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Femoral neck fractures: can the type of synthesis reduce the causes of failure?

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Summary

Femoral neck fractures (FNFs) are one of the most common traumatic fractures. Although a considerable number of implants are available, there is no agreement on the most suitable technique, and complication rates are still unacceptably high. In this article, the main internal fixation implants for FNFs were considered to determine whether, in the literature, a relationship between the type of synthesis used and the risk of failure is present. The variable results reported in literature make it unreasonable to absolutely prefer one implant or construct, although some characteristics of the fracture and patient can guide the choice.

Key words: femoral neck fractures, hip fractures, implant failure, cannulated screws, sliding hip screws

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Introduction

Femoral neck fractures (FNFs) are one of the most common traumatic fractures. They can occur in young healthy individuals due to high loads, while in older patients they are usually the consequence of a low energy fall. Due to the functional importance of the hip, FNFs have considerable mortality and morbidity repercussions in older patients and significant effects on the quality of life in younger ones. FNFs also have important socioeconomic consequences too.

Treatment is surgical and consists of internal fixation or hip replacement. Different techniques can be used according to the type of fracture and patient characteristics: compression plate, locking plate, multiple screw fixation, or arthroplasty/hemiarthroplasty. Internal fixation is used in older adults with non-displaced or minimally displaced FNF, and in younger adults with nearly all fractures to preserve native femoral head. Displaced FNFs in older patients and all FNFs in arthritic patients are treated with joint replacement.

For FNF fixation, although a considerable number of implants is available, complication rates are still unacceptably high, and there is no agreement on the most suitable technique. Main complications are secondary displacement, femoral head avascular necrosis, peri-implant fracture, infection, and malunion. Secondary displacement may evolve into non-union, malunion or hardware failure/rupture. Impaction and cervical varus deformity, which contribute to shortening, are the most

common types of malunion and may have important functional repercussions, such as reduction of abductor muscles arm and, consequently, of their strength.
In this article, the main internal fixation implants for FNFs were considered to determine whether, in the literature, a relationship between the type of synthesis used and the risk of failure is present.

Hints of biomechanics and classification of femoral neck fractures

The loads acting on the hip joint are among the largest loads present in the human body and easily exceed 500% of body weight. The two dominant forces acting on the femoral neck include: one, predominant, perpendicular to the long axis of the femur providing downwards compression on the femoral neck and generating shearing stress on any implant inserted through it; the second one lies parallel to the long axis of the neck. Forces in the anterior-posterior direction are considerably smaller [1]. Typically, internal forces created by the muscles exceed external forces acting on the body. As an example, for the hip joint to be stable during single-leg stance, the gluteal muscles acting at the proximal femur are needed to counterbalance the body weight. Due to the small lever arms between the muscular attachments at the greater trochanter and the center of the hip joint, as compared with the larger lever arm between the center of the body mass and the hip joint, muscle forces of more than two times body weight are required to properly maintain balance [2].
The goal of fracture fixation at the femoral neck is to provide sufficient mechanical stability until the fracture has healed. In general, the mechanical stability of the osteosynthesis is composed of the stability of the implant and the stability of the bone. However, the overall strength of an osteosynthesis construct at the femoral neck is less than the strength of the intact bone. In particular, for comminuted fractures the stability of the osteosynthesis construct heavily relies on the mechanical stability of the implant [3].
At the same time, any fracture within the capsule has the potential to damage the blood supply to the femoral head with this risk increasing with greater levels of displacement. Therefore, prompt reduction and stable fixation is critical and should be achieved as soon as possible to re-establish blood supply to the femoral head [1].
The choice of the most appropriate treatment must consider the fracture pattern. The two main classifications of FNFs are those of Pauwels and Garden. In 1935, Pauwels presented the first biomechanical classification that stratified FNFs in three groups based on inclination of the fracture line relative to the horizontal one. As the angle of inclination increases, the forces pass from being compressive to vertical shearing resulting in higher risks of displacement, nonunion, and failure of fixation (Tab. I) [4].
The Garden Classification, formulated in 1961 by Robert Symon Garden, incorporates displacement, fracture completeness, and relationship of bony trabeculae in the femoral head and neck. It is based on antero-posterior radiographs of the hip and includes four types of fractures. With time, clinicians have simplified the Garden Classification by grouping FNFs as either non-displaced or displaced (Tab. II) [5].
Implants for internal fixation of intracapsular FNFs can be divided into three main groups: multiple cancellous screws, fixed angle devices that allow sliding/compression, and fixed angle devices that do not allow for sliding/compression. Fixed angle devices that allow for compression include sliding hip screws (SHS) and certain intramedullary nails. Fixed angle devices that do not allow for compression are the dynamic condylar screw, proximal femoral locking plates, and blade plates.
Implant systems for FNFs have been compared mainly in biomechanical experiments on human cadaver specimens, various plastic analogue bones, and numerical models: actually, they do not adequately represent real bone behavior in terms of fracture patterns, construct stiffness, and strength [2].

Table I. Pauwels classification for femoral neck fractures.

Type	Description	Displacement
I	Up to 30° between the fracture line and the horizontal line	Stable: compressive forces are dominant
II	Within 30° to 50° between the fracture line and the horizontal line	Less stable: shear forces occur
III	Greater than 50° between the fracture line and the horizontal line	Unstable: shear forces are dominant

Table II. Garden's classification for femoral neck fractures.

Type	Description	Displacement
I	Valgus impacted incomplete fracture, with disruption of the lateral cortex	Non-displaced
II	Complete fracture	
III	Complete fracture with partial varus displacement	Displaced
IV	Complete fracture with complete displacement	

FNFs in the elderly

Moderate evidence supports operative fixation for elderly patients (> 65 years of age) with non-displaced FNF (Garden I and II) [6], while conservative treatment leads to more complications.

In their systematic review, Dan-Feng Xu et al. included 29 studies involving 5071 patients over 65 years of age and found out that conservative treatment of non-displaced FNF in was associated with a higher non-union rate and a tendency toward more avascular necrosis than surgical fixation [7].

Parker et al. compared the outcomes of an age, sex and co-morbidity matched cohort of 346 patients who had a non-displaced intracapsular hip fracture treated using cannulated screws with a group of 346 patients who had a displaced intracapsular fracture treated with hemiarthroplasty. They found out that patients treated by internal fixation had a shorter operation time (43 *versus* 67 min), reduced orthopedic ward stay (11 *versus* 15 days), lower incidence of peri-operative complications (24 *versus* 81), and lower 1-year mortality (19 *versus* 26%). Additional benefits for the fixation group were less pain at 1 year, less reduction in mobility and lower dependence on walking aids, even if hemiarthroplasty had lower re-admission (43 *versus* 14 cases) and re-operation rates (59 *versus* 22 cases). All these differences were statistically significant. These results support the use of internal fixation for non-displaced intracapsular fractures in the elderly and suggest that the final outcome for a non-displaced intracapsular hip fracture is significantly better than for a displaced one, despite a higher re-operation rate after internal fixation [8].

However, outcomes following FNF fixation are not uniformly positive, as many studies have documented rates of reoperation ranging from 8 to 23%. The subsequent procedure is often arthroplasty, but patients undergoing total hip arthroplasty after failed internal fixation compared with those undergoing primary total hip arthroplasty may be at a higher risk of complications [9].

The high proportion of reoperations has generated controversy about the optimal approach for fixing FNFs in elderly patients.

Multiple cancellous screws are the most commonly used implant. Advantages include the relative ease of insertion, maintenance of bone stock, and, possibly, improved rotational strength and preservation of femoral head vascularity in comparison to plates [10].

FAITH (Fixation using Alternative Implants for the Treatment of Hip fractures) is a recent international, multicenter, randomized controlled trial that enrolled 1108 patients aged 50 years or older with a low-energy hip fracture requiring fracture fixation. The scope was to investigate, during 24 months follow-up, the effect of cancellous screws *versus* a SHS on the risk of reoperation and other key outcomes: mortality, fracture healing and fracture complications, including avascular necrosis, non-union, implant failure, and infections. The study showed a similar risk of hip reoperation, even if subgroup analyses, with low-to-moderate credibility, suggested the greater biomechanical stability of SHS might offer advantages in displaced fractures in Pauwels III fractures and in smokers, who have greater risk of osteoporosis and diminished bone density. At the same time, avascular necrosis occurred more frequently in patients treated with SHS [11]. This latter result differs importantly from a previous systematic review of small trials [9]. However, there can be a plausible biological rationale: a randomized trial of 104 patients with FNFs using bone scintigraphy showed reduced vascularity in patients receiving a SHS compared with those receiving cancellous screws [12]. Furthermore, suboptimum positioning of large implants, such as SHS, risks damaging the blood supply of the femoral head whose retinacular vessels may already be partially interrupted by fracture.

In terms of the importance of avascular necrosis, observational studies have shown that many patients remain asymptomatic, with only one in five requiring further surgery [13].

In a secondary analysis of data collected during the FAITH study, Okike et al. categorized 555 patients with a Garden I or II FNFs according to the amount of posterior tilt (as < 20° or ≥ 20°) in the preoperative lateral radiograph. They found that patients with posterior tilt ≥ 20° had a significantly higher risk of subsequent arthroplasty (22.4%) compared with those with posterior tilt < 20° (11.9%). The other factor associated with subsequent arthroplasty was age ≥ 80 years ($p = 0.03$). They concluded that since the degree of posterior tilt is a predictor of failure following internal fixation of Garden I and II FNFs, primary arthroplasty may be considered if posterior tilt is over 20°, especially among older patients. These findings are in agreement with previous studies [14].

In their retrospective study of 308 patients treated with screws, Song et al. concluded that fractures with an initial valgus > 15° or a posterior tilt > 15° are reasonable candidates for primary arthroplasty due to high risk of avascular necrosis and fixation failure [15] (Case 1).

If pain caused by fracture makes it difficult to perform x-ray in lateral projection, preoperative CT allows more accurate assessment of the posterior tilt and, eventually, of the posterior comminution, and should be performed to plan surgery [16] (Fig. 1).

With respect to displaced FNF, strong evidence supports hip replacement in elderly patients. Arthroplasty is associated with a significantly higher functional score and lower risk of reoperation, even if at the cost of greater infection rates, blood loss, and operative time [6,17,18].

In their systematic review, Lewis et al. included 1364 patients with displaced FNF, of which 704 treated with hemiarthroplasty (HA) and 660 with total hip arthroplasty (THA) and observed that THA was superior to HA in terms of risk of reoperation, Harris Hip Score, and Quality of Life (Short Form 36). Overall, the risk of dislocation was greater with THA than HA in the first 4 years, after which there was no difference. There was no difference between THA and HA in terms of mortality and infection. They concluded that THA and HA are reasonable interventions in older patients: THA appears to be superior and should be recommended for displaced FNF in patients with a life expectancy > 4 years and in patients younger than 80 years [19]. Liu et al. concluded the same indications for active patients over 75 years of age [20].

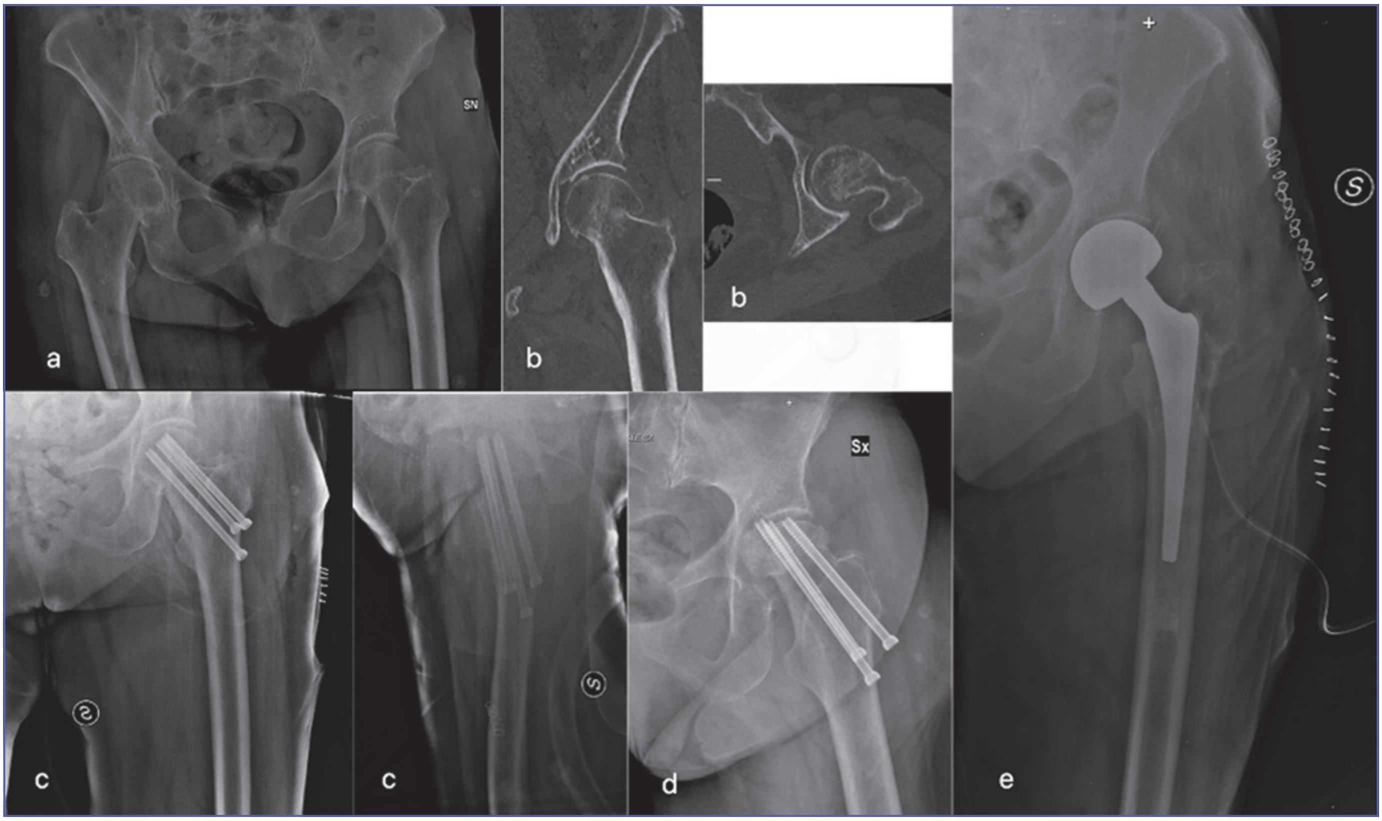

Figure 1. Case 1: F, 89 years old, simple fall. A) subcapital fracture of left femur; B) pre-operative CT-scan shows valgus impacted fracture with posterior tilt; C) close reduction and osteosynthesis with three cannulated screws in inverted triangular configuration at 12 h from trauma; D) At 6 months follow-up, progressive radiographic signs of symptomatic avascular necrosis; E) revision with cemented hemiarthroplasty.

FNFs in younger patients

Femoral neck fractures in patients 60 years of age or younger are challenging injuries to treat because of the high-energy trauma mechanism and the vertical and displaced fracture patterns typically found. Due to the large vertical shear force, the stable fixation of Pauwels III FNFs is very difficult, and failure is unfortunately common [21]. Slobogean et al. included in their meta-analysis 1558 fractures in patients < 60 years of age from 41 studies and observed an 18.0% pooled reoperation incidence for isolated FNFs. The total pooled incidence of avascular necrosis (AVN) was 14.3%, and the total incidence of nonunion was 9.3%, making them the most common complications that contributed to reoperation. When stratified for fracture displacement, displaced fractures were more likely to undergo reoperation and to result in AVN or non-union [22] (Case 2) (Fig. 2).

In younger patients, the best fixation strategy for these fractures remains controversial. Arthroplasty is usually quickly ruled out since the implant normally will not endure lifelong and is associated with important complications, including infections and aseptic loosening. Historically, evidence from small trials suggested multiple cannulated screws were the optimal implant to preserve native hip joint. Nowadays, they remain the preferred treatment for most surgeons for non-displaced fractures, although there is increased preference for the SHS fixation for displaced and vertical patterns [23,24]. However, regardless of the surgical technique used, achieving anatomic reduction and stable internal fixation is be imperative [24,25].

A recent pilot trial of the multicenter study named FAITH (The Fixation using Alternative Implants for the Treatment of Hip Fractures) based on 86 patients between the ages of 18-60 years showed few differences in function and health-related quality of life among internal fixation using either cancellous screws or SHS. Despite modern implants and vitamin D supplementation, neither function nor quality of life returned to baseline in this population, concluding that additional efforts are still needed to improve the outcomes of these challenging injuries [26].

If a gap exists at the fracture site because of comminution or residual malreduction, dynamic fixation (SHS and multiple cancellous screws) produces a controlled collapse that helps to promote bony union. Unfortunately, this telescoping of the dis-

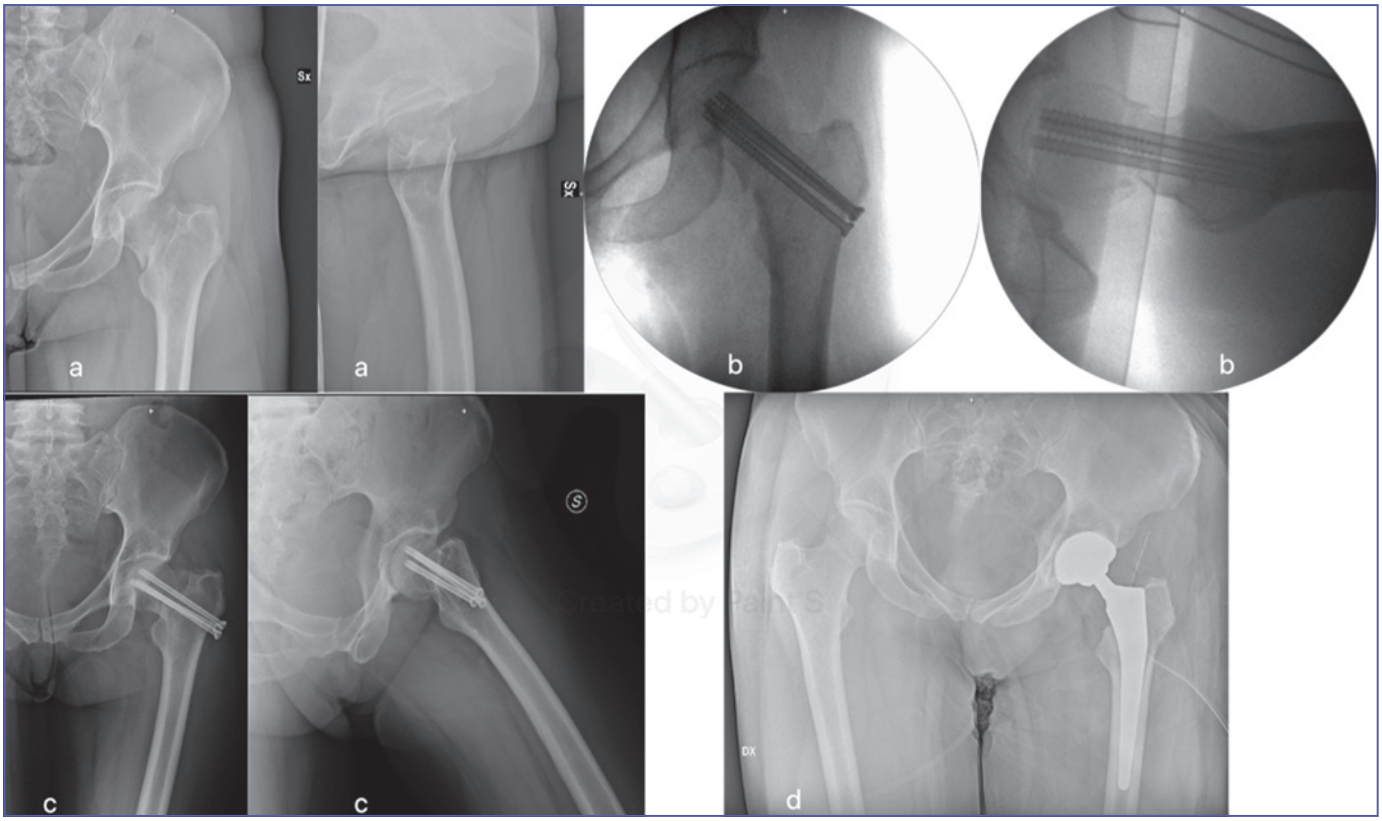

Figure 2. Case 2: F, 43 years old, high energy trauma. A) Pauwels III FNF; B) closed reduction and osteosynthesis with three cannulated screws within 6 hours from trauma; C) at 28 days follow-up, implant failure with secondary displacement; D) revision with arthroplasty.

tal fragment along the longitudinal axis of the unthreaded part of the screw results in progressive post-operative neck shortening. This shortening correlated with significant deficits in gait, physical function, and overall outcome [27].

The use of proximal femur locking plates with multiple, non-parallel converging/diverging screws can serve as a fixed-angle device, that, in theory, should resist femoral neck shortening and improve clinical outcomes. However, it was observed an unacceptable rate of failures with varus collapse and breakage of screws. These mechanical failures support the notion that absolutely rigid fixation supplied by a locking plate construct can be deleterious for FNF healing: exceedingly stiff constructs can inhibit micromotion. In comminuted or not perfectly reduced patterns, a lack of stable bony contact between fragments results in all forces being transmitted through the locking screws of the implant rather than the bone. Alternatively, in the presence of extremely poor bone quality, the implant can resist mechanical failure and the locking screws can telescope through the femoral head, resulting in intra-articular penetration [28].

As for elderly patients, even in younger ones a displaced FNF with a disrupted posterior cortex is associated with an increased risk for avascular necrosis of the femoral head, shortening, secondary displacement, and conversion to hip prosthesis, compared with fractures without posterior cortex disruption [29].

To manage challenging vertical FNFs in patients < 60 years of age, Jacob et al. [16] suggested to evaluate anterior and posterior cortex comminution with pre-operative CT and to fix it with a 135° SHS reinforced with one or two 6.5 mm 16 mm diameter partially threaded and non-cannulated cancellous screws. They identified four fracture comminution scenarios on the axial plane: no comminution, anterior cortex comminution, posterior cortex comminution, and both cortices comminution. Lag screws, which work best when the angle is perpendicular to the fracture line, have to be implanted on the non-comminuted cortex. Screws need to be neutralized and the SHS implant acts both as a neutralization as well as an augmentation to the construct. In case of both cortices comminution cancellous screws can be used as position screws – so tightened only after application of SHS – to help maintain the length of the anterior and posterior columns thereby preventing excessive post-operative collapse. In their study, union was achieved in all four scenarios.

Recently, it has been hypothesized that a plate applied to the inferomedial femoral neck will provide a buttressing effect to resist the high shear forces across vertical FNFs. In a biomechanical study on human cadaveric femurs, Nwankwo et al. [30] concluded that augmented fixation of a SHS construct with a medial buttress plate in Pauwels III FNFs significantly decreased angular displacement and shear displacement compared with augmentation with a single derotational screw. Another recent meta-analysis [31] observed that combine a medial buttress plate in Pauwels III FNFs treated with cannulated screws can reduce healing time, incidence of complications, and improve Harris score. However, it takes a longer operation time and leads to greater intraoperative blood loss. Notwithstanding, literature is still lacking on this surgery and the results are not conclusive.

As already highlighted, in younger patients, FNFs are the consequence of a high energy trauma, and so ipsilateral fractures of the femoral shaft are possible, although rare. The associated FNF is frequently vertical (Pauwels III) and non-displaced. In a polytrauma, failure to recognize a non-displaced or minimally displaced associated FNF prior to shaft fixation can lead to displacement, a technically challenging secondary procedure, and increased risk of short and long-term sequelae. While most authors recommend prompt, but not emergency, surgery for both shaft and neck, no consensus exists as to the most appropriate method of fixation and which to fix first. Single implant fixation with a cephalo-medullary nail has been described in literature, but recent series propose fixing each injury separately in order to achieve better reduction of the femoral neck [32] (Case 3) (Fig. 3).

Priority is given to anatomic reduction and stabilization of the neck fracture by either closed or open methods, while shaft fixation follows as the patient condition allows. At the same time, however, fixing the shaft first can facilitate closed reduction in displaced FNFs. The rare nature of this injury makes it very challenging to study, and most published series are retrospective with very small sample sizes: there are no studies that definitively support one implant choice or method of stabilization over another in combined femoral fractures [33].

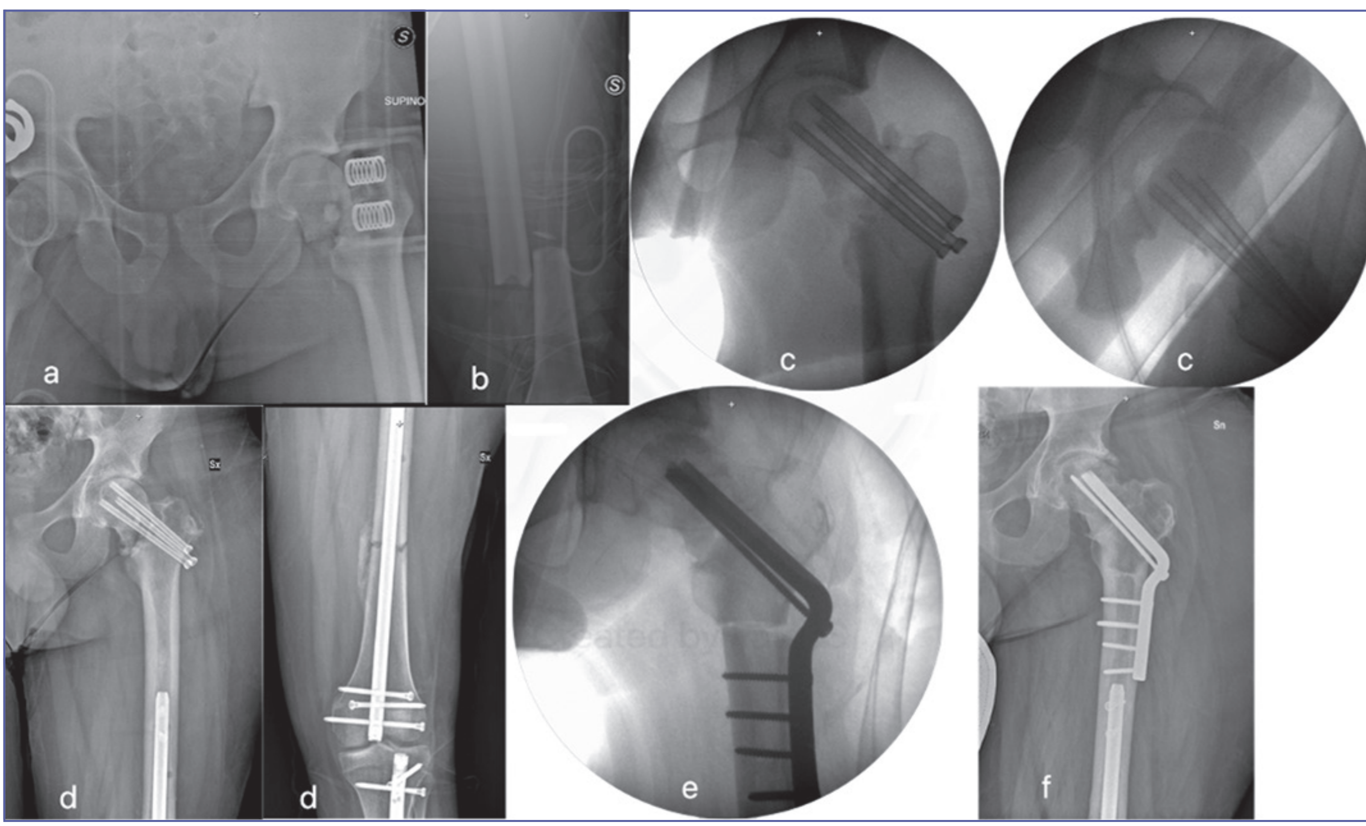

Figure 3. Case 3: M, 19 years old, polytrauma victim of car accident. A) Pauwels III comminuted basicervical fracture of the left femur; B) ipsilateral AO 22A.3 fracture of the femur diaphysis; C) diaphysis fracture was stabilized with temporary external fixator; FNF was treated with closed reduction and synthesis with cannulated screws within 6 hours from trauma. Ex-Fix was converted to retrograde femur nail after 9 days; D) 4 months follow-up: signs of femoral neck non-union, progressive consolidation of diaphysis fracture; E) at 12 months from trauma, surgical revision with femur osteotomy and osteosynthesis with blade-plate; F) bone consolidation at one year follow-up.

Conclusions

For any given fracture, the ideal orthopedic fixation construct must be able to withstand displacement forces, optimize strain during fracture healing, and ultimately accept weight-bearing loads: this is even more important in an unstable setting. For FNFs fixation, although a considerable number of implants is available, complication rates are still unacceptably high, and there is no agreement on the most suitable technique.

When choosing a device, the surgeon must consider the mechanical performance of the implant, the ability of the implant to allow for dynamic interfragmentary compression, and the ease of use and familiarity of the device. Additionally, the surgeon must consider patient and injury factors such as fracture pattern (e.g. Pauwels angle), amount and location of comminution, presence of an ipsilateral femoral shaft fracture, and bone quality. Furthermore, patient age should not be considered an absolute factor, but should be contextualized by taking into consideration comorbidities and the functional request of the individual.

Regardless of the implant used, the quality of reduction is the most important factor for fracture healing [34,35].

With the variable results reported in literature, it is unreasonable to absolutely prefer one implant or construct. The high incidence of FNFs, the lack of surgeon consensus, and the high rates of complications suggest the need for definitive clinical trials to optimize outcomes [23].

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The research was conducted ethically, with all study procedures being performed in accordance with the requirements of the World Medical Association's Declaration of Helsinki.
Informed consent was obtained from each patient for study participation and data publication.

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