# Advances in the surgical treatment of fragility fractures of the upper femur

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**Summary**

**Fragility fractures typically occur in elderly patients. They are related to osteoporosis, because of the weakening of the bone structure, and are the result of low-energy injuries and often involve the metaphyseal segments of bone. The fracture of the upper extremity of the femur are one of the most typical of the elderly patients. They may be intracapsular (femoral neck fractures) or extracapsular (intertrochanteric fractures). Each kind of fracture can be treated in several ways: the intracapsular fracture can be treated with screws, unipolar or bipolar hemiarthroplasty or even with total arthroplasty. The extracapsular fractures instead can be treated with sliding hip screw, intramedullary nail, femoral neck screws, helical blade or primary arthroplasty. What must be remembered is that osteoporotic bone has distinct morphologic characteristics that influence its biomechanical properties and therefore the choices and techniques for internal fixation. Therefore only a complete understanding of the biology of the osteoporotic bone will lead to a good quality of the treatment of the fragility fractures.**

*KEY WORDS: fragility fractures, upper extremity of the femur fractures, osteoporosis.*

## Introduction

Fragility fractures typically occur in elderly patients. They are related to osteoporosis, because of the weakening of the bone structure, are the result of low-energy injuries and often involve the metaphyseal segments of bone.
It is estimated that 200 million people worldwide are at risk for a fragility fracture, and 40% of women and 14% of men older than 50 years will experience a fragility fracture. Many people who have had a fragility fracture will have another fragility fracture later in life. The number of patients who fracture their hip, a common form of fragility fracture, is expected to increase by 190% from 2000 to 2051 (1).
The fractures of the upper extremity of the femur may be intracapsular (femoral neck fractures) or extracapsular (intertrochanteric fractures).

## Femoral neck fractures

Pawels grouped these fractures according to the angle of the rim (≤ 30°, 30°-70°, ≥ 70°), hypotesizing a debated relationship between the obliquity of the fracture, the stability of the reduction and the rate of failure.
Garden classified the femoral neck fractures in four types, according to the displacement, relating it to a possible vascular damage and, ultimately, to the healing of the fracture and to the survival of the femoral head. The appropriate surgical treatment is usually fixation in situ with percutaneous, partially threaded, cannulated screws, for Garden type 1 and 2 fractures, approximately 20% of the cases, and hip joint replacement for Garden type 3 and 4 fractures (2).
Operative treatment is the treatment of choice for the majority of the displaced femoral neck fractures. However, the debate as to whether the femoral head should be retained or replaced continues (2). In their meta-analysis, published in 1996, Rogmark and Johnell (3) showed that, regardless of the type of internal fixation, the failure rate was 21-57% and reoperation was required in 14-53% of all their cases. In contrast, the reoperation rate after arthroplasty was 7%, confirming analogous results of any previous meta-analysis. Moreover, in a recent prospective randomised study, Firhagen et al. (4) reported that, among people over 60 years old, arthroplasty was associated with better functional outcome, higher health-related quality of life and more independence compared with internal fixation.
These fractures are rare among young individuals and there is consensus that any such cases should be treated with closed reduction and internal fixation in an attempt to preserve the femoral head (3). It has been shown that young adults achieve higher rates of fracture union and it is believed to be due to the healing potential and good bone quality of the upper femur in this age group (5).
For relatively healthy, active and mentally alert elderly people, primary total hip replacement has been proposed as a treatment option for displaced intracapsular fractures (6, 7), providing a better outcome than internal fixation. Many randomised study showed fewer complications and reoperations and better function and health related quality of life (2, 7, 8).
For lucid, active, elderly people also, total hip replacement seems to be a reliable option when compared with hemiarthroplasty, according to many recent studies, without increasing the complication rat  (8). However, total hip replacement after acute femoral neck fracture demonstrated to have increased risk for early dislocation and periprosthetic fracture compared with prosthetic replacement performed for osteoarthritis. An attempt to reduce the complications rate may be made by a lateral surgical approach and either a wide or a dual mobility femoral head (2).
Whether cement or non cement the prosthesis is still matter of debate. In a recent review of 7774 patients made by Parvizi (9) at Mayo Clinic, the mortality was more than doubled when cement fixation was used, particularly in patients with known cardiovascular disease. In the most recent meta-analysis Parker (10) showed that cemented prosthesis, compared with uncemented versions, were associated with less pain at 1 year or later and a tendency to better mobility; however, no significant differences in surgical complications were found.

Unipolar or bipolar hemiarthroplasty has been the workhorse for displaced femoral neck fractures for decades. The bipolar prosthesis has a theoretical advantage in that it is designed to move on its inner bearing, in addition to articulate at the prosthesis-acetabulum interface, in order to reduce the acetabular wear, the pain and the dislocation rate and to increase the range of motion (8). However, bipolar prostheses are more expensive and it is still unclear whether or not the inner bearing loses mobility with time and become stiff. A recent meta-analysis reported no statistically significant differences between the two types of prosthesis for the outcomes of dislocation, acetabular erosion, deep wound sepsis, reoperation, deep vein thrombosis or mortality (10-12). Additional studies are needed to evaluate the better prosthesis for active aged individuals with a life expectancy of more than 10 years (2).

**Extracapsular hip fractures**

This category comprises almost 50% of hip fractures and includes the intertrochanteric and the subtrochanteric (up to 5 cm below the lesser throchanter) ones. The first type comprehends undisplaced, displaced and displaced unstable (with reverse obliquity or displacement of the lesser trochanter) kind of fracture.
This kind of fracture presents less risk of femoral head necrosis but more risk of blood loss and are complicated by higher low term mortality.
When surgical treatment is needed (it is almost the rule for femoral fractures) successful internal fixation may be challenging, because they occur in osteopenic bone that has thin trabeculae and decreased capacity to support internal fixation devices. The main matter of debate is how to obtain the stability and consequently a rapid mobilization of the patients, particularly in cases of unstable intertrochanteric fracture, as for example when fragmented corticale bone.

*Sliding Hip screw vs Intramedullary nail*

Sliding hip screw and plate systems have provided satisfactory results in the treatment of intertrochanteric fractures over past decades (13). Nonetheless, they have been associated with a failure plate of up to 23%. Intramedullary sliding hip screw devices were introduced in the late 1980s (Gamma nail, Howmedica) (14,15). The main advantage was good stability with minimal surgical exposure. Historically, the first generation of intramedullary hip screws were developed in order to improve clinical results and minimize complications (14-16). At the same time the variety of trials have been published, comparing new and older designs of intramedullary implants with sliding hip screws.
Despite the theoretical advantage of intramedullary implants most studies failed to confirm any superiority over sliding hip screw and plate fixation. Initial reports concluded that for stable intertrochanteric fractures the treatment options had similar results, but for unstable and fragmented fractures the use of an intramedullary implant had theoretical advantages. However, results from recent prospective randomised and meta-analyses did not reveal the superiority of either implant in terms of intraoperative or postoperative complications, fracture healing problems or reoperations. The same conclusion applies for stable intertrochanteric fractures and for the more unstable fracture patterns such as reverse oblique and transverse fractures. More interestingly recently published investigations support the superiority of the sliding hip screw over intramedullary nails in view of the lower complication rate. Thus, there is no robust evidence in the literature in favour of the use of intramedullary implants as the treatment of choice for the stable and unstable intertrochanteric fractures. It seems that other parameters such as the surgeon's experience, operative technique and implant positioning may play equally important roles in obtaining the optimal oucome (2).

*Femoral neck screws*

In order to achieve better fixation and rotational stability, particularly in the management of fragmented intertrochanteric fractures in the presence of osteoporosis, new implant designs have been developed to allow the use of two femoral neck screws (17). However, the superiority of two lag screws over one has yet to be proven. Kubiak et al. (17) in a cadaveric study compared the biomechanical stability of four part intertrochanteric hip fractures stabilized with an intramedullary nail, using either one large diameter lag screw or two small diameter lag screws. Their results indicated that both implants had similar fracture fixation stability for unstable intertrochanteric hip fractures during static and cyclical loading at forces similar to those generated physiologically while walking. However, fixation with two lag screws was significantly stronger when loaded to failure. Other studies showed increased cut-out risk suggesting their use in younger patients, with a better bone quality.
At the moment, there is not sufficient biomechanical or clinical data on which to base exact indications or contraindications for the use of two lag screws in the treatment of intertrochanteric hip fractures (2).

*Helical blade*

In order to improve the fixation stability, helical blade has been proposed instead of the femoral neck screw. The new device has the property to compact the cancellous bone, to support the osteoporotic bone and, at the same time, provides an anti-rotational mechanism to avoid femoral head rotation.
Biomechanical tests in cadaveric femurs have shown that this new fixation with a helical blade is superior to fixation with a standard sliding screw (18). It seems that these devices are reliable and safe in the treatment of unstable intertrochanteric fractures and are associated with fewer complications than conventional intramedullary devices. The problem seems to be the migration of the blade into the articulation. However, other authors noted that helical blade penetration into the acetabulum occurred in percentage similar to those reported with the use of conventional devices. Moreover the long term results of this implant design are still to be investigated to prove the real value of this new device (2).

*Primary arthroplasty for the treatment of intertrochanteric fractures*

The idea of treating the extracapsular fractures in the elderly patients with arthroprosthesis was proposed many years ago with good results, in range between 75% and 95% (19, 20). Two options exist: either the deficient proximal medial femur can be augmented with a calcar replacement prosthesis (21), or the calcar can be reconstructed (22). Early weight bearing with pain free mobilization and low complication rate have been the main advantages of prosthetic replacement, which has also been used in the past following failed internal fixation of lateral femoral fractures (20).
More recent studies support the feasibility of this treatment option for unstable IT fractures. Rodop et al. (21), using a calcar-replacing bipolar hemiprosthesis, reported excellent and good results in about 80% of cases using the Harris hip-score. Furthermore, no dislocations or stem loosening were seen during a 3-year study period. In another investigation,

Kayali et al. (23). compared the functional outcomes of unstable IT fractures treated with internal fixation or cone hemiarthroplasty at a mean follow-up period of 24 months. Their results showed that, whereas clinical outcomes were similar for the two groups, hemiarthroplasty had a lower postoperative complication rate and earlier weight bearing. Grimsrud et al. (22) used a standard cemented femoral component and reconstructed the fractured metaphyseal bone fragments and greater trochanter with a novel cabling technique. They showed that, at 1-year minimum follow-up, there was no loosening or subsidence of the femoral components, and functional results and complication rates were similar to those associated with internal fixation. Chan and Gill (24) treated IT fractures with a standard cemented femoral stem and retained the lesser and greater trochanters with cerclage wires; of the 40 participants who survived to 6-month follow-up two individuals required reoperation, one for exchange of an oversize femoral component and another for conversion to a total hip arthroplasty because of hip pain, and two more experienced complications related to non-union or fracture of the greater trochanter. The authors of this study supported the principle that standard cemented hemiarthroplasty is a reasonable alternative to a sliding screw device for the treatment of IT fractures. Nevertheless, in a recent prospective randomised series, Kim et al. (25) evaluated the treatment of unstable IT fractures among elderly people and compared the results of long-stem cementless calcar-replacement hemiarthroplasty with those of treatment with a proximal femoral nail. The group treated with the nail had a shorter operative time, less blood loss, fewer units of blood transfused, a lower mortality rate, and lower hospital costs compared with those treated with the prosthesis.

There is a paucity of well-conducted randomised studies to support the superiority of arthroplasty over internal fixation for unstable IT fractures, particularly in the long-term. Potential long-term problems associated with prosthetic replacement, such as loosening, acetabular erosion, stem failure, late infection and late dislocation, have yet to be investigated. Taking into account the higher cost of the implants used and the more demanding surgical technique, it has to be concluded that prosthetic replacement can be only be regarded as an alternative treatment, particularly after failed internal fixation (2).

*Subtrochanteric fractures*

Subtrochanteric femoral fractures constitute 7-34% of proximal femoral fractures (26). They can be the result of high-energy trauma among young individuals or low-energy trauma among older persons with osteoporosis. Intense compressive forces in the medial cortex of the subtrochanteric femoral region lead to a high incidence of implant failure in surgically treated cases (27).

Options for surgical treatment include conventional open reduction with rigid internal fixation, intramedullary fixation and biological internal fixation (26), meaning with this last term the percutaneous application of the plate after closed reduction. Unfortunately, published studies comparing these treatment methods have failed to provide definitive conclusions. In a prospective randomised series, Lee et al. (28) treated fragmented subtrochanteric fractures of young people with the previously cited methods, and failed to show any advantages of the one over the other technique. In another prospective randomised controlled trial, Rahme and Harri (29) compared closed intramedullary nailing without anatomical reduction with open reduction and internal fixation using a fixed angle device for subtrochanteric femoral fractures. They found that internal fixation using a fixed angle blade plate had higher implant failure and revision rates compared to closed intramedullary nailing. Ekstrom et al. (30) in a randomised study compared the outcomes among people with unstable subtrochanteric fractures of using the proximal femoral nail or the Medoff sliding plate. They reported that no significant differences were found between the two groups at 4 and 12 months postoperatively. Shukla et al. (31) retrospectively reviewed the results of the treatment of subtrochanteric fractures using cephalo-medullary nailing over a period of 6 years. They documented good results with a union rate of 95%. At the same time they supported the open reduction of the fracture when necessary, since this was not associated with higher complication rates. Saarenpaa et al. (32) prospectively evaluated the short-term outcomes of Gamma nail and dynamic hip screw fixation in the treatment of subtrochanteric hip fractures among the elderly. They observed that a detailed fracture classification is essential for the choice of fixation device, and that, despite the more frequent perioperative problems associated with Gamma nailing, this technique may be preferable to plate fixation for specific fracture types with medial cortical fragmentation.

Finally, it is not possible to support the superiority of either extramedullary or intramedullary implants as far as the short-or long-term final outcome is concerned (26-28).

*The biology-biomechanics of the osteoporotic bone*

Osteoporotic bone has distinct morphologic characteristics that influence its biomechanical properties and therefore the choices and techniques for internal fixation. The diaphysis undergoes both endosteal cortical resorptions and medullary expansion. The result is a thinning of the cortex and an overall increase in the diameter of the bone (1). Mechanically, these changes are adaptive and serve to maintain the flexural rigidity [= (moment of inertia/periosteal diameter) $\times$ material strength] of the bone by increasing its moment of inertia [= $\pi/4 \times$ (periosteal diameter-endocortical diameter)], thus counterbalancing the increased cortical porosity (decreased density) that would otherwise weaken it (1-33).

In the metaphysis the primary finding in patients with osteoporosis is the decreased bone mineral density, which affects the compressive strength of cancellous bone and increases the likelihood of articular impaction (1).

From a mechanical perspective, decreased bone density and decreased cortical thickness diminish the holding power of screws and lead to fatigue failure of the bone, resorption of the damaged bone, and ultimately to loosening of the implant (1).

From a biologic perspective, it is known that there are decreased numbers of osteoprogenitor stem cells in elderly patients, and remaining cells demonstrate a decreased proliferative response to normal stimuli. Although fracture healing proceeds through normal mechanisms in elderly patients, the process is much slower than in younger patients. In elderly patients, there is a confluence of factors-prolonged fracture healing, less secure fixation, and a patient who is less able to tolerate changes in function or protect the injured limb- that make the treatment of fragility fractures a challenge (1).

Load sharing implants (such as intramedullary nails or bridge or buttress plates) are preferred to load bearing devices (such as compression plates). The relative, elastic, stability offered by these devices leads to secondary (indirect) fracture healing by callous formation, more resistant in poor osteoporotic bone.

Polymetilmetacrylate (PMMA) has been employed in order to augment the stability of the osteosynthesis (34). The main disadvantages are: exotermic reaction, a difficult removal in case of revision, the non reassorbable material. Resorbable calcium based materials overcome these disadvantages, being able to resist mainly to pull out forces.

Another way, reserved to special cases, consists in the use of autologous or omologous onlay bone graftings.

Bisphosphonates are currently employed for prosthesis osteointegration, but their use in traumatology is not established yet.
Material charateristics may help to counteract the "bad bite" of the screws. Discording results have been obtained using idroxyapatite (35). Actually most synthesis devices are made in titanium, which has good osteoconductive properties.

*Fixation methods*

1. Conventional plating
Conventional plates rely on direct bony contact and friction between the bicortical screws and bone for stability. Good bone quality is required to achieve solid fixation. The surgical approach used to apply the plate may damage the blood supply to the fracture site (36).

2. Bridge plating
Bridge plating or "internal external fixation" provides flexible fracture fixation and is typically used for the fixation of multifragmented shaft fractures. The plate is tunneled extraperiosteally and anchored remotely from the fracture site. This technique seems to reduce vascular damage. The flexible fixation leads to healing with callus formation, which may be more rapid then that achieved with standard open fixation (36).

3. Locked screw plating
Each screws is fixed to the plate via a threaded interface. They act like threaded bolts without damaging the periostium. The bone plate contact area is minimized, which is less deleterious to the blood supply. Guides can be used to make percutaneous screw insertion. Locking screws have a larger core diameter than conventional screws because they transfer more bending load, that would break thinner screws (36).

4. Trochanteric stabilization plates (TSP)
They contrast diaphyseal medialization and substain metaepyphisis, avoiding varus angulation of the femoral neck although its comminution (37).

Building the plate-fracture construct essentially impacts the management of strain at the fracture site. The stresses on the plate and screws should be designed to allow fracture healing before the hardware fails. One of the key factors to consider is the amount of the gap at the fracture site. It is important to determine if there is a large gap, where the fracture ends are too far apart to touch when loaded (often defined as > 6 mm), or a small gap.
The working lenght of a plate is defined as the distance from the first screw to the fracture site. When screws are placed close to the fracture site the working lenght is short, if there are empty screw holes close to the fracture site, the working lenght is long. The combination of the gap at the fracture site and the working lenght determines the stability and the stiffness of the construct that are also stability indexes of the fixation done and of the resistance of the materials to repeated cycles of load (36).
On the other hand an excessive stiffness may determine bone healing problems, so when small gaps are present, the screws should be spread out, and two or three screws closest to the fracture site should be left out to make the plate more flexible (36).

*Number of screws*

Insert more than three screws does not increase axial stability, and more than four screws will not increase torsional stability. Working length does affect axial stiffness: the closer an additional screw is placed to the fracture site, the stiffer the screw-plate construct becomes in axial compression. When using bridging plates for a lower extremity fracture, two to three screws on either side of the fracture are recommended, unicortical screws should be used only in patients with excellent bone quality. For upper extremity fracture, three to four screws are recommended to resist the higher torsional forces present in the upper extremities (36).

*Plate length*

Screw pull-out force is inversely proportional to the distance between the fulcrum at the fracture site and the screw position, so longer plates reduce pull-out force. Plate span width is defined as the lenght of the plate divided by the lenght of the fracture. A value of 2 to 3 is used for comminuted fractures, and a value of 8 to 10 is used for simple fractures. Screw density is defined as the number of screws divided by the number of screw holes in the plate, considering recommended a value of 0.5 (36).

*Osteosyntesis and osteoporosis*

Axial loads result in shear stresses at the plate bone interface that are resisted by the frictional force between the plate and the bone. This normal force is equal to the axial force generated by the torque used when inserting screws and is approximately 3 to 5 Nm for 3.5 mm screws placed in a non osteopenic femurs. The screws placed with the most torque will bear the largest load. When axial loads are applied to osteopenic bone, the bone may not be able to resist the shear forces generated by the advancing screw threads. This results in the feeling of "no bite" or "bad bite". Approximately 3 Nm can be generated in osteopenic bone, and this may allow motion with as little as 500 N of load. When the shear stresses exceed the strenght of the cortical bone, the bone is either compressed or resorbed; both conditions lead to screw loosening, that results in high fracture gap strain and the lack of haeling.
When bending loads are applied to nonlocking screws, the bone captured by the screw threads resists shear stresses. The screw-bone interface is the weak link. The force needed to move the screw is equal to the stress resistance of the bone multiplied by its contact area with the screw. As the force increases, the screw heads rotate in the plate until they become parallel to the applied force. The stability of a construct applied to osteopenic bone can be improved by several methods:
– increasing the contact area between the screw and the bone (such as by injection of PMMA or using a cancellous screw with wider threads);
– using locking screws that change shear stresses to compressive stress;
– using angular stability plate, with locked screws, so that the stability of the construct is due to the screw-bone interface of the whole system and not just to that of the single element (36).

*Locking plates*

Locking plates are indicated for patients with osteopenic bone (39). Because locking screws do not depend on a "good bite" for fixation, it may be possible to insert the screws at multiple angles trough periarticular plates to better resist pull-out from the bone. Other advantages of locking plate systems include the better resistance of locking screws to bending and torsion forces; the decreased risk of stripping screws during insertion because the plate does not have to be compressed against the bone for stability; the larger core diameter; and locking screws cannot toggle in the plate.

Locking plates are more expensive than conventional plates. Other disadvantages are the difficulty to achieve an adequate reduction, that must be obtained primarly before plate fixation; and the obliged positioning of the screws (36).

*Fracture reduction*

A stable reduction is the basis for success of the surgical procedure. Closed reduction must be preferred but, if anatomical reduction is not achieved, a gentle open reduction must be performed avoiding excessive periosteal splitting by indirect manoeuvres (Schanz screws as joistick, kirschner wires for temporary fixation, trans-articular too) (38-40).
Non anatomical reduction must be avoided because it eventually exposes to risk of secondary displacement.
A demanding closed reduction that employs excessive traction may cause vascular impairment. If gentle manoeuvres are not effective, open reduction must be preferred (38-40).

Tip-Apex Index

Cut-out is among the most frequent complications of surgery in proximal femur fractures. In order to avoid the varus displacement, predisposing to cut-out, the lenght of the cephalic screw must have a tip-apex index of no more than 2 cm (40).

## Discussion

The surgical treatment of the fractures of the upper extremity of the femur in the elderly is a challenge. The main problem is to conciliate the huge advancement of the biometrial technology with the incomplete knowledge of bone properties.
Stromsoe (37), in 2004, concluded his scientific work with these poostulates:

- ostoporotic bone has no impairment of its capacity for fracture healing;
- impaired function due to inferior surgery in the elderly is unacceptable;
- the problem today is mainly a fixation problem in impaired bone material, not the structure of bone;
- falling is the most important factor in fractures in the elderly, not osteoporosis.

We agree with the concept that the most of the efforts must be reserved to the acknowledgement of the biologic properties of the bone; the surgical technique has to follow and to respect these advancements.

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