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HIP FRACTURES IN ADULTS

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REVIEW ARTICLE

Evolution of Fixation in Peritrochanteric Femur Fractures: A Narrative Review

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Abstract

Fractures of the proximal femur, particularly intertrochanteric and subtrochanteric fractures, remain a major orthopaedic challenge due to their high incidence in the elderly, complex biomechanics, and frequent association with osteoporosis. Management of these injuries has evolved significantly over the past century, shifting from conservative treatment and rigid extramedullary constructs toward biologically favorable, load-sharing intramedullary systems that facilitate early mobilization and functional recovery.

Early fixation methods, including angled blade plates and the Dynamic Hip Screw (DHS), were effective in stable intertrochanteric fractures but demonstrated limitations in unstable patterns, especially those with medial calcar deficiency, lateral wall compromise, or subtrochanteric extension, often leading to varus collapse, screw cut-out, and mechanical failure. These shortcomings drove the development of cephalomedullary nails in the 1990s, beginning with the Proximal Femoral Nail (PFN) and subsequently refined through PFNA, PFNA2, Gamma3, InterTAN, TFNA, and emerging designs such as the Proximal Femoral Bionic Nail (PFBN).

Contemporary evidence supports the use of cephalomedullary nails as the preferred fixation for unstable intertrochanteric (AO/OTA 31-A2/A3) and subtrochanteric fractures due to their central load-sharing position, shorter lever arm, and superior resistance to varus and torsional forces. Nonetheless, complications such as implant fatigue, nail breakage, and peri-implant fractures have been reported. DHS remains a reliable, low-cost option for carefully selected stable intertrochanteric fractures with intact medial calcar and lateral wall.

This narrative review synthesizes the historical, biomechanical, and clinical evolution of fixation strategies for peritrochanteric femur fractures and emphasizes that optimal outcomes depend on appropriate implant selection, fracture morphology, bone quality, and meticulous surgical technique.

KEYWORDS

Peritrochanteric fracture; Intertrochanteric fracture; Subtrochanteric fracture; Dynamic hip screw; Cephalomedullary nail; PFNA; Intramedullary fixation

Introduction

Fractures of the proximal femur represent one of the most common and consequential injuries encountered in orthopaedic practice, imposing a substantial clinical, social, and economic burden worldwide.[1] These fractures predominantly affect the elderly population following low-energy falls, often in the setting of osteoporosis and reduced muscle strength, while in younger individuals they typically result from high-velocity trauma such as road traffic accidents or falls from height.[2] As global life expectancy continues to rise, the incidence of hip fractures is projected to increase further, placing significant strain on healthcare systems.[3,4] Among proximal femoral fractures, intertrochanteric fractures account for more than 50% of cases and constitute a major share of orthopaedic trauma workload.[5] Intertrochanteric and Subtrochanteric femur fracture management is particularly demanding because they occur in a biomechanically critical region subjected to high compressive, tensile, and rotational forces, often in the setting of poor bone quality.[6,7]

The peritrochanteric region, including the femoral neck, intertrochanteric, and subtrochanteric zones represents a complex anatomical and functional transition area between the hip joint and the femoral shaft.[8] Each fracture subtype within this region presents unique biological and mechanical challenges. Intracapsular femoral neck fractures are constrained by compromised blood supply, lack of periosteal healing potential, and exposure to synovial fluid, predisposing them to non-union and avascular necrosis.[9] In contrast, intertrochanteric and subtrochanteric fractures are extracapsular injuries where the primary determinants of outcome are mechanical stability, fracture pattern, and quality of fixation.[10] Among these, intertrochanteric fractures have served as the principal driver for innovation in fixation strategies due to their high frequency, heterogeneity, and susceptibility to implant-related failure.[11]

Historically, treatment of proximal femur fractures evolved from prolonged bed rest and traction to operative stabilization, driven by the need to reduce complications related to immobility and improve functional outcomes.[12] Early internal fixation devices were predominantly rigid, extramedullary constructs that prioritized anatomical alignment but often failed to accommodate fracture impaction and physiological loading.[13] High rates of varus collapse, screw cut-out, and mechanical failure highlighted the limitations of these designs and prompted a gradual shift toward dynamic fixation principles.[14] This evolution culminated in the development of intramedullary load-sharing implants, which more closely align with the biomechanical demands of the peritrochanteric region.

Despite significant advances, the choice of fixation for intertrochanteric fractures particularly in unstable patterns, osteoporotic bone, and fractures extending toward the femoral neck or subtrochanteric region remains an area of ongoing debate.[15] The rapid emergence of newer implant generations, such as modern cephalomedullary nails and hybrid fixation systems, has further emphasized the need to understand not only what is used today, but why these devices evolved. This narrative review aims to trace the historical and conceptual evolution of fixation methods for peritrochanteric femur fractures, with primary emphasis on intertrochanteric fractures, while drawing relevant parallels with femoral neck and subtrochanteric fracture management. By contextualizing contemporary fixation strategies within their biomechanical and biological foundations, this review seeks to provide a rational framework for implant selection and guide future directions in proximal femur fracture care.

Historical Fixation Methods

Neck of Femur Fractures

Historically, fractures of the femoral neck were among the most challenging injuries to manage.[16] Prior to the development of internal fixation, treatment was largely conservative, involving prolonged skeletal traction, bed rest, and attempts at immobilization.[12] Such measures were associated with high rates of nonunion, avascular necrosis, and poor outcomes particularly in displaced fractures, due to the precarious blood supply of the femoral head.[17] The first documented attempt at internal fixation using a plate-and-screw construct was described by Carl Hansmann in Hamburg in 1858, marking a pivotal departure from purely conservative fracture care. In the latter half of the 19th century, following the widespread adoption of anesthesia and antiseptic principles, surgeons such as von Langenbeck and his contemporaries further explored open reduction techniques using metal wires and pins, laying the conceptual foundation for modern internal fixation.[18,19]

In the mid-20th century, the limitations of internal fixation in elderly, displaced femoral neck fractures principally high rates of nonunion and avascular necrosis led surgeons to seek alternative solutions.[20,21] Early pioneers of proximal femoral arthroplasty included Austin Moore, who in 1940 implanted the first Vitallium proximal femoral prosthesis to replace the fractured head and neck segment, later modifying his design to a straight-stemmed prosthesis in the 1950s to improve mechanical alignment and stress transmission along the femoral shaft.[22] The Austin Moore prosthesis was a unipolar, monobloc design, which consisted of a single implant articulating directly with the native acetabulum.[23] Around the same era, the Thompson prosthesis was introduced as another unipolar design with a shorter, curved stem, which was initially used without cement but subsequently adopted in cemented form because of its geometry and favorable fixation characteristics.[24] Despite their historical significance, unipolar designs such as Austin Moore and Thompson prostheses were associated with complications including acetabular wear, thigh pain, and periprosthetic fracture in some series, particularly when uncemented fixation was used.[25] Meta-analytic evidence suggests that cemented Thompson hemiarthroplasty is associated with lower postoperative hip pain, fewer reoperations, and fewer intraoperative fractures compared with uncemented Austin Moore implants, while functional outcomes and mortality rates are similar.[26]

To address acetabular cartilage wear and improve functional outcomes, the bipolar hemiarthroplasty was developed in the 1970s.[27] Bipolar designs incorporate an inner small articulation between a polyethylene bearing and the prosthetic head, and an outer articulation between the metal head and the acetabulum.[28] Although conceptually appealing for reducing acetabular erosion, clinical evidence has not consistently demonstrated superiority in long-term outcomes over unipolar prostheses.[29,30] Modern modular bipolar prostheses allow adjustment of stem size, neck length, and femoral offset, facilitating better leg length equalization and soft tissue tensioning, and enabling easier conversion to total hip arthroplasty if required.[31]

A key debate in clinical practice has been the choice between cemented and uncemented fixation in hemiarthroplasty. Randomized controlled trials and comparative studies indicate that cemented stems generally result in less postoperative pain and better early mobility compared with uncemented implants, without significant differences in mortality or major medical complications.[32] Systematic reviews focusing specifically on bipolar prostheses demonstrate that uncemented bipolar hemiarthroplasty may be associated with lower blood loss and shorter operative time, but cemented fixation remains advantageous in terms of reduced thigh pain postoperatively.[33] Additionally, uncemented designs have been linked with higher rates of periprosthetic fractures in some observational series, highlighting the importance of patient selection and surgical technique.[34]

Over time, the evolution of arthroplasty has progressed further toward total hip replacement (THR) for selected patients, particularly those who are physiologically younger and more active.[35] THR offers the theoretical advantages of improved mobility, lower long-term acetabular wear, and reduced need for future revision compared with hemiarthroplasty—although it may be associated with increased operative time and dislocation risk in some populations.[36,37] Contemporary practice increasingly tailors the choice between hemiarthroplasty and THR based on patient age, functional status, and comorbidities, recognizing that arthroplasty remains a cornerstone in the management of displaced femoral neck fractures refractory to osteosynthesis in old age population and displaced neck of femur fractures.[38]

Intertrochanteric & Subtrochanteric Fractures

The historical trajectory of intertrochanteric fracture fixation reflects a gradual refinement of biomechanical understanding and implant design. Early interventions relied on traction and plaster immobilization, often resulting in malalignment and delayed mobilization.[12] Later in late nineties sliding compression plates were developed to provide controlled impaction at the fracture site. The conceptual work of Ernst Pohl (1876–1962) in advancing principles of controlled fracture stabilization and implant mechanics played a critical role in the emergence of the sliding hip screw concept; these ideas were later translated into clinical practice with the introduction of the Dynamic Hip Screw (DHS) in the 1960s, which represented a major advancement in proximal femoral fracture fixation by allowing controlled axial collapse at the fracture site while maintaining alignment and promoting biological healing. [39,40] Its design - a lag screw inserted into the femoral head and neck connected to a lateral side plate—allowed axial compression and promoted fracture healing, particularly in stable intertrochanteric patterns.[41] Despite its widespread success, DHS demonstrated limitations in unstable fractures, particularly with medial calcar deficiency or lateral wall compromise, leading to varus collapse, limb shortening, and screw cut-out.[42]

The introduction of intramedullary fixation for extracapsular and selected unstable proximal femoral fractures in the 1990s represented a major paradigm shift toward biologically and mechanically favorable load-sharing constructs.[43] Building upon the foundational principles of intramedullary fixation pioneered by Küntscher in the 1940s, modern cephalomedullary nails aimed to reduce the bending moments across the fracture site by positioning the implant closer to the mechanical axis of the femur, thereby improving construct stability and allowing for earlier mobilization.[43,44]

The management of extracapsular proximal femoral fractures—encompassing both intertrochanteric and subtrochanteric patterns—has evolved substantially over the past several decades, driven by a growing understanding of fracture biomechanics, implant–bone interaction, and the biological requirements for fracture healing. Early fixation strategies predominantly relied on extramedullary devices such as blade plates, dynamic condylar screws, and sliding hip screws.[40] While these implants provided angular stability, their eccentric placement relative to the femoral mechanical axis generated high bending stresses, particularly in unstable fracture configurations and in the subtrochanteric region, where axial loads and deforming muscular forces are greatest.[45] These limitations frequently resulted in varus collapse, implant fatigue, malalignment, and nonunion, especially in osteoporotic bone or comminuted fractures, and often necessitated extensive surgical exposure with attendant biological compromise.[46]

The introduction of intramedullary fixation in the 1990s represented a pivotal paradigm shift in the treatment of unstable intertrochanteric and subtrochanteric fractures. By aligning the implant closer to the femoral mechanical axis, intramedullary nails significantly reduced bending moments and functioned as load-sharing constructs, offering superior resistance to axial, torsional, and varus forces.[47] The Proximal Femoral Nail (PFN), developed by the AO/ASIF group and introduced in 1996, was among the first widely accepted cephalomedullary implants specifically designed to address these challenges. Its dual proximal screw configuration—a lag screw for

Table 1. Peritrochanteric fracture subtypes: dominant challenges & usual fixation direction

Region / subtype	Dominant constraint	Typical priority	Common fixation direction
Femoral neck (intracapsular)	Biology (blood supply, synovial environment)	Preserve head in young; arthroplasty in many elderly displaced fractures	Screws / fixed-angle devices / hemiarthroplasty / THA
Intertrochanteric (stable)	Mechanics manageable with controlled impaction	Controlled sliding + impaction	DHS/SHS
Intertrochanteric (unstable: A2/A3)	Varus + rotation + lateral wall problems	Load sharing close to axis; early mobilization	Cephalomedullary nail (PFN/PFNA/ Gamma3/InterTAN etc.)
Subtrochanteric	High bending + muscle deforming forces	Strong load-sharing construct + good reduction	Long cephalomedullary/ reconstruction IM nail; plating when nail not feasible

DHS Dynamic Hip Screw; *SHS* Sliding Hip Screw; *PFN* Proximal Femoral Nail; *PFNA* Proximal Femoral Nail Anti-rotation; *THA* Total Hip Arthroplasty

Table 2. Evolution of fixation methods from older to newer

Era	Representative approaches	Core concept	Typical limitations that drove evolution
Conservative era	Traction, prolonged bed rest	Immobilize until union	Malunion, complications of immobility
Early operative extramedullary	Blade plates, DCS, early side plates	Rigid angular stability	High bending stresses, biological insult, failures in unstable patterns
Dynamic extramedullary	DHS/SHS ± TSP	Controlled sliding compression and impaction	Excessive collapse/varus/ cut-out in unstable patterns; poor in subtrochanteric
Modern intramedullary	PFN, PFNA/PFNA2, Gamma3, InterTAN, TFNA	Central load sharing, shorter lever arm, improved torsional control	Implant-specific complications (migration, cut-out, peri-implant fracture, rare breakage)
Emerging/next-gen	PFBN and other "bionic/biomimetic" constructs	Stress redistribution + comparable effectiveness	Evidence still developing; long-term data limited

DHS Dynamic Hip Screw; *SHS* Sliding Hip Screw; *DCS* Dynamic Condylar Screw; *TSP Trochanter Supporting Plate; PFN* Proximal Femoral Nail; *PFNA* Proximal Femoral Nail Anti-rotation; *PFBN* Proximal Femoral Bionic Nail; *TFNA* Trochanteric Fixation Nail Advance; *THA* Total Hip Arthroplasty

axial load transmission combined with an anti-rotation screw—was intended to enhance rotational and angular stability across a spectrum of unstable fracture patterns.[48] However, complications such as screw cut-out and the "Z-effect," particularly in osteoporotic bone, highlighted the limitations of early designs.[49]

These shortcomings prompted further refinement of cephalomedullary systems, most notably with the introduction of the Proximal Femoral Nail Antirotation (PFNA).[50] The replacement of the traditional lag screw with a helical blade represented a major conceptual advance, as the blade compacts cancellous bone during insertion, improving anchorage and resistance to rotational and varus forces without excessive bone removal.[51,52] This design proved particularly advantageous in elderly patients with poor bone quality and gained widespread acceptance for unstable intertrochanteric and subtrochanteric fractures.[53] Subsequent anatomical adaptations, such as PFNA2, were developed to better accommodate smaller femoral dimensions commonly encountered in Asian populations, reducing entry-

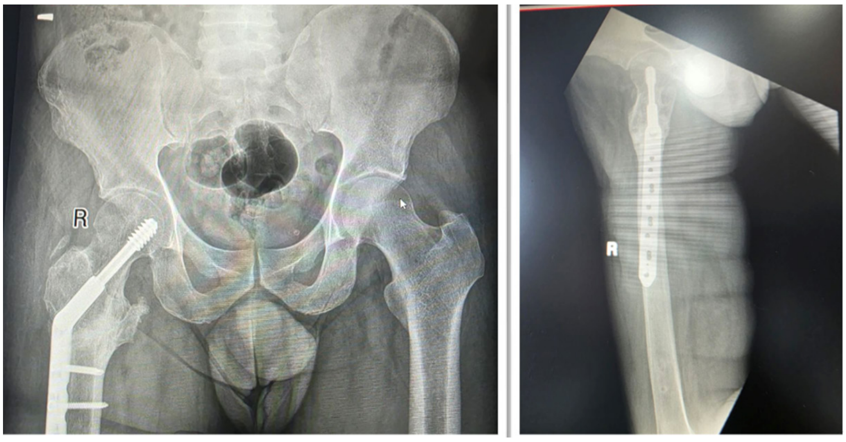

Figure 1 Anteroposterior(AP) and Lateral Plain Radiograph showing placement of lag screw and DHS side plate with long barrel in a case of intertrochanteric femur fracture

related complications while preserving biomechanical benefits.[54]

Continued evolution has produced contemporary cephalomedullary systems such as the Gamma3 and InterTAN nails.[55] These implants incorporate refined proximal geometry, improved instrumentation, and enhanced fixation concepts, including integrated dual-screw mechanisms that allow controlled intraoperative compression with superior rotational stability.[55–57] Reconstruction-type nails have further expanded the indications for intramedullary fixation by enabling stable management of complex fracture patterns, including reverse obliquity fractures, subtrochanteric extensions, and combined proximal femur and shaft injuries.[58]

Across both intertrochanteric and subtrochanteric fractures, this transition from extramedullary to intramedullary fixation reflects a consistent effort to optimize biomechanics while preserving fracture biology. In the subtrochanteric region in particular, where cortical bone predominates and stress concentration is high, contemporary fixation philosophy emphasizes the importance of achieving accurate anatomical reduction-often requiring limited open or percutaneous-assisted techniques-prior to nail insertion.[59]

Overall, the progressive refinement of cephalomedullary nail systems has unified the management principles of intertrochanteric and subtrochanteric fractures, establishing intramedullary fixation as the cornerstone of modern treatment for unstable extracapsular proximal femoral injuries.

Current Fixation Methods

Dynamic Hip Screw (DHS)

The Dynamic Hip Screw (DHS) has long stood as a cornerstone in the management of extracapsular proximal femur fractures, particularly stable intertrochanteric fractures.[60] Its design reflects a simple yet elegant biomechanical principle: the sliding compression mechanism.[61] A large lag screw is inserted into the femoral head along the axis of the femoral neck and is connected to a lateral side plate fixed to the femoral shaft.[62](Figure 1) During weight bearing, the lag screw slides within the barrel of the side plate, allowing controlled dynamic impaction at the fracture site.[63] This movement promotes biological healing by encouraging axial compression without imposing rigid constraints that may interfere with callus formation.[64]

The efficacy of DHS is closely tied to fracture stability and bone geometry. Optimal outcomes are achieved when the medial calcar and lateral wall are intact, which provides both axial and rotational support.[65,66] In such scenarios, DHS allows early partial weight bearing and generally demonstrates low rates of mechanical complications, making it a cost-effective option with minimal surgical exposure and relatively short operative time.[67] Its relatively easier application with shorter operative time has advantages, particularly relevant in elderly or medically frail patients.[68]

However, the limitations of DHS become apparent in unstable fracture patterns or in the presence of lateral wall deficiency.[66] In these cases, sliding compression can lead to excessive fracture collapse, varus malalignment, or lag screw cut-out, compromising fixation and functional outcomes.[69] Moreover, DHS is inherently less suited for subtrochanteric fractures, where high bending moments and muscular deforming forces create a lever arm disadvantage.[6] In such fractures, extramedullary devices do not provide sufficient axial or rotational stability, and delayed weight bearing may be required to prevent implant failure, reducing early mobilization advantages.[70]

Additional modifications, such as the trochanteric stabilizing plate, have been introduced to augment lateral wall support in complex patterns.[71] While these augmentations improve biomechanical resilience, they do not fully overcome the intrinsic limitations of the extramedullary design, particularly in reverse obliquity fractures, comminuted subtrochanteric extensions, or osteoporotic bone.[72,73] Consequently, careful preoperative assessment of fracture morphology, stability, and lateral wall integrity is essential before choosing DHS as the fixation modality. When these prerequisites are met, DHS remains a reliable, low-cost, and technically straightforward option, balancing stability, biological healing, and cost-effectiveness for selected peritrochanteric fractures.[74]

Cephalomedullary Nails: Evolution and Contemporary Application

The recognition of limitations inherent to extramedullary devices like the dynamic hip screw (DHS) in managing unstable pertrochanteric fractures prompted the development of cephalomedullary fixation systems. Early intramedullary nailing for proximal femur fractures can be traced back to the central load-sharing principles demonstrated in long bone fracture treatment by Küntscher in the 1940s.[75] Building on these biomechanical foundations, the Proximal Femoral Nail (PFN) was introduced in the mid-1990s by the AO/ASIF group to address the need for implants that aligned closely with the femoral mechanical axis and reduced the bending moments and lever arm stresses that contributed to failure in unstable fracture patterns. PFN incorporated a cephalad lag screw coupled with distal locking options, intending to provide axial and rotational control while facilitating early mobilization.[76]

While PFN represented a significant advance over extramedullary constructs, clinical experience revealed persistent issues with rotational stability and cut-out in osteoporotic bone. To augment proximal fixation, the Proximal Femoral Nail Antirotation (PFNA) was developed, featuring a helical blade instead of a conventional screw. The blade design compresses cancellous bone during insertion, increasing contact area and enhancing purchase in poor quality bone, particularly relevant in the elderly population with osteoporotic pertrochanteric fractures. This blade-based anchorage mechanism has been widely adopted, and studies suggest that PFNA may offer shorter operative time and reduced blood loss compared with extramedullary devices, while providing adequate stability for many unstable patterns.[77,78]

Subsequent refinements led to region-specific adaptations. The PFNA2, developed with modifications in geometry, proximal diameter, and blade specifications, was optimized for populations with smaller femoral dimensions, such as in many Asian cohorts.[79] These refinements aimed to improve canal fit and decrease the risk of cortical impingement without compromising biomechanical integrity. Alongside PFNA and its iterations, other single-screw intramedullary designs such as the Gamma3 nail have also achieved widespread use.[80] While PFNA and Gamma3 share a broadly similar philosophy, clinical and biomechanical studies note differences in anti-rotation performance and complication profiles, with some series reporting issues such as screw migration or proximal cut-out with single-cephalocervical implants.[81,82]

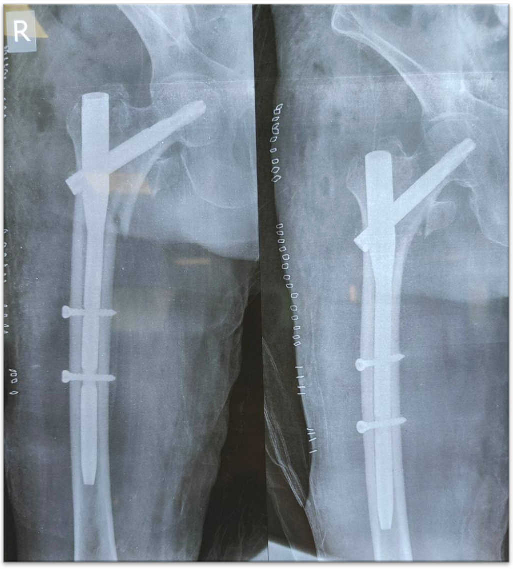

Figure 2 Short PFNA2 with helical blade placement in a case of intertrochanteric fracture.

To further enhance mechanical stability, particularly in high-demand fracture patterns, dual-screw cephalomedullary systems such as the InterTAN nail have been introduced.[83] InterTAN employs two integrated cephalocervical screws designed to provide linear compression and improved resistance to femoral head rotation.[84] Meta-analyses indicate that InterTAN may be associated with lower risks of implant failure, reduced rates of hip and thigh pain, and fewer revision procedures compared with single-screw designs such as PFNA or Gamma3, along with modest improvements in functional scores and union times.[83]

Cephalomedullary nails have become the implant of choice for unstable intertrochanteric fractures (AO/OTA 31-A2 and A3) due to their biomechanical advantages.[85] By centralizing fixation closer to the weight-bearing axis and reducing stress on cortical bone, these nails provide greater resistance to varus collapse and mechanical failure, a limitation often seen with extramedullary plates in such patterns.[86] In reverse obliquity and subtrochanteric extensions—configurations where lateral wall support is compromised and the fracture line transects traditional load-bearing zones—the intramedullary device's shorter lever arm and load sharing characteristics translate into more predictable outcomes.[87]

However, cephalomedullary nails are not without complications. Implant fatigue, nail breakage, and peri-implant fractures have been reported, with some data suggesting higher reported breakage rates with certain designs such as the Trochanteric Fixation Nail-Advanced (TFNA) compared with predecessors like PFNA or Gamma3.[88,89] Nonetheless, these events remain relatively uncommon and must be balanced against the benefits of intramedullary fixation in high-risk fracture configurations.

Intramedullary vs Extra-medullary Fixation

The long-standing debate between intramedullary and extramedullary fixation for pertrochanteric fractures centers on the biomechanical environment of the proximal femur and the ability of implants to withstand loading forces while allowing controlled fracture healing.[90] Extramedullary devices like the DHS are traditionally reliable for stable intertrochanteric fractures with intact medial calcar and lateral wall, where they provide predictable sliding compression and fracture impaction. Multiple studies demonstrate comparable long-term functional outcomes between DHS and intramedullary systems in stable fractures, underscoring the continued relevance of DHS in carefully selected cases.[91]

In contrast, intramedullary nails show clear perioperative advantages in unstable fractures.[92] Meta-analyses comparing PFN with DHS reveal shorter operative time, lower intraoperative blood loss, and earlier progression to full weight bearing with PFN, along with a lower overall complication rate, although long-term functional scores and mortality may not differ significantly.[92] These findings are particularly evident in fractures with compromised lateral wall integrity, comminution, or subtrochanteric extension, in which the shorter lever arm and central axis support of intramedullary nails better counteract bending and torsional forces.[93]

The choice of implant therefore hinges on fracture morphology, bone quality, and patient factors. For stable intertrochanteric patterns, DHS remains a valid option; however, in unstable, reverse obliquity, lateral wall deficient, or subtrochanteric fractures, cephalomedullary fixation is generally preferred due to superior mechanical support and earlier functional rehabilitation.

Current Fixation Options for Intertrochanteric and Subtrochanteric Fractures

In intertrochanteric fractures, the spectrum of fixation devices spans from extramedullary plates and screws in stable patterns to a range of intramedullary nails for unstable configurations. Aside from DHS, options include modern cephalomedullary nails such as PFNA, PFNA2, Gamma3, InterTAN, and emerging constructs like the Proximal Femoral Bionic Nail (PFBN) that combine innovative biomechanics with comparable clinical effectiveness.[94–96]

For subtrochanteric fractures, which are subjected to intense bending and muscle forces, intramedullary nails, typically long-length reconstructions or specialized cephalomedullary designs are the mainstay. Plating techniques, including fixed-angle blade plates or locking plates, may be reserved for scenarios where nail entry is contraindicated or in fracture patterns that compromise traditional intramedullary pathways.[6,97–100]

Fixation Methods: Evolution

The evolution of fixation in peritrochanteric femur fractures mirrors the broader progression of orthopaedic trauma surgery—from rigid mechanical constructs toward biologically friendly, load-sharing systems that prioritize early mobilization and functional recovery. This transition has been driven not only by advances in implant design but also by an improved understanding of fracture biomechanics, bone biology, patient physiology, and healthcare system demands.

From Reduction-Centric to Biology-Respecting Fixation

Early fixation strategies for fractures around the hip were largely reduction-centric, emphasizing anatomical alignment achieved through open techniques and rigid constructs.[99,101,102] While devices such as angled blade plates, dynamic condylar screws, and early side-plate constructs offered mechanical stability, they often did so at the expense of fracture biology.[103,104] Extensive soft tissue stripping, periosteal disruption, and stress shielding contributed to delayed union, nonunion, and implant failure, particularly in osteoporotic bone.[105,106]

The contemporary fixation philosophy increasingly accepts relative stability over absolute rigidity, especially in extracapsular fractures.[107] Controlled collapse, micromotion, and secondary bone healing are now recognized as beneficial rather than detrimental.[108,109] This paradigm shift is most evident in the dominance of cephalomedullary nails for unstable intertrochanteric and subtrochanteric fractures, where central load sharing and minimally invasive insertion respect both mechanical and biological principles.

Intertrochanteric Fractures: The Epicenter of Evolution

Among peritrochanteric injuries, intertrochanteric fractures have experienced the most significant evolution in fixation strategies.[110] Initially treated with traction and later with extramedullary devices such as DHS, these fractures highlighted the limitations of lateralized load-bearing implants, particularly in unstable patterns with medial calcar comminution or lateral wall incompetence. Excessive fracture collapse, varus malalignment, and implant failure prompted the search for more biomechanically favorable solutions.

Intramedullary fixation emerged as a logical advancement, positioning the implant closer to the femoral mechanical axis and reducing bending stresses. The introduction of PFN and PFNA systems further refined this approach by addressing rotational instability and improving femoral head purchase in osteoporotic bone. Helical blade technology, in particular, represents a conceptual leap—favoring bone compaction rather than removal, thereby enhancing fixation strength where bone quality is compromised.

Despite these advances, fixation failure still occurs, underscoring that implant choice alone cannot compensate for poor reduction quality. Varus malreduction, improper entry point, suboptimal implant positioning, and inadequate fracture compression remain key determinants of outcome. Thus, modern intertrochanteric fracture fixation is best understood as an interplay between implant design and surgical execution rather than a purely device-driven solution.

Neck of Femur Fractures: Persistent Biological Challenges

In contrast to intertrochanteric fractures, the evolution of fixation in neck of femur fractures has been constrained by intrinsic biological limitations. Intracapsular fractures

Table 3. Fixation device "map" for intertrochanteric fractures (stable vs unstable)

Fracture context	Device class	Typical implant examples	Why it fits (one-line)
Stable IT (A1; intact medial calcar + lateral wall)	Extramedullary sliding device	DHS/SHS	Predictable controlled collapse and impaction
Unstable IT (A2;comminution/ lateral wall compromised)	Cephalomedullary nail	PFNA/PFNA2, Gamma3, TFNA	Better load sharing and lever-arm advantage
Reverse obliquity / A3, subtrochanteric extension	Long cephalomedullary / recon nail	Long PFNA/PFN variants, long Gamma/ TFNA-type nails	Superior resistance to bending/varus and torsion
When IM nail entry/pathway contraindicated	Plating (selective)	Fixed-angle blade plate, locking plate ± cerclage	Alternative when canal/ entry not usable

IT Intertrochanteric; *DHS* Dynamic Hip Screw; *SHS* Sliding Hip Screw; *PFN* Proximal Femoral Nail; *PFNA* Proximal Femoral Nail Anti-rotation; *PFNA2* Proximal Femoral Nail Anti-rotation for Asian; *TFNA* Trochanteric Fixation Nail Advance; *IM* Intramedullary

Table 4. Generations of cephalomedullary nails

Implant / "generation"	Proximal fixation concept	Main intended advantage	Commonly discussed issues
PFN	Lag screw + antirotation screw	Better rotational control than single screw	Z-effect, cut-out in poor bone (technique/bone dependent)
PFNA	Helical blade	Bone compaction + improved purchase in osteoporosis	Blade cut-out/cut-through can still occur
PFNA2	Modified geometry for smaller femora	Better canal fit; less impingement in many Asian cohorts	Similar failure modes if reduction/positioning suboptimal
Gamma3	Refined single screw CMN	Widely used, streamlined instrumentation	Migration/cut-out reported in some series
InterTAN	Integrated dual cephalocervical screws	Linear compression + improved antirotation	Technique-sensitive; implant-specific complications possible
TFNA	Newer CMN generation	Modern instrumentation / design refinements	Reports of breakage higher in some datasets vs predecessors (still uncommon overall)
PFBN (emerging)	"Bionic/biomimetic" stress pathway	Stress redistribution + comparable effectiveness (early evidence)	Long-term comparative clinical evidence still limited

PFN Proximal Femoral Nail; *PFNA* Proximal Femoral Nail Anti-rotation; *PFNA2* Proximal Femoral Nail Anti-rotation for Asian; *CMN* Cephalomedullart Nail; *TFNA* Trochanteric Fixation Nail Advance; *PFBN* Proximal Femoral Bionic Nail

exist in a hostile healing environment characterized by synovial fluid inhibition, absence of periosteal cambium, and precarious vascular supply to the femoral head. While internal fixation techniques have evolved—from Smith–Petersen nails to cannulated cancellous screws and newer devices like the Femoral Neck System—the fundamental challenges remain unchanged.

The development of implants offering angular and rotational stability reflects an effort to mechanically compensate for poor biology. However, failure rates in displaced fractures remain significant, reinforcing the role of arthroplasty in elderly, low-demand patients. An unresolved debate persists regarding the role of biological augmentation, such as primary bone grafting or vascularized grafts, in young patients undergoing osteosynthesis. While valgus osteotomy and pedicled grafts demonstrate theoretical and historical benefits, their routine use remains limited by technical demand and variable outcomes.

Subtrochanteric Fractures: Where Biomechanics Dominate Biology

Subtrochanteric fractures represent the extreme end of biomechanical challenge within the peritrochanteric region.[6] High compressive forces medially, tensile stresses laterally, and strong deforming muscle vectors historically rendered fixation unreliable.[111] The transition from extramedullary plating to intramedullary nailing was particularly transformative in this subgroup, as it directly addressed the dominant bending and torsional stresses at the fracture site.[97]

Modern long cephalomedullary nails enable stable fixation while preserving periosteal blood supply and facilitating secondary healing. Nevertheless, subtrochanteric fractures continue to demonstrate higher rates of delayed union and nonunion, especially in atypical fractures associated with prolonged bisphosphonate use.[112,113] This has renewed interest in adjunctive strategies, including longer working lengths, avoidance of stress risers, and selective biological supplementation.[114]

Patient-Centered and System Level Drivers of Evolution

Beyond biomechanics and biology, broader societal and healthcare factors have influenced fixation evolution. An aging population with increasing comorbidities demands fixation strategies that permit early mobilization, minimize surgical trauma, and reduce hospital stay. Intramedullary systems align well with these goals by allowing earlier weight bearing and faster functional recovery, particularly critical in preventing complications such as pneumonia, thromboembolism, and deconditioning.[115]

In resource-limited settings, the SIGN intramedullary nail augmented with a lateral plate has emerged as a practical alternative for the fixation of intertrochanteric and selected subtrochanteric femur fractures. This construct combines the load-sharing advantage of intramedullary fixation with the lateral plate acting as a tension band to prevent varus collapse and rotational instability. Open reduction allows accurate anatomical alignment, which is particularly important in the high-stress subtrochanteric region. The technique does not require fluoroscopy, making it well suited to low-resource environments. Reported functional outcomes have been acceptable, with low complication rates. Although not a substitute for modern cephalomedullary nails in high-income settings, this method provides a biomechanically sound and cost-effective solution where implant options are limited.[116]

At the same time, implant cost, availability, and surgical expertise remain important considerations, especially in resource-limited settings. Despite technological advances, the DHS remains widely used and effective in appropriately selected cases, emphasizing that evolution does not imply obsolescence but rather refined indication-based usage.

Future Perspectives and Unanswered Questions

The future of peritrochanteric fracture fixation is increasingly focused on incremental refinement of implants, biologics, and surgical techniques rather than radical reinvention. Contemporary innovations such as titanium alloy nails, hydroxyapatite-coated implants, antibiotic-impregnated devices, and bionic fixation concepts aim to improve osseointegration, reduce infection risk, and enhance implant longevity, particularly in osteoporotic bone.[117–119] Early biomechanical and clinical studies suggest these advances may reduce micro-motion, cut-out, and secondary collapse, yet robust long-term evidence remains limited.

In parallel, the concept of lateral wall reconstruction or augmentation has emerged as a crucial adjunct in unstable intertrochanteric fractures.[120] Deficiency of the lateral wall has been consistently associated with varus collapse and fixation failure when using sliding hip screws or even some intramedullary devices.[121] Techniques such as trochanteric stabilizing plates, cerclage wiring, or augmented nail designs are increasingly explored to restore lateral buttress support and maintain fracture alignment under early weight bearing.[122,123]

For intracapsular femoral neck fractures, which remain particularly prone to nonunion and avascular necrosis, the potential role of primary bone grafting or biological augmentation is gaining attention.[124,125] Pedicled vascularized grafts, calcium phosphate substitutes, or stem-cell–enhanced grafts may theoretically enhance healing by supplementing the compromised local biology.[126–128] However, the evidence for routine clinical application remains sparse, and questions regarding optimal graft type, timing, and fixation technique persist.

Other unresolved questions include:

- Can novel nail designs such as dual-screw or integrated cephalomedullary systems provide clinically meaningful improvements over well-established PFN or PFNA constructs, particularly in osteoporotic or complex fracture patterns?
- How should fixation strategies adapt for atypical, reverse obliquity, or subtrochanteric extensions to minimize complications such as cut-out, malalignment, or implant breakage?
- What is the long-term impact of implant coatings, antibiotic impregnation, or bioactive surfaces on fracture healing, infection, and revision rates?

Addressing these questions will require high-quality randomized trials, large multicenter registries, and long-term outcome studies, particularly in populations with high osteoporosis prevalence and complex fracture patterns. A personalized approach, integrating patient physiology, bone quality, fracture morphology, and implant biomechanics, will likely define the next frontier in hip fracture management.

Conclusion

The evolution of fixation in peritrochanteric femur fractures has progressed from traction and rigid extramedullary devices to modern intramedullary, load-sharing systems that better respect regional biomechanics and fracture biology. While the dynamic hip screw remains an effective and economical option for stable intertrochanteric fractures with intact lateral and medial support, unstable patterns and subtrochanteric extensions are more reliably addressed with cephalomedullary nails. Contemporary management emphasizes not only implant selection but also quality of reduction, biological preservation, and early mobilization. Future advances will likely focus on implant refinement and adjunctive biological or structural augmentation rather than wholesale changes in fixation philosophy, reinforcing the need for individualized, fracture-specific treatment strategies.

Conflict of Interest

None

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