft located within 5 cm of the lesser trochanter (Figure 1). This area experiences high levels of stress and fractures to this area can result in significant complications and poor clinical outcomes if not managed properly.

2. Epidemiology and Risk Factors

The overall incidence rate of fractures of the proximal femur is found to be approximately 230 per 100,000 patients with approximately 5-10% of these fracture occurring within the ST region [1, 2]. Overall the incidence has been estimated to be approximately 15-20/100,000. In terms of age, many studies have found that ST femur fractures occur in a bimodal distribution. One study delineated that approximately two-thirds of all ST fractures occur in patients older than 50 years of age with another 25% occurring in patients aged 17-50 [4]. In terms of gender, females have been found to be at high risk for ST femur fractures with up to a 33% higher incidence rate compared to males [2, 4]. In addition to age and gender, other elicited risk factors include low total bone mineral density, diabetes mellitus, and the use of bisphosphonate medications for the treatment of osteoporosis [5, 6]. The influence of bisphosphonates on the development of atypical femur fractures has garnered significant attention recently with elevated risk with prolongation of therapy, most notably after 5-10 years of treatment [1, 7]. Despite this risk, the overall protection from typical femoral neck and intertrochanteric fractures generated by bisphosphonate use appears to outweigh the increased risk for atypical ST fractures [7]. Overall, due to the prevalence of this injury in the field of orthopedic trauma and with no apparent changes in the incidence in these fractures since 1996 [2] it is prudent for the orthopedic surgeon to have a good understanding of the anatomy of the ST region, presentation, initial work-up, preoperative management, operative stabilization, and postoperative care.

3. Anatomy and Biomechanics

As mentioned before the ST area of the proximal femur is defined as the proximal femur that lies 5 cm distal to the lesser trochanter. The primary structural support to this area is the femorale calcar which is a posteromedial structure that begins just distal to the lesser trochanter and travels proximal to support the posteroinferior femoral neck. Early biomechanical studies found that this section of bone can experience up to 1200 N of force within the ST area with standing and gait [8].

Figure 1: Anatomy of the subtrochanteric area of the femur: the subtrochanteric area of the femur is defined as the area 5 cm distal to lesser trochanter.

Figure 2: Subtrochanteric fracture deformity: The typical deformity of the subtrochanteric femur fracture is one of external rotation and abduction of the proximal segment and adduction of the distal segment.

These forces are important because while these force can be tolerated in young healthy bone they may overpower weaker osteoporotic bone. In addition to the static forces placed on the proximal femur, this region experiences increased stress secondary to the multiple muscular attachments in the region, which include the lateral hip abductors, medial hip adductors, the iliopsoas, and short external rotators. These muscular attachments have been shown to increase stresses around the hip and proximal femur [9]. In addition to the stresses applied to the ST region, these multiple muscle groups produce predictable deformities patterns that must be understood in order to achieve a proper reduction. The classic deformity that occurs in ST femur fractures is proximal segment abduction, external rotation, and flexion caused by the pull of the gluteus medius, gluteus minimus, the short external rotators, and iliopsoas and adduction of the distal fragment by the gracilis and adductor muscle groups. (Figure 2)

4. Presentation: History and Physical Examination

Typically, patients will present in 1 of 2 scenarios. The first one will be a younger patient following a high energy mechanism of injury such as an MVA or fall from height. The patient will usually have multiple injuries and the first priority should be determining whether the patient requires ATLS and volume resuscitation. The second common situation is an elderly patient following a low mechanism of injury which will typically present with an isolated fracture. Following ATLS protocols or in the situation of a low energy MOI, a thorough history should be taken. This should include the MOI, pain, ability to ambulate, the presence of neurologic or vascular symptoms, and the presence of prodromal hip pain or contralateral hip pain. Medication histories should be taken looking for the use of bisphosphonates and the length of therapy.

Examination of the affected lower extremity will reveal a shorted and externally rotated extremity. Injuries are typically closed but examination of the skin should be through as open femur fractures represent extremely serious injuries with significant soft tissue damage. Neurovascular examination should be performed and deficits should be worked up appropriately. Finally, a history of another joint or extremity pain followed by a skeletal survey to rule out other musculoskeletal injuries should be performed.

5. Imaging and Classification

Initial imaging of the patient with a suspected ST fracture includes an AP pelvis and full-length femur films. These initial imagings will allow for proper injury identification and classification of the fracture. Typical findings will be the proximal fragment resting in abduction, external rotation, and flexion with the distal fragment in adduction. The fracture will also typically be in a long oblique orientation with varying amounts of comminution. In the setting of a history of prolonged bisphosphonate use with or without contralateral hip and thigh pain, the surgeon should attempt

Figure 3: Atypical subtrochanteric femur fracture: Initial identification of atypical subtrochanteric femur fractures can be identified by characteristic lateral cortical thickening.

to identify atypical fracture patterns associated with bisphosphonates. Recently the American Society for Bone and Mineral Research developed criteria for the identification of atypical ST femur fractures. Common radiographic features of atypical ST femur fractures include transverse fracture patterns with minimal comminution, lateral cortical thinking, and a posteromedial spike in the setting of a low energy injury (Figure 3). The importance of identifying atypical fractures associated with bisphosphonates is the fact that there is a high incidence of bilateral fractures, recommendations for discontinuation of bisphosphonate and conversion to teriparatide, and the need for prophylactic fixation of lateral insufficiency fractures to prevent completion of the fracture [10, 11]. These recommendations come from the overserved improvement in patients with hip pain and lateral cortical thickening with protected weight bearing and conversion from bisphosphonate treatment to teriparatide and lack of improvement with similar treatment in patients with documented radiolucent lines in the lateral cortex. Advanced imaging modalities, such as CT or MRI, can be performed in cases with equivocal plain radiographs to identify occult cortex lucencies. These imaging modalities should also be used to tract the treatment of the stress fractures [3, 10]. Overall several different classification systems have been developed including the Russell-Taylor classification which is based on the presence of lesser trochanter comminution and fracture extension into the piriformis fossa which helped to guide treatment prior to the development of trochanteric start point intramedullary nails. The AO classification system also has a classification system describing fracture morphology and mechanism.

6. Emergency Department Management

After performing a history, physical examination, and imaging modalities, initial treatment should always begin with any required resuscitative measures as indicated by ATLS protocols. Following stabilization and ruling out other injuries, the patient may be placed in skeletal traction. Skeletal traction through the use of a distal femoral pin has been shown to restore length of the affected extremity and improve preoperative pain scores [12]. Finally, medical optimization with the assistance of internal medicine/geriatrics has been found to improve inpatient mortality, long-term mortality, and length of stay [13].

7. Definitive Management: Nonoperative

Due to the high morbidity and mortality associated with nonoperative management, there are only a few instances where it is acceptable. First the patient in extremis with a high risk of mortality from anesthesia or other medical conditions should avoid surgical treatment. Secondly, hospice patients with minimal discomfort may be treated nonoperatively. However, numerous benefits, such as improved mobility, decrease of pain, and improving the care provided by care givers by the definitive fixation, should be thoroughly discussed with all individuals involved in the medical decision-making process before proceeding with nonoperative management [14].

8. Definitive Management: Intramedullary Nailing

Overall, the use of intramedullary fixation has become the gold standard for the treatment of ST femur fractures (Figure 4). Overall, intramedullary nailing has been shown to decrease operative time, fixation failure, and hospital length of stay when compared to extramedullary devices [15]. Wiss et al. examined 95 acute ST femur fractures and found average time to union to be 25 weeks with 7 complications including 1 nonunion and 6 malunions [16]. Similar results were found by Shah et al. who examined 51 ST fractures treated with intramedullary nailing and found good results with 1 delayed union in a pathologic fracture secondary to malignancy and 1 case of failure of fixation. This study also revealed overall Harris hip scores of 90.1 at 12 months [16]. Despite the apparent success of intramedullary nailing, slight nuances to the techniques of the procedure have been found to improve outcomes, including the nail starting point, proximal screw orientation, and length of the nail.

In terms of the proximal entry point for an anterograde intramedullary nailing, the surgeon has a choice of a piriformis start point and a greater trochanteric start point. Advantages of the piriformis start point include reduction of the incidence of varus malreduction and medial cortex injury with reaming [17]. Disadvantages are difficulty in obtaining a proper start point in obese patients, patients with hypertrophic short external rotators, or greater trochanter overhang. Additional excessive anterior placement of the starting point by as little as 6 mm can increase the risk of anterior cortical blowout [18]. Finally, there is concern for the proximity of the piriformis start point to the cervical vessels of the medial femoral circumflex artery. The second starting point is the trochanteric start point. Advantages include protecting more of the soft tissue structures around the hip and easier placement [19]. However there is a greater concern

Figure 4: Intramedullary fixation of a subtrochanteric femur fracture: This diagram illustrates and provides radiographs of an example of intramedullary fixation of a subtrochanteric femur fracture. Proximal fixation is achieved through the use of cephalomedullary screws and distally with locked interlock screws.

for varus malreduction and vast changes in the "ideal" start point based on patient anatomy [3, 20]. Overall the ideal start point must be chosen based on unique patient and fracture characteristics including body habitus, bony anatomy of the proximal femur, and fracture lines into the greater trochanter or basicervical region.

The next technical aspect of anterograde femoral nailing is the proximal screw orientation. For more proximal diaphyseal femoral fractures the crossed proximal screws are used. However this type of construct only provides stabilization through bony contact at the entry site and cortical contact at the interlocking bolt sites. The development of reconstruction nail designs allows for additional fixation via forces between the cephalomedullary screw and the femoral neck and head preventing varus and flexion deformities [21]. In addition to orientation of the screws, the number of screws has been examined. Grisell et al. examined two different two-proximal screw constructs: one with parallel screws into the femoral head and neck and one with crossed screws. This study determined that the axial stiffness was greater in the cross screw construct [22]. In addition, studies have also shown two distal interlock screws provide greater stability than one [21].

Final aspects to intramedullary nailing include nail length, nail size, and nail material. In terms of nail length, the standard of care is full-length intramedullary nails. This is supported by biomechanical studies revealing weak constructs and peri-implant fractures when comparing long and short intramedullary devices [23]. In terms of implant diameter and material, biomechanical studies have shown that larger proximal diameter implants made of stainless steel provided greater fracture stability in rotation, shear, and axial motion over smaller diameter titanium implants [7]. Overall, long intramedullary nailing of ST femur fractures has been shown to provide great outcomes with limited complications.

9. Definitive Treatment: Plating

Aside from intramedullary nailing, numerous methods of open reduction and internal fixation of ST femur fractures are available. The most successful type of plating involves the use of 95-degree fixed angle blade plates (Figure 5). Despite some studies revealing moderately good results with fixed angle plating with nonunion rates of approximately 0-10% with times to union of approximately 5 months [2, 24], more recent studies have found less appealing results [25]. These recent changes in outcomes, coupled with the high degree of difficulty in applying this fixed angle devices and decreased infection rates, higher union rates, and shorter operative times with intramedullary nailing, have led to decreased use in 95-degree fixed angle plates [14, 25]. Another form of fixed angle plating includes proximal femoral locking plates (Figure 6). These systems have been shown to have better biomechanical properties than blade plate constructs. However recent studies have also shown poor results including high malunion/nonunion rates and subsequent reoperation rates close to 35% [14, 26]. Finally 135-degree compression plates, commonly used for intertrochanteric hip fractures, have been shown to have failure of fixation upwards of 56%

Figure 5: Extramedullary fixation of subtrochanteric femur fractures: This diagram illustrates the use of a 95-degree blade plate construct for the treatment of subtrochanteric femur fractures.

Figure 6: Extramedullary fixation of subtrochanteric femur fractures: This diagram illustrates and provides radiographs of the use of a proximal femoral locking plate construct for the treatment of subtrochanteric femur fractures.

Figure 7: Varus collapse of subtrochanteric femur fractures: This diagram illustrates and provides a radiographic example of a subtrochanteric fracture varus nonunion.

and therefore have been abandoned in the surgical treatment of ST femur fractures [21].

Despite poorer results of open reduction and internal fixation with fixed angle constructs when compared to intramedullary nailing, open plating may still have a prominent role in the acute treatment of ST femur fractures. One study by Robertson et al. showed a large improvement in malunion rates (27% versus 0%) when provisional plating of ST femur fractures was performed prior to intramedullary nailing in fractures that required an open reduction. In addition there was no increase in operative time or blood loss when comparing all cases that required open reduction between the two study groups [15].

10. Complications

The complications of surgical treatment of ST femur fractures are similar to the complications for other types of proximal femur fractures, including mortality, nonunion, malunion, and infection. In terms of mortality rates, ST fracture 1-year mortality rates in elderly patients are similar to rates for femoral neck and IT fractures of approximately 9.5% at 30 days, 27% at 1 year, and up to 60% at 4 years [22, 27]. Interestingly, it appears that patients with atypical proximal femur fractures associated with bisphosphonates have a decreased mortality rate at 4 years when compared to typical ST fracture patterns [27].

In terms of malunion and nonunion rates, the main cause appears to be inability to obtain anatomic reductions intraoperatively. Development of improper reductions can be the result of improper starting points, especially too lateral with the trochanteric starting point, or lack of direct visualization, instrumentation, or provisional plate fixation prior to intramedullary nail insertion. In addition to increased rates of nonunion, excessive varus and flexion of the proximal segment can cause detrimental changes to gait mechanics. In general, the typical failure will result in a varus deformity (Figure 7) and these complications are typically treated

with exchange intramedullary nailing or fixed angle plate constructs with or without bone grafting [14].

In terms of infection, both deep and superficial surgical site infections can occur following operative treatment of ST femur fractures. Typically superficial soft tissue infections can be treated conservatively with antibiotic alone. In terms of deep infections, they may be approached with surgical irrigation and debridement with antibiotics in an attempt to allow the fracture to heal prior to implant removal. However, should the patient be found to have a persistent infected nonunion, removal of the implant is needed followed by temporary fixation with an antibiotic intramedullary device followed by antibiotics until the infection has been effectively treated [14].

11. Summary

ST femur fractures are a less common type of hip fracture but can occur in both young and elderly patients after both high- and low-energy mechanisms of injury. While initial evaluation and treatment involve resuscitation and modalities such as skeletal traction, very rarely should treatment not proceed to surgical fixation. In terms of fixation, intramedullary nailing is the gold standard of treatment and can be performed safely for both typical and atypical ST fractures. However there are many technical aspects to intramedullary nailing that a surgeon must consider. While fixed angle constructs can be used for initial treatment of fixation, these methods are more commonly utilized for ST femoral malunion/nonunion treatment.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Research Article

Standardised Warfarin Reversal Expedites Time to Theatre for Fractured Neck of Femur Surgery and Improves Mortality Rates: A Matched Cohort Study

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Background. This study aims to evaluate outcomes for warfarinised hip fracture patients and compare them with a matched nonwarfarinised group, before and after the introduction of national hip fracture guidelines in the United Kingdom. *Methods*. A retrospective cohort study of 1743 hip fracture patients was undertaken. All patients admitted taking warfarin were identified. These patients were then matched to nonwarfarinised patients using nearest neighbour propensity score matching, accounting for age, sex, hip fracture type, and Nottingham Hip Fracture Score. A pre-guideline group (no standardised warfarin reversal regimen) and a post-guideline group (standardised regimen) were identified. Outcomes assessed included time to INR less than 1.7, time to theatre, length of stay, and 30-day and 1-year mortality. *Results*. Forty-six warfarinised hip fracture patients were admitted in the pre-guideline group (mean age 80.5, F:M 3:1) and 48 in the post-guideline group (mean age 81.2 years, F:M 3:1). Post-guideline patients were reversed to a safe operative INR level within 18 hours of admission, decreasing the time to first dose vitamin K ($p<0.001$). 70% of warfarinised patients were operated upon within 36 hours, compared to 19.6% with no regimen ($p<0.05$). After anticoagulation reversal protocol, thirty-day mortality decreased from 15.2% to 8.3% and 1-year mortality from 43.5% to 33% for warfarinised patients, which is comparable to nonwarfarinised matched patients. There was no significant change in the length of stay pre- and post-guideline for both groups of patients. *Conclusions*. Proactive anticoagulant management and expedient surgery reduces morbidity and mortality when managing this surgically challenging subset of hip fracture patients.

1. Introduction

1.1. Background and Rationale. An estimated 1% of the United Kingdom (UK) population take warfarin [1] for conditions including atrial fibrillation, venous thromboembolic disease (deep vein thrombosis or pulmonary embolism), cerebrovascular disease, or following cardiac valve surgery [2]. It is estimated that 3.2% of hip fracture patients are admitted taking warfarin [3]; this figure is anticipated to increase in accordance with the predicted rising hip fracture incidence [4] in the UK. There are an estimated 80,000 hip fracture cases per year in the UK [5], and therefore approximately 2500 hip fracture patients will be admitted taking warfarin each year [3]. Traditionally, these patients were considered at high risk, due to the increased risk of bleeding and associated perioperative complications. This subset of hip fracture patients poses a surgical challenge, with UK National Institute of Health and Care Excellence (NICE) guidance [4] focusing upon holistic multidisciplinary patient care, including safely optimising anticoagulation and other comorbidities to undergo emergency surgery [4]. This strategy decreases morbidity and mortality for all hip fracture patients [6–8]. Although no agreed national guidelines exist for the reversal of warfarin in the UK, the use of standardised reversal regimens has been shown to be beneficial in-patient optimisation and reduces their delay to theatre [9, 10]. This, combined with national incentivised "Best Practice" tariff (BPT) [11] and NICE guidelines on holistic care for hip fracture patients [4], has reduced mortality and morbidity [12, 13].

Warfarin is a vitamin K antagonist derived from coumarin [14]. Options to reverse its effect include oral vitamin K, intravenous vitamin K at either high or low dosages, dose omission, and blood products, including fresh frozen plasma (FFP) or prothrombin complex concentrates (PCC) [9, 10, 15–17]. Oral vitamin K takes up to 48 hours to be effective. Blood products have a limited window of effectiveness, need to be used in conjunction with vitamin K, and have additional problems of cost and adverse reactions [9, 10]. Intravenous vitamin K is advocated if surgery can be delayed beyond 12 hours; otherwise blood products may have a role [18–20] to reach a safe operative INR [21, 22]. Seventy-seven percent of delays to theatre beyond 48 hours in hip fracture patients are the result of poorly controlled medical comorbidity or pending investigations [23, 24]. Anticoagulation reversal accounts for 11% of comorbidity related delays [24], which is associated with increased 30-day mortality [4, 7, 25, 26]. Outcomes for warfarinised patients have been recently reported by Lawrence et al., showing that after controlling for prognostic factors such as age, ASA, and AMTS, warfarin therapy at the time of hip fracture is associated with increased time to surgery, length of stay, and increased mortality [27]. However, there has been no analysis against a matched group of patients who were not anticoagulated with warfarin on admission.

1.2. Objectives. We hypothesised that the introduction of our standardised regimen for the reversal of anticoagulation in fractured neck of femur patients would expedite their surgery and possibly reduce subsequent length of stay and post-operative mortality. The aims of this study were to evaluate outcomes for warfarinised patients admitted with a hip fracture before and after the introduction of a standardised reversal regimen for warfarin, compared to matched non-warfarinised patients. The measurable outcomes chosen were time to theatre, length of stay, and post-operative mortality.

2. Patients and Methods

2.1. Study Design. This study was a retrospective analysis of prospectively collected matched data. A search through our institution's database was performed on all patients admitted to our institution between the 1st of January 2008 and 28th February 2012 with a hip fracture. A list of patients admitted between these dates for whom the primary International Classification of Diseases-10 (ICD-10) diagnosis code for their spell corresponded to hip fracture (S72.0, fracture of neck of femur; S72.1, pertrochanteric fracture; S72.2, sub-trochanteric fracture) was generated [28]. These patients were cross-referenced with our institutions admissions database to ensure that the data were accurate. This was further cross-referenced with our institutions National Hip Fracture Database (NHFD) records for all hip fracture patients input onto the National Audit Programme [12]. No patients were excluded. The key outcomes assessed included time to first dose of vitamin K and International Normalized Ratio (INR) less than 1.7 (this is our centres agreed safe operative level by surgeons and anaesthetists), time to theatre, length of stay, and 30-day and 1-year mortality. The time to INR of less than 1.7 is taken from time of admission to the time of publication of the laboratory published results on the electronic pathology system for all cases.

2.2. Identification of Patients. From the generated hip fracture patient list, comorbidities were recorded on our institutions' admissions database, which allowed us to identify all patients admitted on warfarin for any reason. These patients were assigned to the "warfarinised" arm of the study. This cohort continued with their warfarin therapy long-term following surgery. The generated hip fracture patient list was also the source of the matched nonwarfarinised patients. This cohort were assigned to the "matched" arm of the study. Post-operatively, the matched cohort were given the standard prophylactic regimen of 4 weeks daily subcutaneous dalteparin as venous thromboembolic event (VTE) prophylaxis.

Warfarinised patients were divided into a pre-guideline and post-guideline group, with the introduction of the BPT of April 2010 being the delineation between these groups. The pre-guideline group included all warfarinised patients between 1st January 2008 and 31st March 2010, whilst the post-guideline group included all patients between 1st April 2010 and 28th February 2012. The pre-guideline group were not treated with a standardised warfarin reversal protocol and received variable amounts of intravenous vitamin K, at variable times based on the clinical judgement of the clinical team. The post-guideline group received a standardised protocol of low dose 2mg intravenous vitamin K every 6 hours from admission until their INR was less than 1.7.

Electronic patient records were used to establish patient demographics, Nottingham Hip Fracture Score, admission date, time to theatre, discharge date, and date of death for each patient, allowing calculation of 30-day and 1-year mortality. The fracture pattern was obtained from the patient's ICD-10 primary diagnosis code [28]. These were categorised as (i) intracapsular fracture and (ii) extracapsular and sub-trochanteric fractures and cross-referenced with the admission database and PACS (Picture Archiving and Communication System) radiological software. Theatre and anaesthetic databases were accessed for timings to theatre, operation type, and ASA grade. The time to theatre was calculated from time of admission in the Emergency Department to the time the patient entered the anaesthetic room in hours. Timings to theatre were categorised as (i) less than 36 hours, (ii) 36-48 hours, (iii) greater than 48 hours, and (iv) no operation. These categories have been devised because the BPT target for time to theatre is less than 36 hours, and the NICE target is less than 48 hours, allowing comparison of our data with the National Hip Fracture Database (NHFD). Length of stay was expressed in days and is the time from admission in A&E to discharge from orthopaedic care and relates to their acute hospital spell. Thirty-day mortality was calculated by including patients who had died on any day up to and including day 30 following admission, and for 1-year mortality calculation patients who died up to and including 365 days from their day of admission were included in the analysis.

2.3. Statistical Analysis

2.3.1. Patient Matching. The pre-guideline and post-guideline warfarinised cohorts were matched separately with nonwarfarinised patients using a "one to one nearest neighbour model" of propensity score matching for the variables of age (years), sex, fracture type, and Nottingham Hip Fracture Score [29]. Patient matching was necessary to compare outcomes for patients admitted on warfarin versus those who were not anticoagulated. Once each warfarin case had been matched to a nonwarfarin case, that patient was eliminated from any further matching to avoid duplication of patients and allow direct comparison of outcomes for these patients.

2.3.2. Outcomes. Data were collated in Microsoft Excel 2010, and data analysis was performed using SPSS Statistics for Windows (version 22.0, IBM Corp., Armonk, NY, 2013) and the statistical package R (R version 3.0.2 (2012-09-25)) [30]. Descriptive statistics were used to describe the study population, with independent samples t-tests used to analyse continuous variables and chi-squared test used to analyse categorical variables. Statistical significance was assumed if $p<0.05$. For the pre-guideline and post-guideline groups their matched nonwarfarinised cases were compared for any difference in age, sex, fracture type, and Nottingham Hip Fracture Score (NHFS). Kaplan-Meier survival curves were used to compare survival between warfarinised and nonwarfarinised patients in the pre-guideline and post-guideline groups. Additionally, a further analysis of survival comparing warfarinised patients from the pre-guideline group to warfarinised patients in the post-guideline group was undertaken, with patient death being the survival outcome in both cases. This was calculated from day of admission to date of death or date of final follow-up. Chi-squared analysis was used to compare the survival curves between the two groups, with a p value of less than 0.05 ($p<0.05$) being considered significant.

3. Results

3.1. Study Population. A total of 1743 patients were initially identified from electronic patient records, 786 from the pre-guideline group and 957 from the post-guideline group. In the pre-guideline group 46 patients (5.9%) were admitted taking warfarin (33 females, 13 males), with a mean age of 80.5 years (±7.6 years, range 61-93 years). There were 26 intracapsular hip fractures and 20 extracapsular hip fractures, and the mean NHFS predicted a 9.2% (±6.5%) 30-day operative mortality. In the post-guideline group 48 patients (5.0%) were admitted taking warfarin (32 females, 16 males), with a mean age of 81.2 years (±8.0 years, range 62-100 years). There were 28 intracapsular hip fractures and 20 extracapsular hip fractures, and the mean NHFS predicted a 7.2% (±3.7%) 30-day operative mortality. Each patient was matched for age, sex, fracture type, and NHFS; there was no significant difference in these variables between warfarinised or nonwarfarinised patients in the pre-guideline group. In the post-guideline group there was no statistical difference between variables except in NHFS. The nonwarfarinised matched group had a mean NHFS of 9.8% (±7.6%) for 30-day operative mortality; this was statistically significant compared to the mean 7.2% for the warfarinised controls ($p=0.04$). This data is summarised in Table 1.

3.2. Comparison of Warfarinised Groups Pre- and Post-Guideline. Comparing the demographics of the two warfarinised groups showed no statistical difference in age ($p=0.641$), in sex 3:1 female ($p=0.901$) to male ($p=0.743$) ratio, or between extracapsular ($p=1.000$) and intracapsular ($p=0.960$) fractures. There was a statistically significant difference ($p=0.006$) between mean NHFS of 9.2 (±6.5) and 7.2 (±3.7), for pre-guideline and post-guideline groups, respectively.

3.3. Warfarin Reversal Management to Safe Operative Level. As shown in Table 1, the mean admission INR was 2.6 and 2.5 for the pre-guideline and post-guideline warfarinised groups, respectively. In the pre-guideline group there was no standardised reversal regimen, and each patient received different treatment. Patients received either no treatment or intravenous vitamin K, with doses ranging from 1mg to 10mg. The mean time from admission to administering the first dose of intravenous vitamin K was 13.07 hours (± 7.07), with a range of 1-28 hours after admission.

In the post-guideline group all patients received the same standardised reversal regimen with a mean time to 1st dose vitamin K of 3 hours; comparing this to the pre-guideline group of 13.07 hours, this result was statistically significant (please see Table 2).

3.4. Time to Theatre. As shown in Table 3, there was a mean delay to theatre of 70.36 hours (± 61.9 hours) from admission for the warfarinised patients, pre-guideline. The mean time to theatre for the matched pre-guideline nonwarfarinised patients was significantly lower, 44 hours ($p=0.03$). In the post-guideline patients who were on warfarin, there was a mean time to theatre of 46 hours (± 37.927 hours). The mean time to theatre for those not taking warfarin was 43 hours ($p=0.755$).

In the pre-guideline group of patients taking warfarin, 19.6% were operated upon in less than 36 hours compared to 45.7% of the nonwarfarinised group at the same time. Following the introduction of a local warfarin reversal protocol and incentivised guidelines, 70.8% of patients taking warfarin were operated upon within 36 hours, which is comparable to the 77% of nonwarfarinised patients at the same time. Prior to the introduction of national guidelines giving the 36 [18] and 48-hour [19] targets, there were no specific targets, but the NHFD reported outcomes for surgery within 48 hours [26]. Therefore, comparing the pre-guideline groups, 28.3% of warfarinised patients and 65.2% of nonwarfarinised patients were operated upon within 48 hours. After national targets were introduced, these figures improved to 77.1% of warfarinised patients and 85.4% of nonwarfarinised patients having surgery within the 48-hour target. Since the introduction of a local warfarin reversal protocol there has been a statistically significant decrease in

Table 1: Summary of study population demographics for propensity score matched cohorts pre- and post-guidelines. (M: male, F: female, IC: intracapsular, EC: extracapsular; comparing warfarin cases column relates to the warfarin cases pre- and post-guideline; $* \ p < 0.05$ is statistically significant.)

		Pre-Guideline			Post-guideline			P-Value
		Case	Matched	P-value	Case	Matched	P-value	Comparing warfarin cases
Total		46	46/786		48	48/957		
Age years	Mean	80.5 (±7.6)	80.5 (+/- 7.4)	0.97	81.2 (+/- 8.0)	81.3 (+/- 8.3)	0.97	0.641
	Range	61-93	61-93		62-100	62-104		
Sex (%)	M	13 (28.3)	14 (30.4)	0.89	16 (33.3)	17 (35.4)	0.92	0.743
	F	33 (71.7)	32 (69.6)	0.93	32 (66.7)	31 (64.6)	0.9	0.901
NHFS		9.2 (+/- 6.5)	8.9 (+/- 5.2)	0.86	7.2 (+/- 3.7)	9.8 (+/- 7.6)	*0.04	*0.006
Fracture Type (%)	IC	26 (57)	26 (57)	1.0	28 (58)	28 (58)	1.0	0.960
	EC	20 (43)	20 (43)	1.0	20 (42)	20 (42)	1.0	1.0
INR on Admission	Mean	2.6 (+/-0.9)			2.5 (+/- 1.0)			0.87
	Range	1.2-5.1			1.4-4.9			

Table 2: A comparison of pre- and post-guideline time to first dose of 2mg intravenous vitamin K from admission.

		Pre-Guideline	Post-Guideline	P Value
Time to 1st dose Vitamin K (Hours)	Mean	13.07 (+/-7.07)	3.00 (+/-1.11)	*<0.001
	Range	1-28	2-6	

time to theatre for 36 hours (p=0.039) and 48 hours (p=0.041) when comparing the two warfarinised groups.

3.5. Length of Stay. The mean length of stay was 5.1 and 1.6 days less for the nonwarfarinised matched patients in the pre- and post-guideline groups, respectively (p=0.10 and 0.22). Following the introduction of the local warfarin protocol, the length of stay increased by 5 days; however, this was not statistically significant (p=0.408) (Table 4).

3.6. Mortality. Referring to Table 5, in the pre-guideline group, 30-day mortality for the warfarinised and nonwarfarinised patients was 15.2% and 8.7%, respectively (p=0.34). One-year mortality was 43.5% and 26.1% for the warfarinised and matched nonwarfarinised patients, respectively (p=0.15). There was a mean follow-up of 54 months allowing Kaplan-Meier analysis and chi-squared analysis of the difference between the two curves (see Figure 1).

In the post-guideline group, 30-day mortality for the warfarinised and nonwarfarinised patients was 8.3% and 6.2%, respectively (p=0.63). One-year mortality was 33.3% and 33.3%, respectively, for the warfarinised and matched nonwarfarinised patients (p=1.00). There was a mean follow-up of 38 months allowing Kaplan-Meier analysis and chi-squared analysis of the difference between the two curves (see Figure 2). There was no statistical difference in long-term survival between warfarinised and nonwarfarinised patients (p=0.992). There was also no significant difference in long-term survival between pre- and post-guideline warfarinised patients (p=0.67) and between pre- and post-guideline matched patients (p=0.43)

Figure 1: Kaplan-Meier curve of pre-guideline matched warfarinised and nonwarfarinised patients during 54-month follow-up (follow-up duration in days).

4. Discussion

The NHFD has shown that introduction of national guidelines has had a significant beneficial effect on outcomes for all hip fracture patients [12]. However, they do not

Table 3: A comparison of time to theatre between pre- and post-guideline, and warfarinised and matched patients.

		Pre-Guideline			Post-Guideline			Odds Ratio (95% CI) Pre- and Post-Guideline		P Value
		Case	Matched	P-value	Case	Matched	P-value	Comparing Warfarin Cases	Comparing Matched Cases	Comparing warfarin cases
Time to Theatre (Hours)	Mean (SD)	70.4 (61.93)	44.2 (40.97)	*0.039	46 (37.97(	42.5 (80.90)	0.79			*0.036
	Range	13-307	9-183		12-183	13-571				
Time to Theatre (Hours) n (%)	<36	9 (19.6)	21 (45.7)	*0.024	34 (70.8)	37 (77.1)	0.279	7.83 (2.96-20.70)	4.50 (1.76-11.51)	*0.039
	36-48	4 (8.7)	9 (19.6)		3 (6.3)	4 (8.3)				*0.041
	<48	13 (28.3)	30 (28.3)	*0.002	37	41 (85.4)	0.12	6.47 (2.50-16.72)	3.83 (1.24-11.78)	<0.001
	>48	25 (54.3)	14 (30.4)		11 (22.9)	5 (10.4)				*0.047
	No op	8 (17.4)	2 (4.3)		0 (0)	2 (4.2)				

Table 4: A comparison of pre- and post-guideline length of stay between warfarinised and nonwarfarinised matched patients.

		Pre-Guideline			Post-Guideline			Change in LOS		P Value	
		Case	Matched	P Value	Case	Matched	P Value	Case	Matched	Comparing Warfarin Cases	Comparing Matched Cases
Length of Stay (Days)	Mean (SD)	17.3 (14.2)	13.2 (9.4)	0.10	22.4 (39.7)	14.8 (15.1)	0.22	5.1	1.6	0.408	0.53

Table 5: A comparison of pre- and post-guideline mortality % at 30 days and at 1 year for warfarinised patients and nonwarfarinised matched patients.

		Pre-Guideline				Post-Guideline				Hazard Ratio (95% CI)		P Value
		Case	Matched	P Value	Hazard Ratio (95% CI)	Case	Matched	P Value	Hazard Ratio (95% CI)	Comparing Warfarin Cases	Comparing Matched Cases	Comparing Warfarin Cases
Mortality (%)	30-Day	15.2	8.7	0.34	1.81 (0.14-5.90)	8.3	6.2	0.63	1.36 (0.44-4.16)	0.97 (0.48-1.96)	1.42 (0.76-1.96)	0.299
	1 Year	43.5	26.1	0.15	1.70 (1.34-2.15)	33.3	33.3	1.0	0.96 (0.75-1.24)	1.16 (0.65-2.07)	0.86 (0.41-1.78)	0.312

identify specific subsets of high-risk patients who may benefit from specific optimisation, for example, warfarinised patients requiring an anticoagulation reversal protocol to ensure national targets are met. Patients admitted with a hip fracture requiring emergency surgery whilst being anticoagulated with warfarin pose a challenging surgical dilemma. Our findings suggest that having a warfarin reversal protocol as part of preoperative optimisation has significantly reduced the time to theatre for this challenging subset of patients. The majority of warfarinised patients (77%) are undergoing their emergency surgery within the national targets, which has likely contributed to a reduced length of stay and decreased 30-day and 1-year mortality [4, 11].

Reviewing the NHFD reveals that the average age for hip fracture patients is 80 years, with a 3:1 female to male ratio [4]. Our pre-guideline cases had a mean age of 80.5 with 71.7% being female, which is consistent with the NHFD audit demographic data. In the post-guideline group the mean age was slightly higher at 81.2 years, with 33% of patients being male; this differs from the NHFD population, with males known to have poorer outcomes following hip fracture [31]. The national average life expectancy in 2010 was 79 years for males and 83 years for females [32], with our cohort having their hip fracture at approximately this age and the age range for the cohorts reaching 93 years and 100 years in the pre- and post-guideline groups, respectively. These patients would have a high mortality risk due to their age and comorbidities even prior to the additional increase in mortality risk associated with hip fracture, which is an independent clinical risk factor [33]. A comparable distribution is seen when comparing the type of fracture to that recorded in the NHFD (57% intracapsular types, 40% extracapsular types, and 3% unknown) [12].

The previously reported proportion of patients taking warfarin admitted with a hip fracture is reported as a minimum of 3.2% [3]. This was higher in our study population,

Figure 2: Kaplan-Meier curve of post-guideline matched warfarinised and nonwarfarinised patients during 58-month follow-up (follow-up duration in days).

being 5.9% and 5.0% for pre- and post-guideline groups, respectively. As patients live longer, they have an increased risk of developing comorbidities requiring warfarin therapy to reduce their embolic relative risk [3, 17]. Our warfarinised patients were older than those seen in Ashouri et al.'s population, which may explain our higher proportion of warfarinised patients [3].

The biggest delay in warfarin reversal was the time to the first dose of vitamin K. Without a protocol this was poorly addressed with a mean time to first dose of 13 hours. This significantly reduced to 3 hours ($p<0.001$) after protocol introduction, with all patients INR being in a safe operative range within 24 hours of admission. It is well reported that the early hip fracture surgery is associated with improved outcomes, with national guidance suggesting surgery within 48 hours [4, 7, 8, 11]. Indeed, recent studies have suggested that outcomes deteriorate when surgery is delayed beyond 12 hours [6]. Repeated low dose intravenous vitamin K is appropriate to achieve surgery within 36 hours [9], but if surgery within 12 hours was necessary to improve outcomes, then blood products would need to be considered [18]. The use of FFP and PCC is unreported in hip fracture literature and should be given with caution and on haematology advice, due to potential complications including Transfusion Related Acute Lung Injury (TRALI), anaphylaxis, blood borne infections (HIV and Hepatitis B), and allo-immunisation [34, 35].

Length of stay has fallen since the introduction of the national guidelines but was greater for warfarinised patients compared to their matched controls in both the pre- and post-guideline groups. In the pre-guideline group the delay in preoperative reversal of warfarin contributed, with delayed surgery being associated with increased length of stay, morbidity including pressure sores and respiratory infections, and mortality [7], to complications not seen in our cohort.

The NHFD reports on 30-day and 1-year mortality, but there is no long-term mortality data. For our cohorts we have mortality data reported at final follow-up of mean 54 months and 34 months in the pre- and post-guideline groups, respectively. Mortality at 30 days and 1 year was higher in the pre-guideline warfarinised group (15.2% and 43.5%) compared to their matched cases (8.7% and 26.1%). This supports the proposition that delays to theatre and poor preoperative warfarin anticoagulation reversal are associated with poorer outcomes in warfarinised patients compared to their matched cases [7, 8, 31]. Chatterton et al. reported post-mortem data for deaths within 30 days with pneumonia being the commonest cause of death [13]. Given the delays to theatre preoperatively (mean 70 hours), warfarinised patients were at high risk for pneumonia secondary to poor lung ventilation because of immobility, posture, opiate medications, and pain. Following the introduction of the warfarin reversal protocol and national incentivised guidelines, 30-day mortality for the warfarinised and nonwarfarinised patients had reduced to 8.3% and 6.2%, respectively ($p=0.63$), which is comparable to the NHFD data [12]. Reversing the INR rapidly and safely has meant that 77% of patients were operated upon within 48 hours, which is known to improve outcomes [7, 8, 32, 36]. One-year mortality was 33.3% in both the warfarinised and matched nonwarfarinised patients (Figure 2), with no difference between mortality curves ($p=0.992$). Long-term follow-up is rare for hip fracture patients, and the Kaplan-Meier curves demonstrate that mortality is greatest in the first year followed by mortality plateaus with no difference (pre-guideline $p=0.776$, post-guideline $p=0.992$) between the warfarinised and nonwarfarinised curves by 54 and 38 months of follow-up, respectively.

The strengths of this study design include the case matching to enable comparison between outcomes in warfarinised and nonwarfarinised hip fracture patients. Matching was utilised to address the issues of confounding in the design phase of the study. The method of matching used a one to one nearest neighbour model [29], which allows direct analysis of treatment of anticoagulation reversal compared to those not anticoagulated at admission. Limitations include the patient list being generated utilising the ICD-10 codes for hip fracture [28]. This should not have affected our study because hip fracture coding in the UK has not changed since 1995 [37], predating our study period. In addition, a systematic review of 32 studies has shown that discharge coding accuracy levels are sufficiently robust for research use [38]. Furthermore, our data was cross-referenced with multiple sources to confirm accuracy. Due to the retrospective nature of this study we were also unable to obtain specific data on post-operative complications including wound issues, thrombotic events, or pressure sores.

This matched cohort study of a surgically challenging subset of hip fracture patients shows poorer outcomes for warfarinised patients than a matched cohort of nonwarfarinised patients. Implementing a proactive warfarin reversal policy coupled with national incentivised care standards facilitates rapid surgery, improving holistic care and 30-day and 1-year mortality. Intravenous vitamin K is safe to achieve surgery within 36 hours; however if surgery within 12 hours could improve outcomes further, then blood products may be required, an area that requires further research.

Data Availability

All data collected for the construction of this research paper are available on the database of the Royal Stoke University Hospital fractured neck of femur database, which is overseen

by the senior author of this paper. The collected and processed data used for the statistical calculations are on a spreadsheet in the possession of all authors. Both the database and spreadsheet can be accessed on request.

Disclosure

Level of evidence is level III.

Conflicts of Interest

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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