Narrative Review

THE CHOICE OF FEMORAL STEM IN THE PROXIMAL FEMORAL FRACTURE

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ABSTRACT

Proximal femoral fractures are common in elderly patients and are associated with significant morbidity and healthcare costs. Hip arthroplasty, including hemiarthroplasty and total hip arthroplasty, is a standard treatment for displaced femoral neck fractures, particularly in older adults. A critical aspect of these procedures is the selection of the femoral stem, which influences early mobility recovery and long-term implant outcomes. This review discusses the key considerations in femoral stem selection, including cemented versus cementless fixation, stem geometry, material composition, and modularity. Cemented stems are favored in elderly patients with osteoporotic bone due to their ability to provide immediate mechanical stability. In contrast, cementless stems are preferred in younger patients due to their potential for long-term biological fixation through osseointegration. Modular stems offer intraoperative flexibility but present a higher risk of mechanical complications. Femoral stem selection should be tailored to the patient's age, bone quality, and functional demands to minimize complications and optimize clinical outcomes.

KEYWORDS: *proximal femoral fractures, arthroplasty, hemiarthroplasty, total hip arthroplasty, stem*

INTRODUCTION

Proximal femoral fractures are among the most prevalent injuries encountered in the orthopedic field, especially in patients above 50 years old. The incidence of these fractures is 2-3 times higher in females compared to the male population (1). These fractures often result from low-energy trauma, such as a fall from a standing height, although can also occur due to high-energy trauma, especially in younger male individuals. Given the growth of the elderly population globally, the incidence of proximal femoral fractures, particularly hip fractures, continues to rise, contributing significantly to morbidity, mortality, and healthcare costs (2).

Various techniques and implants have been described to assist the management of proximal femoral fractures, with the primary goal of restoring function and mobility as quickly and safely as possible while minimizing complications and the need for reoperation.

Hip arthroplasty, either as hemiarthroplasty (HA) or total hip arthroplasty (THA), is the standard treatment for medial displaced femoral neck fractures (Garden type 3-4) among the elderly population. It has been demonstrated to promote quick mobilization and satisfactory long-term outcomes (3). The selection of the appropriate femoral stem is a

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key aspect of this decision-making process, impacting both short-term outcomes, such as mobility recovery, and long-term consequences, such as implant survival and the risk of revision surgery (4).

Since this type of fracture primarily affects the elderly population, on the one hand, HA is indicated for very old patients due to poor bone quality and frailty; on the other hand, THA provides a reliable option for individuals with medial neck fractures who have painful hip osteoarthritis.

Internal fixation with cannulated screws or sliding hip screws is recommended in medial partial fractures or minimally valgus displaced fractures (Garden type 1 and 2) affecting young individuals with no signs of hip osteoarthritis (5). Delayed fracture treatment (more than 24-48 hours) should be treated with THA for compromise of the blood supply of the femoral head (6). A delayed internal fixation of medial fractures may lead to nonunion or avascular necrosis (5, 6). The choice of femoral stem approaching hip arthroplasty in medial femoral fractures is crucial.

This narrative review discusses the various femoral stem options available for treating proximal femoral fractures, their advantages and disadvantages, and the clinical implications of selecting the optimal stem for different patient populations.

Classification of femoral stems

The classification of femoral stems is key in determining the most suitable implant for a given patient. The classification system proposed by Radaelli et al. (7) describes 3 relevant characteristics of the femoral stem: geometry, location of modularity, and length. Each feature has significant implications for the surgical approach, postoperative recovery, and long-term outcomes.

The choice of femoral stem is especially important in the context of femoral fractures, where the condition of the surrounding bone and the patient's ability to bear weight postoperatively must be carefully considered. Stems are further classified by their method of fixation.

Cementless femoral stems rely on 3 key principles: achieving primary stability, facilitating mid-term biological fixation through osseointegration (bone growth occurs on the porous surface of the stem), and ensuring balanced femoral stress distribution for long-term survivorship. Most cementless femoral stems are made of either titanium aluminum vanadium alloy or cobalt-chrome molybdenum alloy.

In a randomized controlled trial, Healy et al. (8) demonstrated that titanium stems are associated with lower rates of stress shielding, reducing bone resorption around the implant. However, there is no significant correlation between titanium stem and thigh pain or functional outcomes.

Titanium alloy's biocompatibility and its lower modulus of elasticity play a key role in promoting osteoinduction, osteoconduction, and oxygenation (9). In contrast, among the cobalt-chrome stems, there is a high risk of loosening and implant failure (8). Stainless steel, though available, is less commonly used due to its lower biocompatibility and susceptibility to corrosion (7-9). Radaelli cementless classification system (7) (Fig. 1) identifies 6 primary stem geometries and subtypes:

- <u>Type A</u>: flat taper – fixation achieved through medial to lateral metaphyseal cortical bone engagement and by 3-point fixation along the stem's length;
- <u>Type B:</u> quadrangular tapers – fixation is obtained by filling the metaphyseal and proximal diaphysis in the coronal plane, with enhanced filling in the sagittal plane. This provides a more uniform load transfer on proximal cortical bone and high torsion stability;
- <u>Type C:</u> fit-and-fill – archives rotational stability through the complete filling of the metaphyseal canal and close engagement with the femoral cortex both proximally and distally;
- <u>Type D:</u> conical – short conical stems are designed for cases with abnormal proximal femoral morphology, such as development dysplasia of the hip or high valgus femoral necks. The fixation and rotational stability are reached at the level of the lesser trochanter. Short conical stems are typically monoblock, even if there has been a recent resurgence in the use of long monoblock, which is relatively simple to implant and avoid modularity complications;
- <u>Type E</u>: cylindrical - features a circular cross-section and aims for full diaphyseal engagement;
- <u>Type F</u>: calcar-guided short stems – designed to preserve bone stock and to restore physiological biomechanisms, resembling flat-wedge stems but they are smaller with a pronounced medial curve.

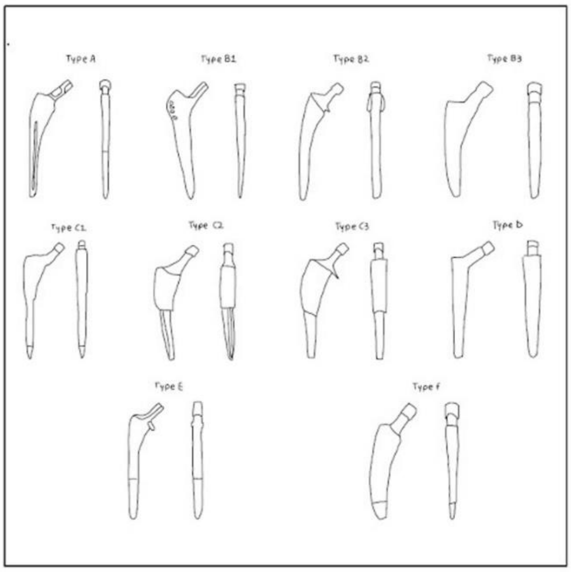

Fig. 1. *Schematic drawing representing Radaelli cementless classification according to femoral stem geometry.*

Anatomical femoral stems

Anatomical femoral stems are designed to closely mimic the natural anatomy of the femur closely, replicating its natural curvature. They are typically selected when preserving the natural biomechanics of the hip (10). Their anatomical shape promotes improved load transfer and alignment, resulting in a more physiological distribution of torsional forces. These stems are shaped to match the unique geometry of an individual's proximal femur, aiming to provide better fit and load distribution by replicating the natural curvature and contours of the femoral canal. Differing from straight or conventional femoral stems, anatomical stems often feature specific angulations and offsets that accommodate individual variations in femoral anatomy, such as femoral anteversion and medullary canal shape (10).

Anatomical femoral stems adapt proximal geometry with a curvature mimicking the natural anatomy of the metaphyseal region of the proximal femur. These stems provide excellent offset adjustment, improving stability and biomechanics, and distribute loads more naturally along the femoral canal, reducing stress shielding. The anatomical design aims to improve patient outcomes by reducing complications associated with implant misalignment and promoting better functional results (Fig. 2).

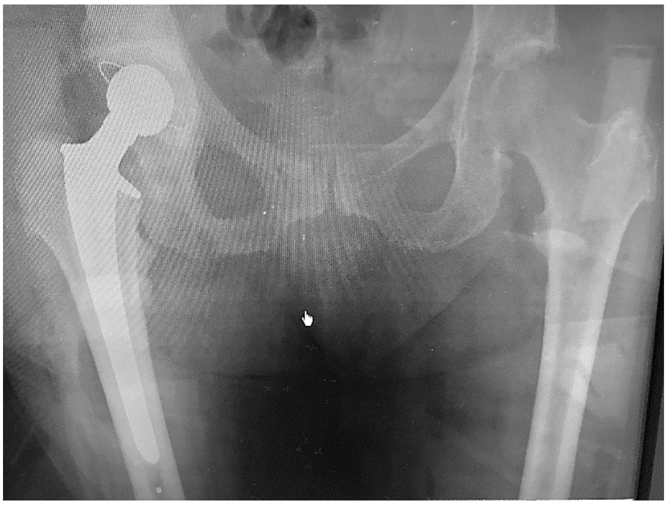

Fig. 2. *Post-operative X-ray of 80-year-old female patients after cemented THA with anatomical Lubinus II (Link, Hamburg, Germany) femoral stem for proximal femoral fracture.*

Monoblock versus modular stems

The choice between monoblock and modular stems can impact the surgical approach and the patient outcomes.

Monoblock stems, made of a single solid piece, reduce the risk of fretting and micromotion at the junctions but restrict the surgeon's ability to make intraoperative adjustments. In contrast, modular stems provide surgeons greater flexibility during implantation, offering customizable options for length and version and providing greater intraoperative adaptability. However, they may be more susceptible to mechanical issues such as modular devices, intraoperative fractures, modular junction fatigue fractures, corrosion, and higher implant costs (11).

Modular stems are seldom utilized to manage proximal femoral fractures but are particularly useful in revision or complex cases (Fig. 3).

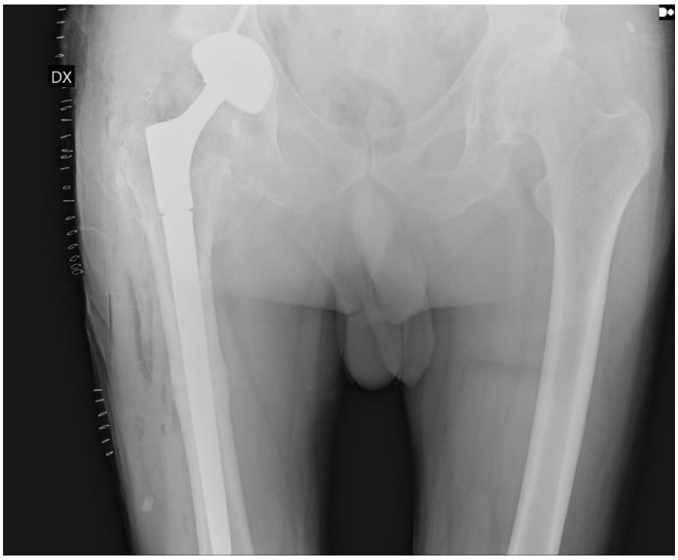

Fig. 3. *Post-operative X-ray of a 78-year-old patient who sustained displaced proximal femoral fracture 2 years after nailing of the proximal femur. Modular Lima revision stem (Lima Corporate, Villanova di San Daniele del Friuli, Udine, Italy) was chosen to manage proximal femoral weakening after nailing.*

Modular and monoblock stems in the revision setting showed similar re-revision rates and Harris Hip Scores for hip function. The intraoperative fracture rate was significantly higher with modular stems (11.6%) than monoblock stems (5.0%). Subsidence more significant than 10 mm occurred more frequently in the monoblock group. The application of extended trochanteric osteotomy was more popular in monoblock stems (22.7% vs 17.5%, $P = 0.003$). The incidence of postoperative complications, such as periprosthetic femoral fracture and dislocation, was similar between both stems. Overall, postoperative hip function and survivorship were similar between the modular and nonmodular groups (12).

Modular stems

Regarding stem modularity**,** femoral components have been designed to optimize limb-length equalization, femoral offset, femoral anteversion, impingement-free ROM, and soft tissue tension.

An increased femoral offset (perpendicular distance between the center of the femoral head and a line drawn down the center of the femoral shaft) has been shown to reduce the hip abductor force and hip reaction force without significantly impacting bone strains. Studies show no significant radiographic differences between increased- and standard-offset components, making the increased-offset approach a valuable option in improving hip joint mechanics without adverse effects on stability or bone integration. These biomechanical studies support using an increased-offset femoral component with cementless fixation (13). Common forms of modularity include head modularity, neck modularity, and subtrochanteric modularity.

- Head modularity allows for attaching different diameters and neck lengths to any given stem size or geometry. However, this type of modularity is associated with a higher risk of mechanical issues, such as dislocation, reduction, taper fracture, and corrosion;
- Neck modularity enables the adjustment of limb length and offset independently of stem size after fixation has been completed;
- Subthorcantheric modularity involves cylindrical or conical stems designed to achieve diaphyseal fixation. Most implant fractures occur at the junction between the osseointegrated distal and nonintegrated proximal parts. Bush et al. (14) recommended using longer proximal components to improve load transfer and reduce junctional strain. Notably, nonmodular stem fractures usually happen at the subtrochanteric level.

Stem length

Stem length plays a critical role in the final selection of femoral components. A short femoral stem is a type of hip implant shorter than traditional femoral stems ($\leq$ 120 mm). These stems are designed to preserve more bone in the proximal femur by occupying less space in the femoral canal. They aim to support a less invasive approach and allow for improved bone preservation, which can benefit younger or more active patients who may require future hip revisions (15). The short design is favorable for a minimally invasive approach and is well suited for a direct anterior approach in THA (16). The short stems reduce stress shielding, maintain a natural loading pattern, and promote patient recovery by reducing bone removal and trauma. They are especially suitable for younger or highly active patients and are increasingly utilized in modern hip replacement surgeries to enhance long-term outcomes and potential revision options (17).

The use of short stems in proximal femoral fractures is controversial. It should be limited to selected cases, such as younger patients with good bone quality, the integrity of the calcar region, and high functional demand (18) (Fig. 4).

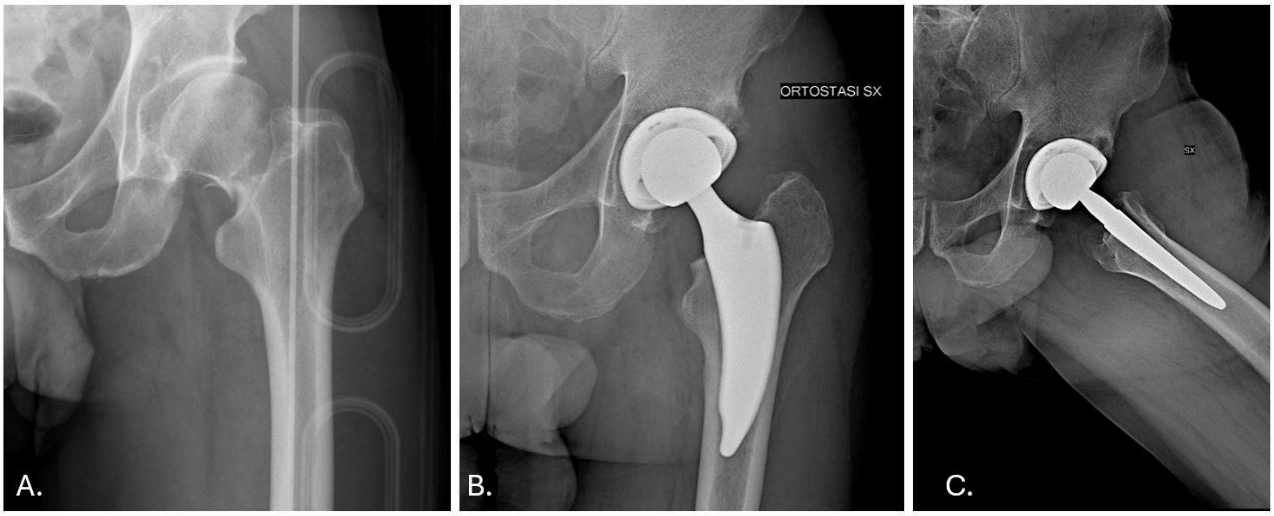

Fig. 4. *Preoperative X-ray of a 58-year-old man sustaining displaced medial proximal femoral fracture (**A**) 3 months anteroposterior (**B**) and axial (**C**) view after THA with Minima S short stem and Delta TT cup (Lima Corporate, Villanova di San Daniele del Friuli, Udine, Italy).*

Cemented versus cementless stems

Cemented femoral stems use bone cement (typically polymethylmethacrylate or PMMA) to secure the implant. This type of stem is often favored in elderly patients with poor bone quality, as the cement helps create a stable and immediate fixation. Cemented stems can also provide immediate weight-bearing capacity, which benefits patients with limited mobility. However, concerns have been raised about the potential for long-term complications with cemented stems, including cement fatigue and potential loosening over time. Furthermore, patients who underwent cemented fixation for proximal femoral fracture demonstrated significantly increased perioperative mortality, raising potential concerns about cementation in severely ill patients (19). Mabrouk et al. compared Polished Taper Slip (PTS) stems with composite beam (CB) stems, revealing a significantly higher risk of fracture in patients with underlying comorbidities who received PTS stems (RR:9.9; $p<0.001$) (20).

Cemented and cementless femoral stems each have several advantages and disadvantages. Cemented stems provide immediate stability, mainly among the elderly population with poor bone quality and lower complication rates, including reduced incidences of dislocation, loosening, and periprosthetic fractures. Additionally, cemented stems generally have lower revision rates (Fig. 5).

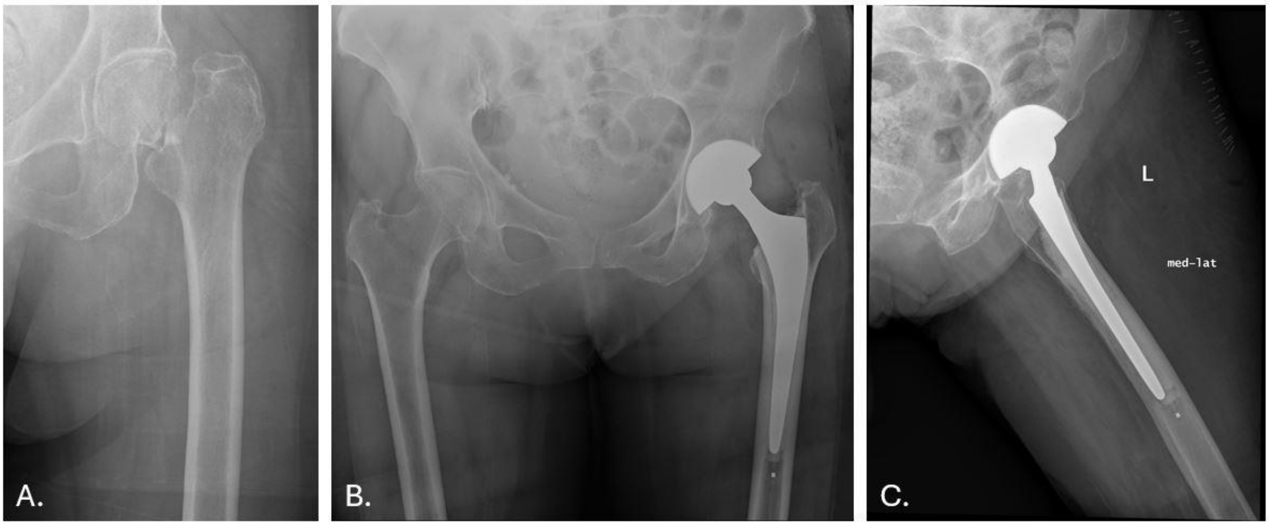

Fig. 5. *Preoperative X-ray of an 81-year-old female patient sustaining displaced medial proximal femoral fracture (**A**). Post-operative anteroposterior (**B**) and axial (**C**) view after cemented stem and uncemented cup THA with H-Max stem and Delta TT dual mobility cup (Lima Corporate, Villanova di San Daniele del Friuli, Udine, Italy).*

However, cement-related complications, such as embolism and cardiovascular risks, can occur, and the procedure typically involves longer operative time and more blood loss (20). On the other hand, cementless femoral stems offer the advantage of shorter operative times and less intraoperative blood loss, as well as eliminating the risks associated with bone cement. However, cementless stems carry a higher risk of early complications, such as dislocation, periprosthetic fractures, and loosening, particularly in elderly patients (20).

Overall, the choice between cemented and cementless stems depends on patient-specific factors such as age, bone quality, and the risk of complications(21) (Fig. 6).

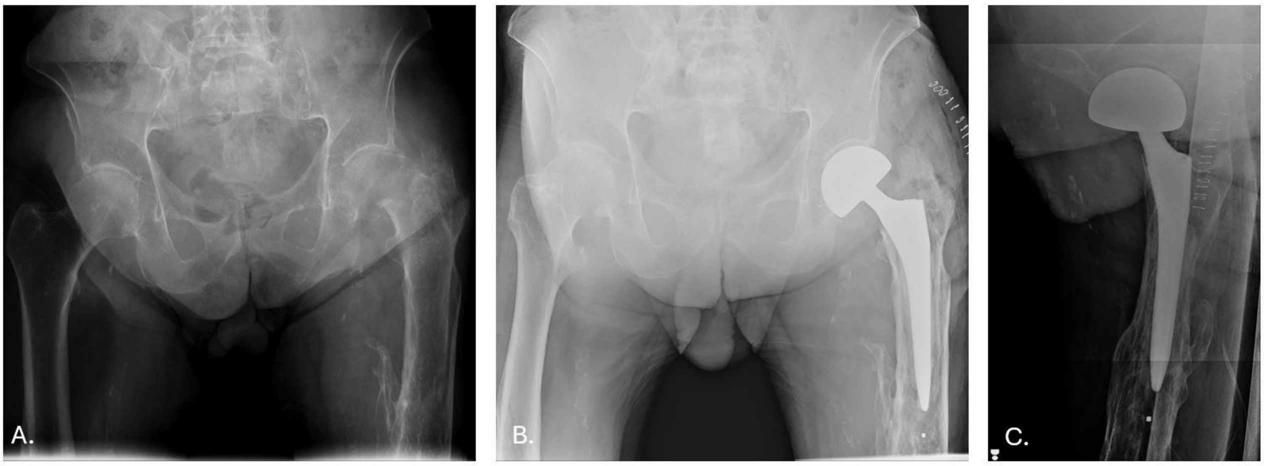

Fig. 6. *Preoperative X-ray of an 85-year-old male patient sustaining a displaced medial proximal femoral fracture in a previously healed shaft femoral fracture (A). The widening of the femoral canal, poor bone quality, and dysmorphic changes in femoral anatomy recommended a cemented stem. Post-operative anteroposterior (B) and axial (C) view after cemented HA with H-Max stem and bipolar head (Lima Corporate, Villanova di San Daniele del Friuli, Udine, Italy).*

Femoral stem in the treatment of proximal femoral fractures

When considering femoral stem selection in treating proximal femoral fractures, the surgeon must consider multiple factors, including the patient's age, bone quality, fracture pattern, and functional status (19-21). Proximal femoral fractures are more common in elderly individuals, many of whom present with osteoporosis. This poor bone quality often guides the decision toward cemented femoral stems, which provide immediate mechanical stability even in compromised bone conditions. Additionally, the high prevalence of comorbidities in this patient group necessitates a treatment strategy that allows for early mobilization to prevent complications such as deep vein thrombosis, pulmonary embolism, and pressure ulcers (22).

In younger patients with better bone quality, cementless femoral stems may be preferable due to the potential for biological fixation (20). The ability of the bone to grow into the implant provides long-term stability without the potential for cement-related complications. However, the surgeon must be mindful of the patient's activity level and expected functional demands. A younger, more active patient may place higher mechanical loads on the implant, necessitating a stem that can withstand these forces over an extended period (23).

The choice of stem length is also an important consideration. Standard-length stems are commonly used in hip arthroplasty procedures, but short stems are gaining popularity, especially in the context of femoral neck fractures (24). Short stems preserve more bone stock and may reduce the risk of periprosthetic fractures, a significant concern in elderly patients with osteoporotic bone. These stems are associated with less stress shielding and improved load transfer to the proximal femur, which may enhance functional outcomes. On the other hand, short stems require expert surgeons and younger patients with good bone quality and integrity in the calcar region, representing a reliable solution limited to selected cases. Long stems may be indicated in cases of extensive femoral damage or revision surgery, where additional support and fixation are required (25).

For patients with severe femoral fractures, including comminuted or highly displaced fractures, modular stems may offer a solution due to their versatility (26). The ability to adjust length and version intraoperatively allows the surgeon to optimize the fit of the implant and ensure proper alignment, which is critical for restoring function and reducing postoperative complications. However, using modular stems may increase the risk of mechanical complications, including stem loosening and junctional failure, particularly in patients with high physical activity levels.

Biomechanical considerations

The biomechanical properties of femoral stems are fundamental to their function and long-term success. Ideally, the stem should allow for physiological load transfer, minimizing stress shielding and promoting healthy bone remodeling.

Stress shielding refers to the reduction of bone density that occurs when the bone's mechanical load is transferred to the implant rather than being borne by the bone itself. This can ultimately result in the loosening of the implant and the need for revision surgery (27). The geometry, stiffness, and material of the stem significantly affect the load distribution between the femur and the implant.

Generally, titanium alloys are used for the femoral stems due to their lightweight, corrosion-resistant, and biocompatibility (28, 29). These alloys offer good dynamic mechanical strength and high success rates (30).

The prosthesis, when inserted, transfers the load from the femoral head and acetabular cavity at the hip to the prosthesis itself (31-33). This can affect the biomechanics of the joint and the surrounding bone. In particular, the stress applied to the bone may promote its physiological remodeling (34, 35).

When a prosthesis is introduced into the bone, the distribution of loads is altered, causing the atrophic bone to form in unloaded areas and denser bone in overloaded areas. This results from the different stiffnesses between the bone and the prosthetic materials, with metals having a higher stiffness, leading to stress shielding. To mitigate the effects of stress shielding, it is pivotal to design prostheses that better mimic the biomechanical properties of natural bone and allow for a more even distribution of mechanical load on the surrounding bone.

Tapered stems**,** for example, have been shown to offer more gradual force distribution, which can reduce the risk of stress shielding. These stems are designed to distribute stress more evenly across the proximal femur. They engage the proximal femoral bone more effectively, reducing the stress shielding risk and promoting better bone preservation. This design transfers less load to the distal femur and minimizes bone resorption in the proximal femur (36, 37).

In contrast, cylindrical stems tend to transmit more load to the distal portion of the femur, leading to higher rates of stress shielding in the proximal region. These stems often rely on distal fixation, which can exacerbate bone loss in the proximal femur over time. This design was more common in early prosthesis models. Another biomechanical consideration is the rotational stability of the implant, which is crucial for preventing implant loosening and ensuring long-term success.

Cemented femoral stems provide excellent rotational stability due to the rigid fixation achieved by the cement mantle. Acting as an intermediary between the stem and the bone, the cement fills irregularities, effectively preventing rotational and axial micromotions immediately after surgery. This solid fixation ensures strong short-term stability, which is crucial to avoid early implant loosening. However, the cement can degrade or weaken over time, especially in younger and active patients, leading to limited rotational stability and an increased risk of aseptic loosening.

In contrast, uncemented stems rely on achieving rotational stability through osseointegration, where bone tissue grows into or onto the stem surface, providing long-term biological fixation. Initially, these stems may exhibit more micromotion since they rely on a press-fit fixation, dependent on the mechanical friction between the implant and bone.

This can pose a risk of rotational instability until osseointegration is fully achieved. However, once bone growth secures the stem, uncemented implants offer superior long-term rotational stability, particularly with tapered or porous-coated designs that improve load distribution and bone-implant contact (38, 39).

Uncemented stems are typically favored for younger patients or those with good bone quality due to their long-term stability and lower risk of loosening over time. However, for patients with poor bone quality, the early stages of fixation can present challenges, as initial micromotion may lead to early implant failure.

Clinical outcomes and complications

Several clinical studies have examined the outcomes of different femoral stems in treating proximal femoral fractures, focusing on cemented versus uncemented designs. Cemented femoral stems are often recommended in elderly patients with osteoporotic bone because they provide immediate stability, reducing early postoperative complications such as implant loosening and dislocation. This is particularly important for older patients, as early mobilization and weight-bearing are crucial to avoid complications like bedrest-related issues or thrombosis (40). However, the long-term performance of cemented stems can be compromised due to cement fatigue, particularly in younger and active patients. Over time, the cement can degrade, increasing the risk of implant loosening.

In the study by Joshi et al. (41) on the long-term results of Charnley low-friction arthroplasty in young patients, cemented femoral stem failure in younger individuals was primarily attributed to cement fatigue and mechanical failure. Young and active patients typically place higher mechanical stresses on the implant and the surrounding cement mantle, which can lead to early degradation of the cement. Over time, this can result in loosening of the prosthesis. Additionally, the study highlights that the higher levels of activity in younger patients accelerate the wear and tear of both the implant and the cement, leading to higher failure rates compared to older, less active populations. The bone remodeling response also differs in younger patients, contributing to the risk of failure.

On the other hand, uncemented stems, which rely on biological fixation through osseointegration, tend to perform better in the long term in younger patients with good bone quality.

In the study by Flecher et al. (42), the authors highlight several reasons why cementless stems are preferred for hip arthroplasty in young patients. First, cementless stems facilitate osseointegration, allowing bone to grow into the implant, which provides a strong and durable fixation. Additionally, cementless designs typically have a lower modulus of elasticity, closely mimicking natural bone and reducing the risk of stress shielding. This characteristic promotes healthier bone remodeling and helps maintain long-term bone quality.

Periprosthetic fractures are a significant concern, particularly with uncemented stems, as inadequate initial fixation can lead to weakened bone around the implant and an increased fracture risk. Cemented stems, by contrast, distribute the load more evenly along the femur, potentially reducing this risk.

Edelstein et al. (43) analyzed a national Medicare sample and found that cementation of the femoral component can affect fracture and mortality risk. Their findings suggest that while cemented stems provide immediate stability, which may reduce the likelihood of periprosthetic fractures, they can still be associated with specific risks, particularly in the elderly with lower bone quality.

Conversely, Fleischman and Chen (44) discuss how uncemented stems are often linked to a higher incidence of periprosthetic fractures, especially if adequate initial fixation is not achieved. These fractures can occur due to insufficient bone support or excessive mechanical stress on the implant. The authors emphasize that careful surgical technique and considerations of bone quality and implant design are essential to minimize these risks. An alternative potential complication is implant loosening, which can occur with cemented and uncemented stems. Loosening can occur due to various factors, including poor initial fixation, bone quality, and mechanical stresses on the implant.

For cemented stems, loosening often results from cement degradation over time. The cement may fail to maintain a secure bond between the implant and the bone, leading to micromotion that compromises stability and can precipitate fractures. In the case of uncemented stems, loosening is primarily linked to inadequate osseointegration. If the bone fails to integrate with the stem properly, the implant may not achieve the necessary stability, increasing the risk of periprosthetic fractures (45).

Factors such as surgical technique, implant design, and patient factors like bone quality and activity levels are crucial in determining the likelihood of loosening. Dislocation is another complication that may occur following femoral stem implantation. Several factors, including implant design, surgical technique, and individual patient characteristics, influence the risk of dislocation.

The design of the femoral stem is critical; modular stems, for instance, allow for intraoperative adjustments that can optimize fit and alignment, thereby enhancing stability. These designs enable surgeons to tailor the components to the patient's anatomy, which can significantly reduce dislocation risk. Conversely, poorly designed stems or those with inadequate neck length may compromise stability and range of motion, increasing the likelihood of dislocation (46).

Surgical technique also plays an important role. Precise alignment and positioning of the femoral stem and acetabular component are essential for maintaining joint stability. Surgeons must carefully balance the surrounding soft tissues to avoid excessive tension or laxity, which can lead to instability and increase dislocation risk postoperatively (47).

Patient-specific factors further contribute to the risk. Muscle strength, coordination, and overall health significantly influence a patient's ability to stabilize the hip joint, especially during weight-bearing activities. Older patients or those with conditions such as obesity or neurological disorders may be particularly vulnerable to dislocation due to weaker musculature and impaired proprioception.

Finally, effective postoperative management is crucial for minimizing dislocation risk. Early mobilization, appropriate physical therapy, and patient education on hip precautions can strengthen surrounding musculature and enhance coordination.

CONCLUSIONS

The selection of the appropriate femoral stem for treating proximal femoral fractures is a complex decision that necessitates careful consideration of various factors, including patient characteristics, bone quality, fracture type, and the specific attributes of the implants. Cemented stems provide immediate stability and are particularly advantageous for elderly patients with compromised bone quality, ensuring a secure fit from the outset. In contrast, uncemented stems facilitate long-term biological fixation, making them a preferred choice for younger, more active individuals who require greater durability and resistance to wear.

The geometry and material composition of the femoral stem and the decision to use monoblock versus modular designs significantly influence the procedure's success. Key biomechanical factors, such as stress shielding, rotational stability, and load distribution, must be meticulously evaluated to minimize potential complications and enhance clinical outcomes.

In conclusion, the choice of the femoral stem should be individualized based on the specific needs of the patient and the characteristics of the fracture. A comprehensive understanding of the available stem options and their respective advantages and disadvantages is essential for obtaining optimal results in treating proximal femoral fractures.

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Conflict of interest statement

The authors have no conflicts of interest to disclose.

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