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TOPIC HIGHLIGHT

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Management of femoral neck fractures in the young patient: A critical analysis review

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Abstract

Femoral neck fractures account for nearly half of all hip fractures with the vast majority occurring in elderly patients after simple falls. Currently there may be sufficient evidence to support the routine use of hip replacement surgery for low demand elderly patients in all but non-displaced and valgus impacted femoral neck fractures. However, for the physiologically young patients, preservation of the natural hip anatomy and mechanics is a priority in management because of their high functional demands. The biomechanical challenges of femoral neck fixation and the vulnerability of the femoral head blood supply lead to a high incidence of non-union and osteonecrosis of the femoral head after internal fixation of displaced femoral neck fractures. Anatomic reduction and stable internal fixation are essentials in achieving the goals of treatment in this young patient population. Furthermore, other management variables such as surgical timing, the role of capsulotomy and the choice of implant for fixation remain controversial. This review will focus both on the demographics and injury profile of the young patient with femoral neck fractures and the current evidence behind the surgical management of these injuries as well as their major secondary complications.

Key words: Osteonecrosis; Femoral neck fracture; Young patient; Capsulotomy; Surgical timing

Core tip: This critical analysis review provides an overview of the pathophysiology of femoral neck fractures in the young adults. Additionally, it offers recommendations to guide the orthopedic surgeon in the management of femoral neck fractures and its most common surgical complications. Few studies have reviewed this controversial subject and provided treatment guidelines.

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INTRODUCTION

Femoral neck fractures account for nearly half of all hip fractures with the vast majority occurring in elderly patients after simple falls[1]. Currently there may be sufficient evidence to support the routine use of hip replacement surgery for low demand elderly patients in all but non-displaced and valgus impacted femoral neck fractures. This is based on a multitude of randomized controlled trials documenting improved short and long-term hip function and lower re-operation rates with hip arthroplasty as compared to internal fixation in elderly adults[2-5]. Furthermore, early weight bearing protocols post-arthroplasty minimizes complications of prolonged inactivity[6].

For the non-elderly patient with good bone quality, preservation of the natural hip anatomy and mechanics is a priority as their high functional demands and young age preclude their candidacy for replacement procedures[7]. While only 3%-10% of these fractures occur in younger adults, the major differences in physiology, injury characteristics and activity level necessitate a dedicated treatment pathway[8,9]. However, the biomechanical challenges of femoral neck fixation and the vulnerability of the femoral head blood supply lead to a high incidence of non-union and osteonecrosis of the femoral head (ONFH) after internal fixation of displaced femoral neck fractures[10-15]. These complications are highly symptomatic in active patients leading to salvage procedures with significant failure rates.

Undisputedly, anatomic reduction and stable internal fixation are essentials for achieving the goals of treatment in this young population allowing preservation of the femoral head while minimizing rates of non-union and osteonecrosis[16]. Other management variables such as surgical timing, the role of capsulotomy and the choice of implant remain controversial. This review will focus both on the demographics and injury profile of young patients with a femoral neck fractures and the current evidence behind the management of these injuries and their secondary complications.

Consideration of physiological age

The age range describing a young patient is most often between skeletal maturity and the age of fifty[8,9,12-15,17]. More recently, patients up to 65 years have been considered within this definition[6,18,19]. The majority of surgeons prefer to treat young patients (< 60 years) and elderly patients with non-displaced fractures with internal fixation and favor arthroplasty for displaced fractures in patients above 80 years[20]. However, for patients outside these categories, the treatment approach is variable. For the "young-elderly" population, chronologic age becomes less important and establishing a patient's physiologic age becomes the first step in management[21]. Several variables have been used to characterize the physiologic age of a patient; pre-injury activity level, medical co-morbidities and bone quality. In addition to chronological age these variables dictate the goals of management for these two populations and have an impact on the outcomes of surgical treatments. Bone quality influences the success of internal fixation of femoral neck fractures. Cadaveric studies of femoral neck fixation have shown a positive correlation between bone density and achieved fixation stability[22,23]. In a review of over one thousand patients with femoral neck fractures, Parker et al. found the incidence of non-union to be age dependent with a rate of 5.9% in patients younger than 40 years compared to 24.9% for patients in their 70s. In addition to non-union, failure of osteoporotic bone around multiple screw fixation leads to increased screw sliding and shortening of the femoral neck. Femoral neck shortening of more than 5 mm has been correlated with decreased functional outcomes and an increased incidence of requiring walking assistance[24].

Overall, secondary surgical procedures are significantly more common in elderly patients treated with internal fixation compared to those treated with arthroplasty[25]. Although risks of non-union and osteonecrosis are significant in the younger patient, arthroplasty is avoided as first line treatment. Highly active patients have increased failure rates of hip prosthetics and less favorable functional outcomes compared to their elderly counterparts[7,26]. Robinson *et al*[19] developed a scoring system used to categorize patients between the ages of 65-85 years within the two physiological age categories. Five variables were quantified: mobility, patient living conditions, bone quality, cognitive status and medical condition. Patients with a high "physiologic status score" underwent internal fixation and patients with a lower score underwent arthroplasty. Forty two percent of patients had scores in the arthroplasty range. Observed revision rates at 21 mo were 5% for internal fixation group and 2% for the arthroplasty group. Although follow-up observation time was short these rates were significantly lower than those previously published. This work imparts the necessity of appropriate patient selection based on physiological age.

Demographics of the young femoral neck fracture patient

The literature suggests that femoral neck fractures in young adults are most often a result of high-energy trauma such as motor vehicle collisions[14,27]. Patients often present with poly-traumatic injuries such as other fractures or head, chest and abdominal trauma[28]. While this is true for patients with dense bone, more recent work demonstrates femoral neck fractures in chronologically young patients occur from low energy trauma with a higher than expected frequency[13,29,30]. A study conducted by Robinson *et al*[8] examined ninety-five patients with both intra and extra-capsular hip fractures under the age of 50 over a five-year period. They identified two demographics within this population; a male predominant group between the ages of 20 and 40 years who sustained high-energy injuries, and a larger group between the ages of 40 and 50 years who sustained fractures after falls. The majority of patients within the latter group had long standing medical conditions and a high prevalence of alcoholism. This demonstrates that there are two main reasons for femoral neck fractures in chronologically young adults, significant trauma in healthy patients or comparatively low energy trauma in patients with predisposing diseases, alcoholism or early age related bone fragility. A low threshold for referral to specialist services for analysis of bone marrow density and/or treatment of osteoporosis should be observed in young patients with femoral neck fractures.

Anatomy

Femoral head vascularity is at risk after femoral neck fractures because the vascular supply is intra-capsular. The most common hypotheses of causes for femoral head ischemia after femoral neck fracture are direct disruption or distortion of the intra-capsular arteries during the initial femoral neck fracture, compression secondary to elevated intra-capsular pressure due to fracture hematoma, pre-operative traction and quality of the surgical reduction and its ability to restore blood flow[31-41].

Blood supply to the femoral head comes from three main sources, the medial femoral circumflex artery (MFCA), the lateral femoral circumflex artery (LFCA) and the obturator artery. The majority of the blood supply to the femoral head, more specifically to the vital superior-lateral weight-bearing portion, comes from the lateral epiphyseal artery, a branch of the MFCA. This artery courses up the posterior-superior aspect of the femoral neck where it is prone to damage during femoral neck fracture fragment displacement. The second largest contributor to femoral head blood supply is the LFCA whose ascending branch gives rise to the inferior metaphyseal artery supplying the anterior-inferior aspect of the femoral head. Finally, the smallest and most variable contributor to blood supply in the adult femoral head is *via* the obturator artery which enters the head via the ligamentum teres[42-46].

INITIAL EVALUATION

The mechanism of injury is important. As previously discussed, a large majority of young patients with femoral neck fractures present after high-energy trauma. If a young patient with femoral neck fracture presents after a low-energy trauma or no clear history of trauma, a more in depth history should be carried out. Low-energy fracture can be due to underlying osteoporosis[29,47], stress fracture or pathologic bone. One should inquire specifically about risk factors for osteoporosis, previous pain about the hip both at rest or with activity and constitutional symptoms including fever, weight loss and night sweats.

In a poly-trauma presentation, Advance Trauma Life Support (ATLS) protocol is promptly initiated; fixation of the femoral neck fracture is dealt with following the appropriate treatment algorithm based on priority of the injuries. Nevertheless, in isolated or in poly-trauma situations, the patient needs to be medically optimized prior to surgery and evaluated by an anesthesiologist.

Physical examination findings in patients of all ages with femoral neck fractures are similar. Classically, the affected limb is painful, especially with movement, shortened, flexed and externally rotated. However, the diagnosis of femoral neck fracture in young patients can be more elusive. With a significant proportion of patients presenting after high-energy injuries and often in poly-traumatized patients, these fractures can easily be overlooked[28]. In the presence of a femoral shaft fracture, an ipsilateral femoral neck fracture will occur up to 9% of the time[48]. In this clinical setting, the diagnosis is missed approximately 30% of the time[49,50]. Most of these fractures (between 25% and 60%) are non-displaced at initial presentation[51]. Because of the morbidity associated with osteonecrosis, a high index of suspicion should be entertained when evaluating the poly-traumatized patient. Prompt recognition of femoral neck injuries cannot be underemphasized as timing to surgical intervention may affect outcomes[6].

IMAGING AND CLASSIFICATION

Regardless of the mechanism of injury, antero-posterior (AP) pelvis, AP and lateral plain radiographs of the affected hip and entire femur should be obtained. In addition, traction-internal rotation radiographs may allow for a better interpretation of fracture pattern[52]. Up to 2%-10% of femoral neck fractures may not be clearly visible on standard radiographs and computed tomography (CT) can aid in the diagnosis[53]. In cases of significant trauma where an abdomino-pelvic CT scan is required, it is recommended to extend imaging to the level of the lesser trochanter in order to fully evaluate the femoral neck. This enables identification of occult injuries, especially in the obtunded patient where a reliable physical examination is difficult. Recent studies have found CT scan to be as effective as MRI in detecting these fractures and reducing the chance of a missed injury[54].

Several characteristics identified on imaging have been shown to influence the biomechanical stability of the fracture. First, the verticality of the fracture line in the coronal plane should be assessed. Pauwels first recognized the significance of high angle fractures in the 1930s. He established a descriptive classification scheme that helps determine fracture stability based on the "Pauwels angle". A femoral neck fracture line < 30 degrees from the horizontal plane is Pauwels Type Ⅰ, fractures with an angle between 30 and 50 degrees is Pauwels Type Ⅱ, and an angle of > 50 degrees categorizes a Pauwels Type Ⅲ fracture. Increased verticality of the fracture decreases the load shared through the fracture fragments resulting in a biomechanically unstable pattern, susceptible to the development of mal-unions, non-unions and osteonecrosis[6,52,55-57].

Another well-known and widely used classification system is that of Garden, originally published in 1961[58] (Figure 1). Low inter and intra-rater reliability has led to it being mostly used for femoral neck fractures in the elderly population where the classification can be simplified to non-displaced (Garden Ⅰ or Ⅱ) *vs* displaced (Garden Ⅲ or Ⅳ) in order to dictate appropriate management[59-61]. Secondly, special consideration should also be given to fractures with posterior neck comminution. Several studies have indicated this to be a poor prognostic factor after internal fixation and correlate the comminution with

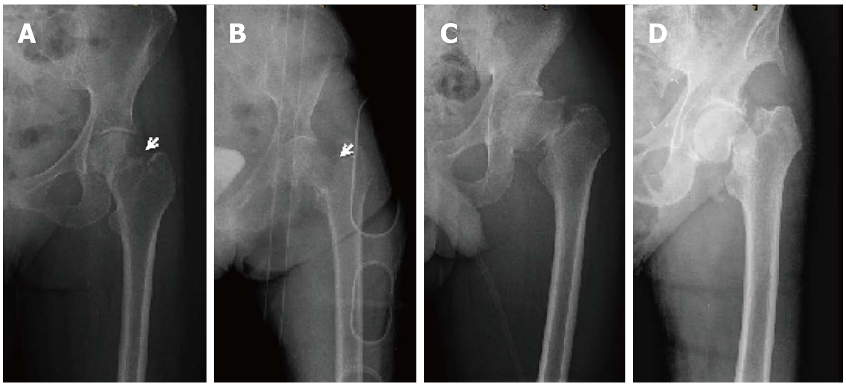

Figure 1 Garden classification. A: Incomplete fracture of the femoral neck with valgus impacon. Note the radiopaque overlap of the femoral neck and head; B: Displaced complete fracture of the femoral neck; C: Less than 50% displacement of a complete fracture of the femoral neck; D: Complete fracture of the femoral neck with complete displacement.

fracture severity and instability[62-64].

PRINCIPLES OF MANAGEMENT

Non-operative treatment of femoral neck fractures in younger patients has a very limited role and is only reserved for the sickest of patients whose surgical risks negate any benefit of fixation. Moreover, operative management is recommended for non-displaced impacted fractures. In a prospective study of three hundred and twelve patients with impacted femoral neck fractures (Garden Ⅰ-Ⅱ), Raaymakers *et al*[65] found that 5% of healthy patient below age 70 had secondary displacement and only 87% of patients in this age group achieved union. Considering the pre-injury activity level of most young patients, surgical management is recommended, as union rates are higher with operative treatment[17,62,66]. Goals of the surgical management of femoral neck fractures in young adult patients are three-fold: (1) Return to pre-injury level of function; (2) Achieve an anatomic reduction of the fracture to preserve the blood supply and effectively prevent ONFH; and (3) Provide a stable fixation while preserving bone stock to achieve union.

PRE-OPERATIVE CONSIDERATIONS

Surgical timing of displaced and non-displaced fracture

The consensus for time to surgery following femoral neck fracture in the young patient is still a matter of debate. Minimally or non-displaced fractures are classically treated on an urgent basis and displaced fractures are managed on an emergent basis with the aim to regain and preserve blood flow to the femoral head. The difficulty with basing this decision on an X-ray finding is that the single time radiographs may not represent ongoing instability or displacement. Studies have shown that early fixation decreases osteonecrosis and increases functional outcome[14,67]. In a retrospective study, Jain *et al*[68] looked at thirty-six young patients with femoral neck fractures. Patients treated within twelve hours of injury had a decreased rate of osteonecrosis as compared to the delayed fixation group. However, there was no difference in functional outcome between the early and delayed fixation group. In contrast, other studies have found no difference in osteonecrosis rates between early and delayed time to fixation[17,69]. Razik *et al*[70] retrospectively analyzed ninety-two patients with femoral neck fractures and found no difference in rates of osteonecrosis when comparing treatment within 6 h post-injury, and delayed treatment 48 h post-injury. They found that the rate of osteonecrosis was related to the type of fixation, which may be indicative of surgeon treatment bias. The conflicting results in the literature are indicative of the wide amount of variance in the studies, which did not uniformly control for cofounding variables such as the quality or the type of reduction and fixation[71]. Given the controversial evidence and considering the impetus to prevent osteonecrosis and improve functional outcome, we recommend treating displaced femoral neck fractures on an urgent basis.

Anesthesia consideration

There is little debate regarding the benefits of intra operative regional anesthesia compared to general anesthesia in young healthy adults; however special circumstances including extreme hypovolemia or coagulopathy associated with poly-trauma, or patient specific factors including respiratory or cardiovascular comorbidities might warrant a particular anesthetic approach. A meta-analysis of randomized controlled trials of hip fractures in all aged group showed a decrease in incidence of deep vein thrombosis and reduction in fatal pulmonary embolism with regional anesthesia[72]. General anesthesia was associated with a reduction in the length of the operation. A lumbar plexus block may be the post-operative modality of choice for analgesia of the hip as it reliably blocks the lateral femoral cutaneous, femoral and obturator nerves[73].

SURGICAL MANAGEMENT

Open vs closed reduction

The decision between attempting an open or closed approach for fracture reduction is the first step when attempting primary fixation. Most authors agree on performing a closed reduction and internal fixation for management of non-displaced femoral neck fractures (Garden Ⅰ-Ⅱ) given low rates of ONFH and non-union[17,74]. However there is considerable debate between the two strategies for reduction of displaced fractures (Garden Ⅲ-Ⅳ). Obtaining an anatomic reduction is paramount in the young patient as a poorly reduced fracture is a major risk factor for non-union and ONFH[62,75,76]. Some authors argue that closed reduction can achieve anatomic reduction with intra-operative fluoroscopy; they suggest that this approach decreases cost, is less invasive and saves operating time[77]. Care should be taken while performing the close reduction, as multiples attempts are associated with an increased risk of ONFH[34,78]. Others support the need for an open reduction to facilitate direct visualization for anatomic reduction, and with the same token, provide relief of a possible intra-capsular tamponade[66]. Traditionally, there are two different surgical approaches for the internal fixation of femoral neck fractures; the Watson-Jones (antero-lateral) and the Modified Smith-Peterson (anterior)[77,79]. There is no gold standard as to proceed with closed or open reduction for displaced femoral neck fractures in young adults as long as anatomic reduction is achieved.

Closed reduction can be attempted by adequate sedation and relaxation of muscle tone. Leadbetter first described in 1939 the maneuver to reduce of femoral neck fractures[80]. The affected leg is flexed to 45° with slight abduction and then extended with internal rotation while longitudinal traction is applied. The reduction is verified with fluoroscopy in the AP and lateral view of the hip to verify the anatomic reduction. The quality of reduction can be ascertained using Garden's alignment index, which evaluates the angle of the compressive trabeculae as compared to the femoral shaft on both AP and lateral hip radiographs. Anatomic reduction is achieved with an angle of 160° on the AP, and 180° on the lateral view. Varus angulation of less than 160° on the AP view and posterior angulation of more than 5° on the lateral view indicate an unsatisfactory reduction[62,77].

Hematoma decompression

Another topic of controversy in treating femoral neck fractures in young patients is the role of capsulotomy for hematoma decompression. The theoretical goal of capsulotomy is to relieve the tamponading effect of the developed intra-capsular hematoma and subsequently increase blood flow to the femoral head. There is good evidence in the literature correlating hemarthrosis following femoral neck fracture and increased intra-articular joint pressure[36].

In an interventional study, Beck *et al*[81] injected saline into intact intra-capsular space of eleven patients before having surgical dislocations and subsequently measured blood flow to the femoral head with laser Doppler flowmetry. The measurable blood flow to the femoral head disappeared with increased pressure (average 58 mmHg) and the blood flow returned once the saline was re-aspirated. In contrast, in a prospective study involving thirty-four patients with femoral neck fractures, Maruenda *et al*[35] found no correlation between increased intra-capsular pressure and femoral head perfusion. Interestingly they also showed no difference in intra-capsular pressure between non-displaced and displaced fractures. Others have suggested higher pressures are found in non-displaced fractures[34]. Disruption of the hip capsule during facture fragment displacement is thought to be responsible for the decreasing intra-capsular pressures.

Numerous clinical studies have shown a reduction in intra-capsular pressure with capsulotomy and a resulting improvement in femoral head blood flow[33,38-40]. However there are no clinical data documenting improved outcomes with capsulotomy. In their retrospective study of ninety two young patients with femoral fractures, Upadhyay *et al*[62] found no difference in the rate of osteonecrosis with patients treated with open (capsulotomy) or closed reduction (no capsulotomy) and internal fixation. In the above-mentioned study by Maruenda *et al*[35] five out of the six patients that developed osteonecrosis had pre-operative intra-capsular pressures below diastolic pressure. They concluded what many presently think: high-energy trauma and the initial fracture displacement probably play a more significant role than intra-capsular tamponade in the development of osteonecrosis.

Some surgeons perform capsulotomy while proceeding with their open procedures while others opt for fluoroscopic guided hip capsulotomy; this latter technique has been previously found to be safe and effective at decreasing intra-articular pressure[82]. Nevertheless, given the current evidence, we do not recommend the routine use of capsulotomy for femoral neck fractures.

Choice of construct

There are several biomechanical constructs available for the fixation of femoral neck fractures and knowing when and how to position the implant is paramount to attain a stable fixation. Compression screws (CS) and fixed-angle dynamic implants, or a combination of both, promote union during weight bearing by allowing the fracture fragments to slide along the implant while being axially loaded[71]. Fixed-angle and length stable implants, such as blade plates, maintain intraoperative reduction by providing a rigid construct[71]. Currently, hemiarthroplasty or total hip arthroplasty are not used as the primary surgery in young patients. Total hip arthroplasty and valgus osteotomy are used as salvage operations in case of failure of fixation. There is still a debate on the optimal method of fixation for promoting union and preventing ONFH in young patients[70]. This is mainly because most opinions on fixation in this population are extrapolated from studies in elderly osteoporotic patients.

Multiples compressive screws: The use of the multiple compressive screws has been advocated for Garden type

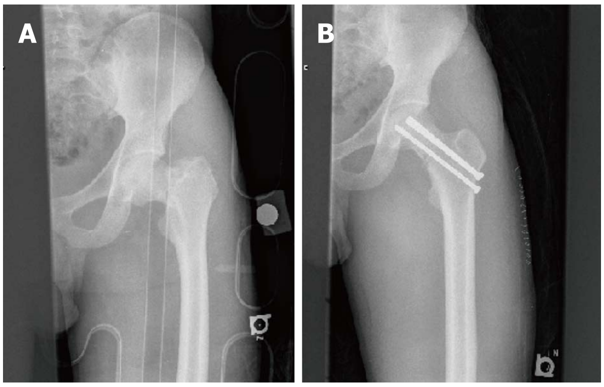

Figure 2 Cannulated screw fixation. A: Anterior posterior view; B: Anterior posterior view with cannulated screw.

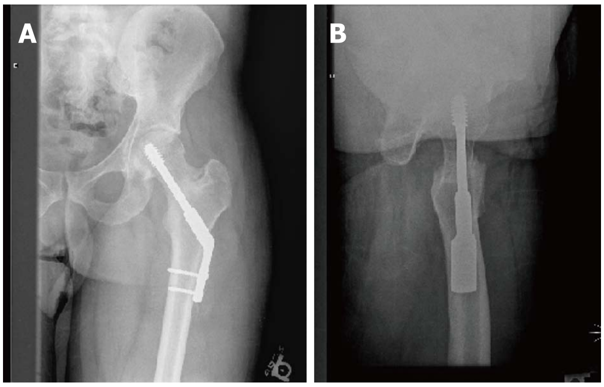

Figure 3 Dynamic hip screw fixation. A: Anterior posterior view with 2 holes 135° dynamic hip screw; B: Lateral view of 2 holes 135° dynamic hip screw.

Ⅰ-Ⅱ in attaining union[83]. In a prospective randomized controlled trial of patients allocated to CS or dynamic hip screw (DHS) with non-displaced or minimally displaced femoral neck fracture, Watson *et al*[84] found no difference in union rate, ONFH or functional outcome between the groups. Numerous studies have looked at biomechanical variations of this construct including the number and placement of the screws or variability in the proprieties of the screws themselves such as the length of the threads[85]. For instance, parallel screws have been shown to be superior construct than convergent screws in maintaining stability reduction[86]. Some authors advocate the use of a fourth screw in cases of fractures with posterior comminution[6]. However, optimal stiffness can be achieved with a three-screw configuration[16]. Three parallel screws placed perpendicular to the fracture line in a inverted triangle with the most inferior screw placed on the medial aspect of the distal femoral neck provides the ideal stability and compression at the fracture site[6] (Figure 2).

Fixed angle implants: The dynamic compressive screw has been advocated as a more stable construct than compressive screws for high shear angle neck fractures (Pauwels type Ⅲ)[86] (Figure 3). Addition of a derotational screw placed in the cranial part of the femoral neck superior to the dynamic hip screw can improve the rotational stability of the construct (Figure 4). In a biomechanical study comparing four commonly used constructs for Pauwels type Ⅲ fractures, Bonnaire *et al*[86] found the DHS with derotational screw to be more load stable than compressive screws, a fixed-angle plate or a simple DHS construct. However, for more stable fracture patterns this screw may be of little benefit. Recently Makki *et al*[87] showed no benefit in union rate or development of ONFH in patients with Garden Ⅰ-Ⅱ femoral neck fractures treated with a DHS alone or with a DHS with a derotational screw[87]. Furthermore, in their retrospective study of ninety-two young patients with femoral neck fractures, Razik *et al*[70] found that DHS alone or DHS supplemented with a derotational screw had significantly less osteonecrosis for Garden Ⅲ-Ⅳ fractures.

In a cadaveric study, Aminian *et al*[88] compared the stability of DHS, CS, dynamic condylar screw and a proximal femoral locking plate (PFLP) for Pauwels type Ⅲ femoral neck fractures. PFLP was the most stable for this fracture pattern, followed by the dynamic condylar screw, the DHS and CS. Currently, no clinical studies directly compare proximal femoral locking plate with DHS and/or DHS with derotational screw. We recommend the treatment of Garden Ⅰ-Ⅱ fracture with CS and Garden Ⅲ-Ⅳ with a DHS and the addition of a derotational screw for Pauwels type Ⅲ fractures.

Replacement arthroplasty: Replacement arthroplasty is not considered a first line treatment in young patients as bone stock should be preserved and the potential complications of replacement arthroplasty avoided. The major early complications are dislocations for total hip arthroplasty and acetabular erosion for hemiarthroplasty[89]. In the elderly patients, short-term follow up has shown better functional outcome for total hip arthroplasty over hemiarthroplasty[90,91]. Studies have shown that internal fixation has higher re-operation rates and that both hemiarthroplasty and internal fixation have comparable functional outcomes[92]. To this date, there are no level- Ⅰ studies comparing arthroplasty to internal fixation in the young adult.

SUBACUTE PRESENTATION AND MANAGEMENT

The term "neglected" femoral neck fracture has been described as a subacute presentation of at least 30 d delay after initial injury[93]. This pathology is more prevalent in developing countries where urgent orthopedic care is not readily available[93]. There is no consensus on the treatment of this pathology and different surgical managements have been described in treating non-union of femoral neck fractures in young adults[94]. Operations such as internal fixation with valgus intertrochanteric osteotomy and internal fixation with vascularized muscle pedicle bone grafting or non-vascularized bone grafting

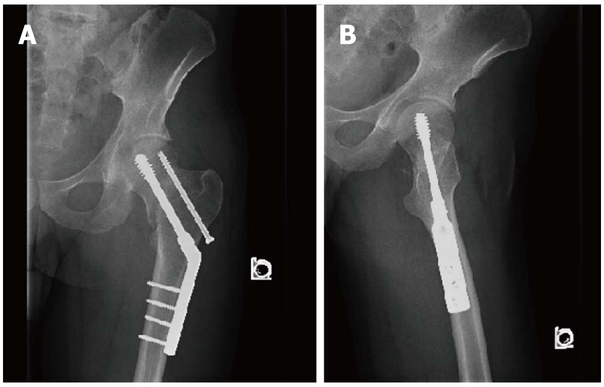

Figure 4 Dynamic hip screw with derotation screw. A: Anterior posterior view pre-operative of 4 holes 145° dynamic hip screw; B: Lateral view pre-operative of 4 holes 145° dynamic hip screw.

are frequently used to achieve union[95]. Valgus osteotomy and free fibular bone graft has had better reported outcomes with osteonecrosis rates ranging from 0-17% and non-union from 0%-15%[93].

POST-OPERATIVE CONSIDERATIONS

The postoperative recommendations are geared to lower the incidence of wound infection, deep vein thrombosis (DVT), and pulmonary embolism as well as to encourage mobilization. An antibiotic regimen with a first generation cephalosporin is indicated for 24 h[96]. The patients should be placed on DVT prophylaxis for thirty days with a pharmacologic agent such as low molecular weight heparin[97]. Physiotherapy should not be delayed and patients should be encouraged to mobilize with no restriction on range of motion of the hip. The patients are usually subject to toe-touch weight bearing with a walker or crutches for 12 wk until the fracture is healed. They are then progressed to full weight bearing as tolerated. The patient should follow-up in 10-14 d post-operatively to assess the wound for infection and to assess the stability of the fixation construct. Follow up visits are indicated at six weeks and three months to assess for clinical and radiologic signs of non-union, osteonecrosis and hardware failure.

COMPLICATIONS

Femoral neck fractures in the young are not known to be associated with a high mortality rate as they are in the elderly population[28]. However, young patients suffer great morbidity from the injury due to high rates of osteonecrosis and tolerable yet significant delays in union. In this section we present a brief overview of these two complications with an emphasis on their management.

Osteonecrosis of the femoral head

Osteonecrosis of the femoral head, previously referred to as avascular necrosis, remains one of the greatest concerns in the young patient with a femoral neck fracture. Despite our increasing understanding of the pathophysiology surrounding post-traumatic osteonecrosis, the incidence has been documented to be as high as 86% in young adults post femoral neck fracture[6]. The development of osteonecrosis has been correlated with multiple factors including age at time of injury (older patients develop less osteonecrosis), the degree of displacement, presence of posterior comminution, verticality of the fracture line, quality of reduction, and implant removal[25,55-58,98]. Osteonecrosis of the femoral head can present anywhere between 6 mo and many years after the initial injury, however, most cases will present within 2 years[99,100]. For this reason, patients should be followed at least for two years post-operatively looking for signs of osteonecrosis, both clinically and radiologically.

Patients will characteristically present complaining of pain localized in the groin, sometimes radiating to the anterior-medial thigh and/or ipsilateral knee. The pain is usually described as deep, throbbing and is exacerbated by weight-bearing activities or at night. There exist many different imaging modalities for diagnosing ONFH however plain radiographs and MRI remain the most useful[101-104]. To date, there is no universally accepted classification. Ficat and Arlet, one of sixteen different systems existing in the literature, is the most commonly quoted[105,106].

Surgical management of osteonecrosis of the femoral head: Treatment of post-traumatic osteonecrosis depends on multiple factors including patient age, stage of disease, level of activity and symptoms. In the majority of cases, once osteonecrosis develops and particularly if it is symptomatic, it will eventually progress to subchondral collapse and secondary osteoarthritis[107]. Once this occurs, the only definitive option remaining is total hip arthroplasty. However, questions remain surrounding the young patient with pre-collapse and early post-collapse ONFH. Multiple joint salvaging techniques have been proposed for patients in whom revision arthroplasty within the patient's lifetime is a foreseeable concern.

Core decompression has been almost exclusively studied in the treatment of idiopathic ONFH. It is the most common method of treatment for pre-collapsed stages of ONFH[108]. It is theorized to work by reducing elevated intra-osseous pressure, improving venous outflow and thereby restoring vascular inflow. Despite early studies showing improvement for all stages of disease, a recent review of four prospective studies with validated outcome scores and a minimum two year follow up showed only minimally improved outcomes[109]. In all four studies, better results were found in pre-collapse and smaller femoral head lesions[110]. Overall, core decompression is a cost-effective choice over observation and its use is recommended as a first line treatment for pre-collapse disease[100].

Various methods of non-vascularized bone grafting have also been used in the treatment of ONFH. Bone grafting has been recommended when there is less than 2 mm of subchondral bone depression, when under 30% of the femoral head is involved and when core decompression fails[111]. It has also been used in conjunction with other methods, such as core decompression. Post-traumatic osteonecrosis tends to create large lesions and decompression alone is thought to be insufficient to completely prevent collapse[100,112-118]. Without good reproducible evidence, evaluation of these techniques in long-term prospective studies is necessary before they can be recommended for routine use.

Vascularized bone grafting using either a local muscle pedicle iliac crest graft or a free vascularized fibular graft have been described for young patients with femoral neck non-union or ONFH. Commonly cited indications from studies of non-traumatic ONFH include no evidence of bony collapse or articular collapse of less than 3-mm in lesions involving less than 50% of the femoral head[119]. The main pitfalls of vascular grafting are donor site morbidity and advanced microvascular surgical techniques[120]. Although less predictable for larger lesions typical of post-traumatic ONFH, when following indications, vascularized bone grafting can be effective if used early and should be considered for improving hip function and delaying disease progression[119-125].

For patients with more advanced ONFH, usually with post-collapse disease, proximal femoral osteotomies have been proposed with the premise of moving the lesion away from the weight bearing zone. There is currently no general consensus on indications for proximal femoral osteotomies with some authors obtaining good results while others observed high failure rates[126-134]. Other concerns surrounding these procedures are poorer outcomes with more challenging subsequent total hip arthroplasty, with increased rates of blood loss, operative time, femoral shaft fracture and component loosening[135,136]. We believe that in the right hands osteotomies can lead to reproducible results however without generalizable results one should proceed cautiously when considering proximal femoral osteotomies for treatment of ONFH.

Non-union

The incidence of non-union after femoral neck fixation has been reported to be between 10% to 33%[137]. Initial fracture displacement, quality of reduction and increasing patient age correlate with a higher risk of non-union[16,138-140]. A recent study evaluating the survivorship of the hip in patients younger than 50 years after femoral neck fractures, reported that 8% of patients were diagnosed with non-union and 23% with evidence of osteonecrosis[17]. Moreover in this series, patients with anatomic reductions had only a 4% rate of aseptic nonunion.

In comparison to osteonecrosis of the femoral head, patients with non-unions present with symptoms earlier, often several months after internal fixation. Most commonly patients describe a history of persistent pain, typically localized to the groin and over the anterolateral aspect of the injured leg, aggravated by weight-bearing[141]. Three to six months should have elapsed before a nonunion may be diagnosed but evidence of failure of fixation can allow the diagnosis to be made sooner[141]. Plain radiographs may demonstrate a lucent fracture zone, osteopenia or bone loss, or signs of instability of the implant such as changes in screw position or backing out of the screws. When plain radiography is equivocal, computed tomography can help determine whether bony union has occurred[140].

Once non-union has been diagnosed, several factors will decide whether salvage of the femoral head is a viable revision option, including the patient’s physiological age, femoral head viability, the amount of femoral neck resorption, and the duration of the nonunion[140]. Four options are available for treatment: fixation with new hardware, angulation osteotomy, prosthetic replacement and arthrodesis. In the physiologically young patient, salvage of the femoral head and preservation of the hip joint is preferable. This can be achieved by either improving the mechanical environment to favor healing with valgus-producing osteotomies or by improving the biologic milieu at the non-union site with bone graft[140].

In young patients femoral neck non-union is thought to be more often a result of mechanical factors over biological ones. Varus displacement of the femoral head leads impaired blood supply to the fracture and femoral head resulting in non-union and avascular necrosis[142]. Two features commonly seen in young patients have been identified as predicting higher incidences of fixation failure and non-union; posterior wall comminution and high shear angled fractures (Pauwels Type Ⅲ)[62,143-147]. With a vertical fracture line, the calcar does not offer enough support to prevent the femoral head from shearing and displacing into varus[74]. It is unclear whether posterior comminution indicates a more extensive soft tissue and vascular injury or whether this pattern compromises stability after fixation[141].

Valgus osteotomy reorients the fracture so that its plane is nearly perpendicular to the force across the hip joint. This converts the shearing forces parallel to the nonunion to compressive forces to stabilize the non-union and promote healing. This procedure also restores femoral length improving the abductor mechanics by restoring the abductor moment arm[140]. As much as 2 cm of length can be gained in some instances[148]. Rotational and angular deformities can also be corrected at the same time. The disadvantage of this osteotomy as a salvage procedure is that the valgus orientation of the proximal femur increases contact pressures on the femoral head potentially leading to degenerative disease or progression of osteonecrosis. Although there are no concrete contraindications for this procedure, Varghese *et al*[149] have demonstrated that a decreased preoperative femoral neck bone stock was a risk factor for non-union after valgus osteotomy.

Several published series reporting on the outcomes of valgus-producing proximal femoral osteotomies for the treatment of femoral non-union have demonstrated positive results. Marti *et al*[150] reported a union rate of 86% after osteotomy in 50 patients with femoral neck non-unions with a average time to union of 4 mo. Mean postoperative Harris Hip Score was 91 points in reviewed patients. Although 22 patients had radiographic evidence of osteonecrosis at the time of osteotomy only three of these patients showed progressive collapse of the femoral head that eventually required hip replacement surgery. Four other patients required replacement surgery for persistent non-union or hardware failure. Ballmer *et al*[151] reported on a series of 17 patients treated with valgus osteotomies with a total union rate of 88%. Three patients required revision fixation but eventually healed. Three patients had progressive osteonecrosis and required hip arthroplasty. Excellent functional results were reported in 11 of the 17 patients. Some authors have recently advocated sliding hip screws for the same purpose based on favorable outcomes and technical ease associated with this implant[152,153]. We recommend the use of valgus intertrochanteric osteotomy for the treatment of aseptic non-union after femoral neck fracture fixation.

Autogenous bone grafting is used in an attempt to improve the biologic milieu at the nonunion site. This can be done using non-vascularized, free vascularized or muscle pedicle-type grafts[154-157]. Rarely are bone grafting procedures undertaken for isolated femoral non-unions, but are indicated more so when concomitant ONFH is present. There are no clear indications for the use of grafting techniques for femoral neck non-union, however these procedures should be considered when there is considerable loss of bone stock or non-unions are present in well-aligned fractures with low shear angles.

RECOMMENDATIONS

The role of conservative management in young patients with femoral neck fracture is limited to patients who are medically unfit; we recommend treating displaced femoral neck fracture on an urgent basis; we do not recommend the routine use of capsulotomy for femoral neck fractures given the lack of evidence to support the development of osteonecrosis from intracapsular hematoma; we recommend the treatment of Garden Ⅰ-Ⅱ fracture with compressive screws and Garden Ⅲ-Ⅳ with a dynamic hip screw and the addition of a derotational screw for Pauwels type Ⅲ; we recommend core decompression for pre-collapse osteonecrosis of the femoral head; we recommend the use of valgus intertrochanteric osteotomy with or without bone grafting for the treatment of aseptic non-union after femoral neck fracture fixation.

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