# Evolution of Femoral Neck Implants: In Search of the Perfect Implant

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## Abstract

Femoral neck fractures have significant orthopedic difficulty, particularly in younger patients with high-energy trauma. The femoral neck system improves rotational stability, allows for controlled dynamic compression, and is less invasive than cannulated cancellous screws. However, steep learning curves, more significant starting expenditures, and more long-term data still need to be addressed. Emerging technologies, such as robotic-assisted surgeries and personalized implants created with artificial intelligence and 3D printing, can transform fracture therapy by boosting accuracy, lowering complications, and improving patient-specific care. Future advances will improve results and patient happiness.

**Keywords:** Femoral neck fractures, femoral neck system, cannulated screws, rotational stability, angular stability, minimally invasive surgery, fracture fixation, osteoporotic fractures, clinical outcomes, implant innovations.

## Introduction

Femoral neck fractures are a significant orthopedic challenge, particularly among young patients with high-energy trauma. These fractures account for a substantial proportion of patient's morbidity and decrease of quality-adjusted life years. These intra-capsular fractures are also riddled with complications, such as non-union and avascular necrosis (AVN) of the femoral head. The introduction of advanced fixation methods like the femoral neck system (FNS) has brought a paradigm shift in managing these fractures, particularly in unstable cases where traditional cannulated cancellous (CC) screws may fall short.

This comprehensive article explores the historical evolution of femoral neck fracture fixation, the benefits of FNS over CC screws, the challenges associated with its use, and future innovations that promise to shape the landscape of orthopedic trauma care.

1) Historical evolution of femoral neck fixation: from conservative management to advanced systems

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a. Early management approaches

Historically, femoral neck fractures were managed conservatively with bed rest, traction, and casting. These methods, while simple, resulted in high rates of complications, including non-union and AVN, as shown in (Fig. 1).

The need for better outcomes led to the development of internal fixation techniques in the early 20th century.

RS Garden developed the garden screw in the 1950s. It was a large cancellous screw that was specifically designed for femoral neck fractures, allowing for compression at the fracture site and improved stability, as shown in (Fig. 2).

Smith-Petersen Nail: One of the earliest devices used for internal fixation. It is a triflanged blade, which helps give rotational stability. (Fig. 3) Implants were based on a Smith-Peterson nail to which was attached a side plate. These implants are termed "static" or "fixed" implants (FNP) as they have no capacity for sliding.

- Dynamic hip screws (DHS) with derotation screw: Introduced in the mid-20th century, providing better stability for femoral neck fractures. For many years, the DHS implant was a workhorse implant for intertrochanteric hip fractures, which works on the principle of controlled collapse. However, DHS also helps to fix the neck of femur fractures and helps to achieve some compression at the neck of femur fractures. Derotation screw helps to achieve more rotational stability (Fig. 4).
- CC screws (CCS): These became the standard for treating femoral neck fractures due to their minimally invasive nature

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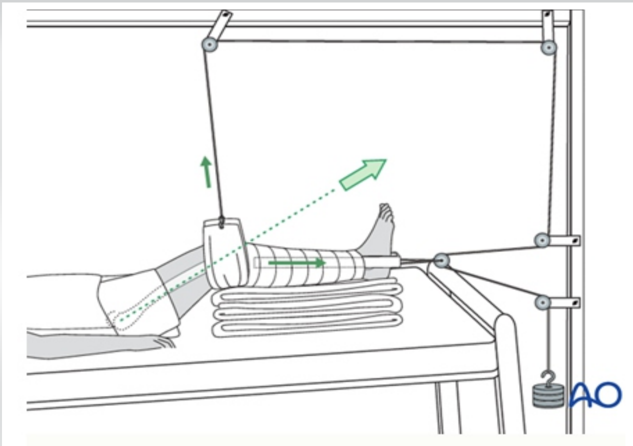

**Figure 1:** Traction was applied to Balkan's frame to align the proximal fractures of the femur.

**Figure 2:** Garden screw. **Figure 3:** Smith Peterson nail

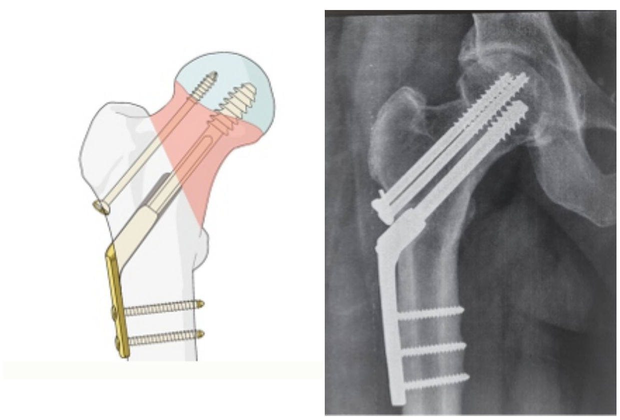

**Figure 4:** Dynamic hip screw with derotation screw fixation schematic diagram and xray.

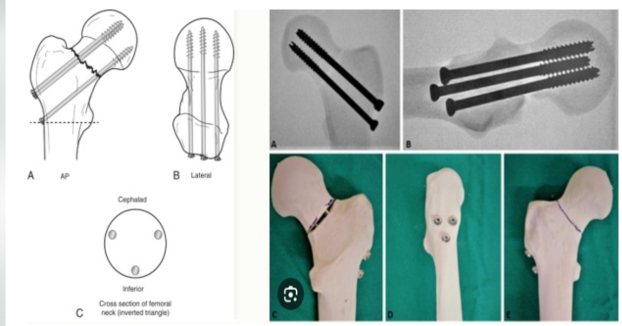


**Figure 5:** Cancellous cannulated screws- recommended position of screws.

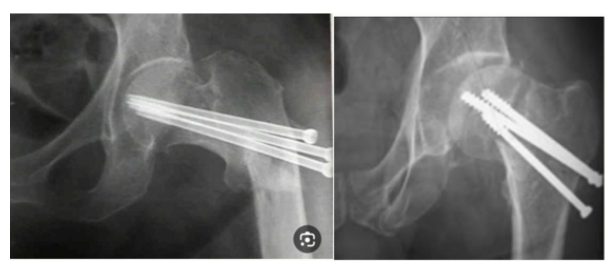

**Figure 6:** Cancellous cannulated screws- varus collapse.


**Figure 7:** Diagram and X-ray of the FNS showing its components.

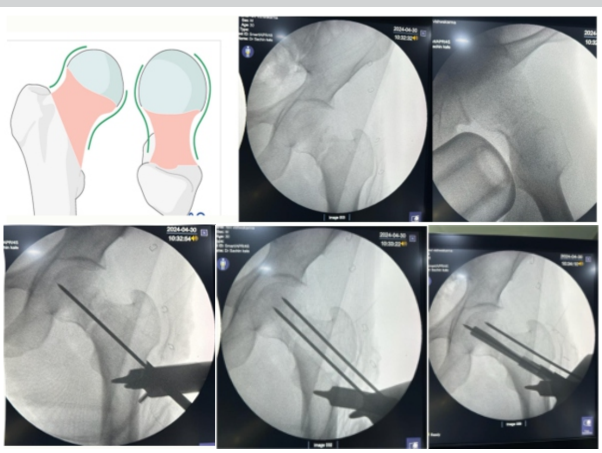

**Figure 8:** Correct reduction of femoral neck fractures is paramount for good outcomes.

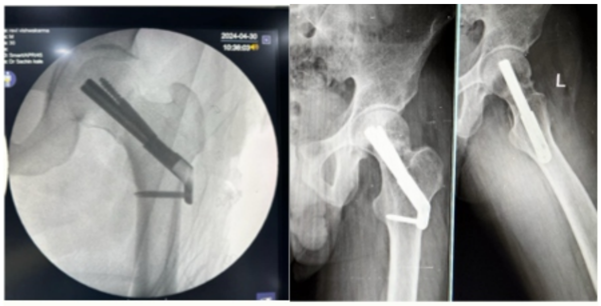


**Figure 9:** Final immediate post-operative xray of FNS fixation.

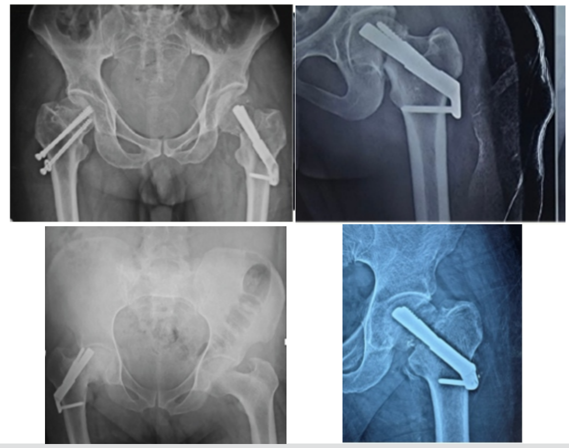

**Figure 10:** Shows cases of FNS failure with screw cut-out with varus collapse.


**Figure 11:** FNS with additional derotation screw helps to improve the stability of the construct.

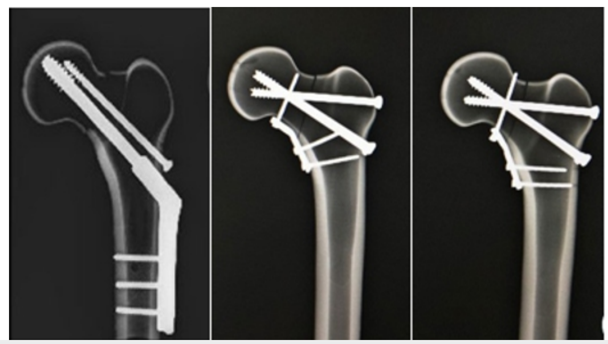

**Figure 12:** Radiographs with modifications to conventional fixation modalities: Dynamic Hip Screw with Derotation Screw, Cannulated Screws with a Contoured Conventional Medial Plate, and Cannulated Screws with a Contoured Medial Locking Plate. Courtesy - Zanardi et al (https://doi.org/10.31579/2694-0248/019)

and ease of use. However, accurate reduction is the key to a successful outcome (Fig. 5).

## Limitations of CC (Cancellous cannulated) screws

CCS, while effective in many cases, have limitations, especially in unstable fractures or patients with poor bone quality (e.g. osteoporosis). These limitations include:

- Rotational instability: Particularly problematic in high-angle fractures (Pauwels Type III), leading to a higher risk of non-union (Fig. 6).
- Lack of dynamic compression: Static fixation can lead to insufficient compression, increasing the likelihood of implant failure.
- Higher rates of screw cut-out: Particularly in osteoporotic bone, leading to revision surgeries.

## The Advent of the FNS: A Game Changer in Fracture Management

### Design and components of the FNS

To address the challenges associated with CCS, the FNS was developed. The FNS combines the benefits of dynamic compression with enhanced rotational stability, making it a versatile option for managing both stable and unstable femoral neck fractures.

- Key components:
- Femoral neck bolt: A large, central load-bearing screw that provides stability
- Anti-rotation screw: Positioned at an angle to prevent rotational movement
- One/two hole plate: Minimizes lateral protrusion and reduces soft tissue irritation (Fig. 7).

The unique biomechanical design allows controlled collapse at the fracture site, which promotes bone healing while maintaining alignment under weight-bearing conditions.

The FNS system benefits from a minimally invasive approach

Pearls: Reduction is of paramount importance. If the closed reduction is not satisfactory, there should be no hesitation in opening up the fracture site. Insert an additional guidewire to maintain reduction while reaming (Fig. 8).

Finally, the barrel plate and derotation screws improve the

**Table 1: Comparative analysis of various implant designs for femoral neck fractures**

| Fixation method | Strengths | Limitations | Complication rates |
|---|---|---|---|
| Dynamic hip screw with De rotation screw | Good biomechanical stability, early mobilization | In High neck femur fracture Limited rotational stability, implant cut-out risk | Non-union: 5–15%, AVN: 5–15% |
| Cannulated screws | Precise fixation preserves bone stock | Inadequate strength in unstable fractures Implant back out common | Non-union: 10–20%, AVN: 10–20% |
| Femoral neck system | Superior rotational stability, minimally invasive | Limited long-term data Newer Implant learning curve | Non-union: 5–10% (preliminary) |

rotational stability of the FNS implant (Fig. 9).

## Comparative Analysis of Fixation Methods

### Comparative Analysis: FNS versus CCS (Table 1)

### Advantages of FNS over CCS

1. Rotational stability:
• The FNS system significantly reduces the risk of rotational instability through its anti-rotation screw, which locks with the femoral neck bolt, forming a single stable construct.
• In contrast, CCS often fail to prevent rotation in high-angle fractures, leading to non-union.
2. Controlled dynamic compression:
• Unlike the static fixation of CCS, the FNS provides controlled dynamic compression. This feature allows for slight axial collapse, which enhances bone healing by maintaining compression at the fracture site.
3. Minimally invasive approach:
• The FNS requires a smaller incision and fewer components, reducing surgical trauma, preserving soft tissues, and leading to faster recovery.
4. Reduced implant back out/cut-out:
• The larger central femoral neck bolt provides better purchase in osteoporotic bone compared to the smaller CCS, reducing the risk of screw Back out /cut-out (Fig. 10).

### Clinical outcomes and success rates

Studies have shown that FNS has a lower incidence of complications compared to CCS, particularly in elderly patients with osteoporotic bones:
• Non-union rates: 5–10% with FNS compared to 10–20% with CCS
• AVN incidence: Reduced due to better preservation of the femoral head blood supply with FNS
• Revision surgeries: Fewer revisions are required due to the FNS system's enhanced stability.

### Challenges and limitations of the FNS

1.Learning curve:
• The FNS requires specialized training for optimal use. Surgeons accustomed to CCS may find the technique challenging initially, particularly in terms of precise guidewire placement and component assembly.
2. Higher initial costs:
• The FNS system is more expensive than CCS, which may limit its use in settings with budget constraints. However, the reduced need for revision surgeries can offset these costs.
3. Limited long-term data:
• Although short-term studies have shown promising results, more long-term data are needed to fully establish the FNS's superiority over CCS in various patient populations.

## Biomechanical perspectives about the design of fixations based on femoral neck morphologies

Based on the studies done by finite element analysis on biomechanical models, Wang et al. in 2023 article showed that for Pauwels type I fractures (<30°), reduce the number of CCS utilized for fixation. The study discovered that employing a single CCS to treat this sort of fracture can still fulfill the biomechanical parameters for healing.
Porous tantalum screws (PTS) are an alternative to CCS for Pauwels type I fractures. The study indicated that PTS had similar fixation results as two CCS while decreasing injury to the femoral head's blood supply.
Continue to suggest three CCS for Pauwels type II fractures (30°–50°). While the study indicated that utilizing two CCS or PTS may offer adequate fixation for this fracture type, more clinical testing is required.
For Pauwels type III fractures (>50°), implant a medial buttress plate (MBP) to the medial femoral neck beside two CCS. The study discovered that the MBP helps to disperse the load on the CCS and creates a more stable biomechanical environment for fracture recovery.
To prevent injury to the inferior retinacular artery (IRA), employ a modified anterior approach while putting the MBP. The IRA is vital for femoral head perfusion, and damage to it can cause surgical problems.

## Future Perspectives and Innovations

Additional tip- Inserting a superior derotations crew along with FNS helps to implore the fixation construct according to the surgeon (Fig. 11). Other novel fixation techniques, such as DHS with derotation screw and medial plate on femoral neck region with cancellous cannulated screws have been proposed (Fig.

12). Long terms outcomes are yet to be studied on these fixation techniques.

### Robot-assisted surgeries

Advances in robotic systems are likely to significantly impact femoral neck fracture management in the future. Robotic assistance can enhance the precision of guidewire placement and implant insertion, reducing the risk of mal-alignment and complications.

- Benefits of robotic assistance:
- Increased accuracy in implant positioning.
- Reduced operative time and radiation exposure.
- Enhanced outcomes in complex fracture patterns.

### Personalized implants using artificial intelligence (AI) and 3D printing

The future of femoral neck fracture management may involve the use of patient-specific implants designed using AI and 3D printing technology. These implants can be tailored to each patient's unique anatomy, ensuring better fit, stability, and outcomes.

- Potential benefits:
- Reduced risk of non-union and AVN.
- Faster recovery times with fewer complications.
- Enhanced patient satisfaction due to personalized treatment.

### Augmentation techniques

In patients with severe osteoporosis, bone augmentation techniques, such as cementing around the implant, can improve fixation stability and reduce the risk of implant failure.

### Conclusion

The evolution of the FNS represents a significant advancement in managing femoral neck fractures. By combining dynamic compression, rotational stability, and a minimally invasive approach, the FNS offers a superior alternative to traditional CCS, especially in unstable fractures, and offers early weight bearing and mobilization.

Integrating robotics, AI, and personalized implants will likely become the new frontier in fracture management as technology advances. These innovations promise to improve patient outcomes, reduce complications, and ultimately enhance the quality of life for individuals suffering from femoral neck fractures.

**Declaration of patient consent:** The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient has given his consent for his images and other clinical information to be reported in the Journal. The patient understands that his name and initials will not be published, and due efforts will be made to conceal his identity, but anonymity cannot be guaranteed.

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