Kenneth A. Egol
Philipp Leucht *Editors*

# Proximal Femur Fractures

## An Evidence-Based Approach to Evaluation and Management

Springer

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*This book is dedicated to my family, Lori, Alex, Jonathan, and Gabby, for their unending support and to all those who dedicate themselves to be better physicians and surgeons*

Kenneth A. Egol, MD

*To my wife Alesha and our son Finn for their never-ending support and love and for bringing joy and balance to my life*

Philipp Leucht, MD

# Foreword

I began studying hip fractures in the late 1950s leading to my doctoral thesis focused on the forces required to cause fractures about the proximal femur. I am excited to know that fractures of the hip remain a critically important topic in orthopedic surgery and education. The significant and increasing number of hip fractures that occur each year makes them a common problem treated by the majority of practicing orthopedic surgeons and an ever-increasing public health concern. In this important context, the timing of this publication is spot on. The editors, Drs. Egol and Leucht, have assembled an international panel of experts in hip fracture care to write the chapters of this text. The book is organized into thirteen well-written chapters encompassing all fracture types, anatomical and biomechanical considerations as well as complications and expected outcomes.

Dr. Egol and Dr. Leucht are busy academic orthopedic trauma surgeons, who have dedicated themselves to patient care, education, and musculoskeletal research. Working at one of the largest academic centers for orthopedic care, they provide much needed fracture care services for New York City's underserved populations and train residents and fellows in the nation's largest orthopedic surgery training program. The contributors to this book have devoted many years to practice and the study of fractures of the proximal femur, thereby sharing their expertise to all who read the text and the patients they treat. The editors and authors are to be congratulated for compiling a comprehensive text presenting practical treatment principles in a clear and concise manner. This text will benefit anyone who treats patients with fractures of the proximal femur.

Seattle WA, USA — Victor Frankel, MD, PhD, KNO

# Preface

The incidence of proximal femur fractures is ever increasing, in part due to the aging population being more prone to this particular injury type and increased number of younger trauma patients surviving high-energy injuries. While there are many textbooks written about the fundamentals of proximal femur fracture management, none of these books outline the current evidence-based approaches that have begun to significantly improve diagnosis and management of these complicated fractures.

In this book, we have assembled a group of renowned authors from around the world with the goal to establish a text that can be used as a one-stop shop for academic and community-based orthopedic surgeons seeking evidence-based information on these difficult fractures. The book is divided into three succinct sections: basic principles including anatomy, biomechanics, and surgical approaches to the proximal femur; detailed chapters focusing on individual fracture locations and types; and, finally, chapters summarizing optimal perioperative medical management and quality and safety concerns.

Authors of the individual chapters are internationally recognized experts and were asked to provide readers with a comprehensive summary of the specifics of each fracture type, with special emphasis on up-to-date, evidence-based literature. Surgeons will be able to utilize this text to prepare for any particular proximal femur fracture procedure and subsequently will enter the operating room with an in-depth knowledge of the anatomy, preoperative evaluation, perioperative medical management, surgical approach, and fracture-specific reduction and fixation techniques. The format is beneficial for a quick review of the newest evidence but also allows an in-depth review of the details associated with specific fracture types around the hip.

We thank the authors for dedicating their time and expertise in generating this outstanding book. We would also like to thank the editorial staff at Springer for their hard work and editorial expertise. We hope that this book will serve you as a valuable tool and that you will often return to these chapters in preparation for surgical procedures involving proximal femur fractures.

New York, NY, USA — Kenneth A. Egol, MD
New York, NY, USA — Philipp Leucht, MD

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# 1 Anatomy of the Proximal Femur

Sanjit R. Konda

## Introduction

The proximal femoral anatomy starts its developmental path as early as 4 weeks in utero and continues development through puberty. The complex signaling pathways that lead to differentiation, growth, and maturation of the bone, cartilage, muscle, tendon, and synovial joints of the hip result in a complex structure responsible for supporting the entire body weight and allowing for ambulation. Understanding the proximal femoral geometry, blood supply, and anatomical structures allows for a methodical approach to treatment of fractures of the proximal femur.

## Intrauterine and Childhood Development

A complex host of physiologic and biomechanical factors play a role in the intrauterine development of the proximal femur. Limb formation in the embryo starts at 4 weeks with development of limb buds which are outpouches from the ectodermal layer of the ventrolateral wall [1]. The underlying mesodermal layer is responsible for development of the bone, cartilage, muscle, tendon, and synovial joints. By 7 weeks, the cartilaginous femur and acetabulum have developed, and a controlled apoptosis between the two structures occurs creating a cleft which is the future hip joint [2]. At 8 weeks' gestation, the start of the fetal stage of development, there is a shift from primarily cell differentiation to primarily cell growth and maturation. The ossification center of the femur appears in the central aspect of the femoral shaft and ossification proceeds proximally and distally. Concurrently, the proximal femur arterial supply appears at the proximal femoral shaft at the site of the nutrient artery with capillary invasion into the cartilaginous model of the proximal femur. At 11 weeks the hip is fully formed in appearance [3]. At 12–14 weeks, vascularization of the proximal femur takes the form of a ring of vessels around the base of the femoral neck. These vessels will gradually differentiate into the medial and lateral circumflex vessels [2]. By 16 weeks the femur is ossified proximally to the level of the lesser trochanter, and the femoral head and acetabular articular surfaces are covered in mature hyaline cartilage (Table 1.1).

Femoral anteversion is first defined at 11 weeks' gestation at which time it measures 5–10°. As the fetus develops, femoral anteversion increases to maximum of 45° at the time of

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**Table 1.1** Timeline of proximal femur development during gestation

| Timepoint | Milestone |
|---|---|
| 4 weeks | Limb buds form from ectodermal layer of ventrolateral wall |
| 7 weeks | Cartilaginous models of femur and acetabulum have developed from mesodermal layer. Apoptosis creates cleft between acetabulum and femur which is the site of future hip joint |
| 8 weeks | Shift from cell differentiation to cell growth and maturation. Appearance of femoral ossification center. Appearance of blood supply at nutrient artery site with capillary invasion into cartilage model of the femur |
| 11 weeks | Hip fully formed in appearance |
| 12 weeks | Vascular ring of vessels formed at the base of femoral neck |
| 16 weeks | Femur ossified to the level of lesser trochanter. Femoral head and acetabulum covered in mature hyaline cartilage |

birth. Subsequently, in the normally developing femur, femoral anteversion gradually decreases to 15° by 16 years of age [4, 5].

The relationship between the neck-shaft angles of the proximal femur also varies through development starting in the fetal stage. At 15 weeks' gestation the neck-shaft angle is 145° and gradually decreases to 130° by 36 weeks' gestation [3]. A range of normal neck-shaft angles throughout childhood development has been established in a cohort of 400 children (800 hips), and the authors found that by age 18 the mean neck-shaft angle was 127.3° [6].

## Blood Supply to the Femoral Head

As the blood supply to the proximal femur matures through gestation, it develops into three distinct arterial systems, the capsular (retinacular), foveal, and intraosseous [7–12]. The foveal blood supply through the ligamentum teres has consistently been shown to provide minimal blood supply to the femoral head. In fact, resection of the ligamentum teres during open hip reduction procedures in patients with dysplastic hips has shown no increased incidence of osteonecrosis of the femoral head further supporting the notion of minimal contribution to femoral head vascularity [2].

The capsular blood system originates with the medial and lateral femoral circumflex arteries which branch off the profunda femoris in 79% of cases. In 20% of cases 1 of these arteries branches off the femoral artery, and in 1% of cases both arteries arise directly from the femoral artery [13]. The medial and lateral femoral circumflex arteries form an anastomotic extracapsular ring around the base of the femoral neck. The medial circumflex artery is the main contributor of blood supply to the femoral neck, and the deep branch of the medial circumflex artery is the conduit for a majority of the blood flow and comprises the majority of this anastomotic ring. Branching off the extracapsular ring are the ascending cervical (retinacular) arteries which penetrate the joint capsule at the base of the femoral neck along the intertrochanteric line. From here, there are four main groups of ascending cervical arteries of which the lateral (superior) cervical artery is the most important to provide perfusion to the femoral head [7–12]. There is new literature to suggest that the inferior retinacular artery may also provide a significant amount of perfusion to the femoral head [14]. The ascending cervical arteries form a secondary vascular ring at the subcapital region of the femoral neck termed the subsynovial vascular ring of which the terminal branches of the deep branch of the medial circumflex vessels penetrate the posterosuperior aspect of the femoral head 2–4 mm proximal to the start of the articular surface (Fig. 1.1).

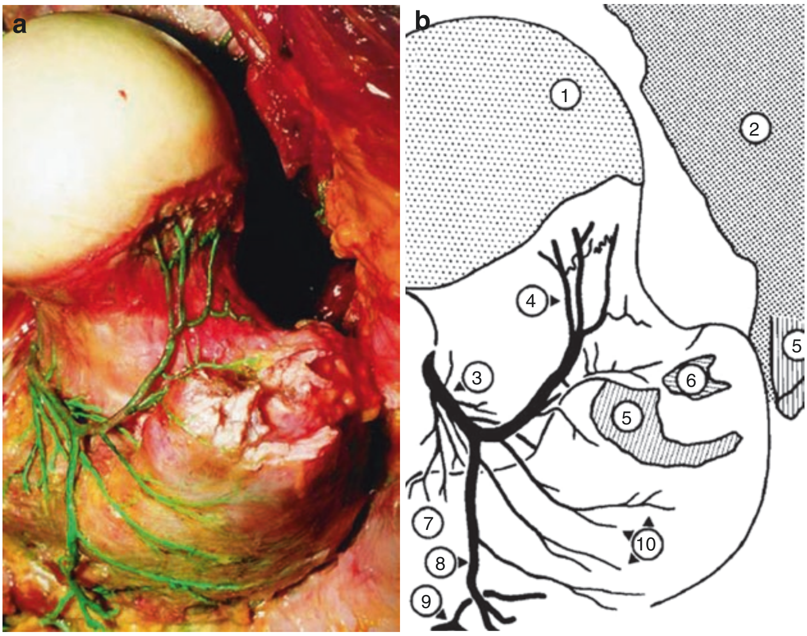


**Fig. 1.1** (**a**) Photograph showing the perforation of the terminal branches into the bone (right hip, posterosuperior view). The terminal subsynovial branches are located on the posterosuperior aspect of the neck of the femur and penetrate the bone 2–4 mm lateral to the bone-cartilage junction. (**b**) Diagram showing: (*1*) the head of the femur, (*2*) the gluteus medius, (*3*) the deep branch of the MFCA, (*4*) the terminal subsynovial branches of the MFCA, (*5*) the insertion and tendon of gluteus medius, (*6*) the insertion and tendon of piriformis, (*7*) the lesser trochanter with nutrient vessels, (*8*) the trochanteric branch, (*9*) the branch of the first perforating artery, and (*10*) the trochanteric branches (Figure and Caption copyright Gautier et al. [12].)

## Anatomy of the Proximal Femur

### Proximal Femoral Geometry

Normal constant relationships between the femoral head, femoral neck, greater trochanter, and femoral shaft exist in the grown adult. These relationships are important to define as they are the normal relationships that should be established in the course of operative treatment of a fracture about the proximal femur. As described by Dror Paley, the normal tip of the trochanter to the center of femoral head line orientation to the mechanical or anatomical axis is 90° ± 5° (lateral proximal femoral angle [LPFA]) and 84° ± 5° (medial proximal femoral angle [MPFA]). Another reference line is the neck anatomic axis or medial neck-shaft angle (MNSA) which is 130° ± 10° ([15]; Fig. 1.2).

### Internal Geometry of the Femoral Neck

The internal geometry of the femoral neck was defined in 1838 by Ward [16]. He described a trabecular network of which there were compression trabeculae medially along the femoral neck and tensile trabeculae laterally along the femoral neck. Secondary trabeculae are oriented throughout the rest of the proximal femur in accordance with Wolff’s law which states that living bone will react to mechanical loading and unloading of

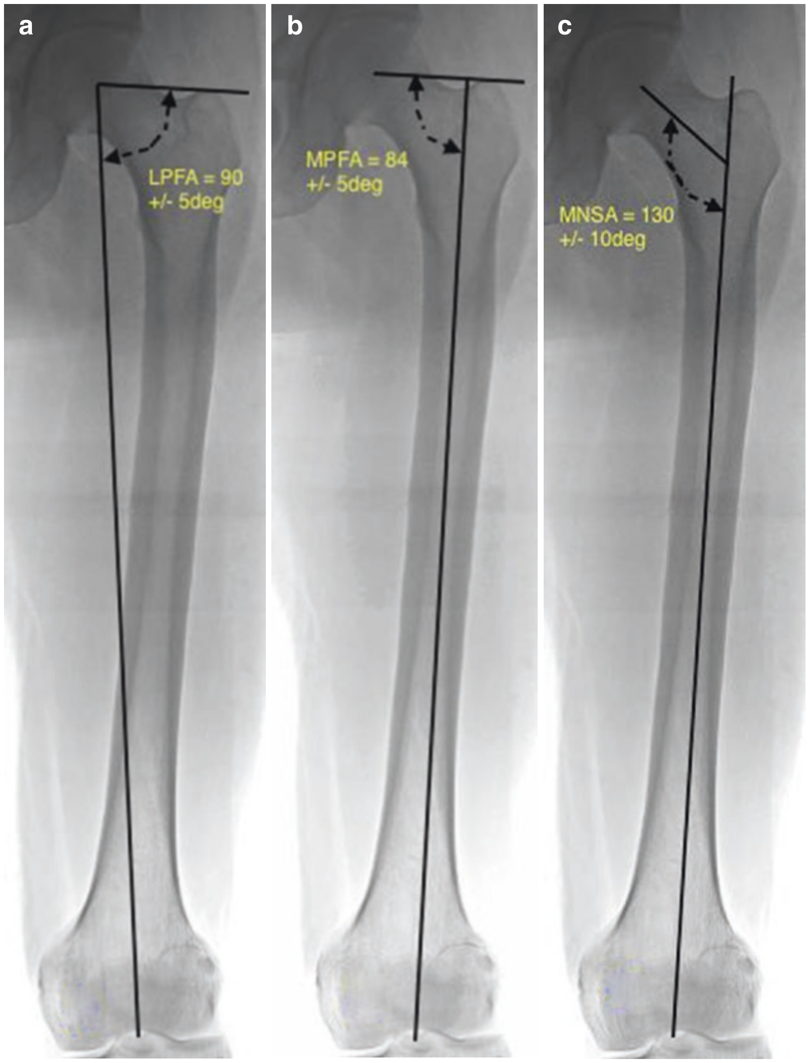


**Fig. 1.2** (**a–c**) Angle measurements of the proximal femur. The normal tip of the trochanter to the center of femoral head line orientation to the mechanical or anatomical axis is 90° ± 5° (lateral proximal femoral angle [LPFA]) and 84° ± 5° (medial proximal femoral angle [MPFA]). Another reference line is the neck anatomic axis or medial neck-shaft angle (MNSA) which is 130° ± 10°

bone segment. In the case of repetitive loading, the bone will remodel overtime to become stronger (i.e., increased trabeculae in the femoral neck) to accommodate the increased load. The area of the femoral neck deficient in trabeculae is termed Ward's triangle ([16, 17]; Fig. 1.3).

## Anatomic Regions of the Proximal Femur

The proximal femur can be divided into four main regions: femoral head, femoral neck, intertrochanteric, and subtrochanteric. Figure 1.4 depicts these radiographically. The femoral head-neck junction is defined as the subcapital region of the femoral neck and it is located intracapsularly. The femoral neck-intertrochanteric junction is defined as the basicervical region and this is located extracapsularly. The intertrochanteric region is defined by the area encompassed by the greater and lesser trochanter of the femur. The region extending 5 cm distal to the lesser trochanter is defined as the subtrochanteric region (Fig. 1.5).

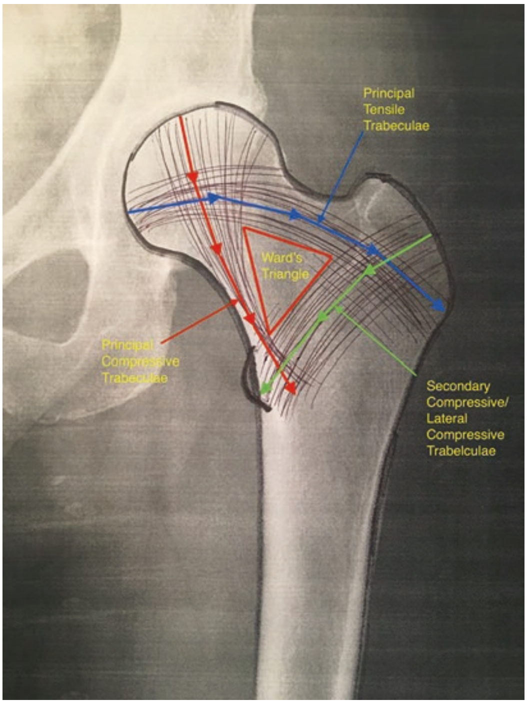


**Fig. 1.3** Plain AP radiograph of the left hip demonstrating the principal compression and tension trabeculae of the proximal femur as well as the secondary compressive trabeculae. Note the central aspect of the femoral neck which is devoid of trabeculae called Ward's triangle and which is bounded by the principal tensile and compressive trabeculae and the secondary compression force

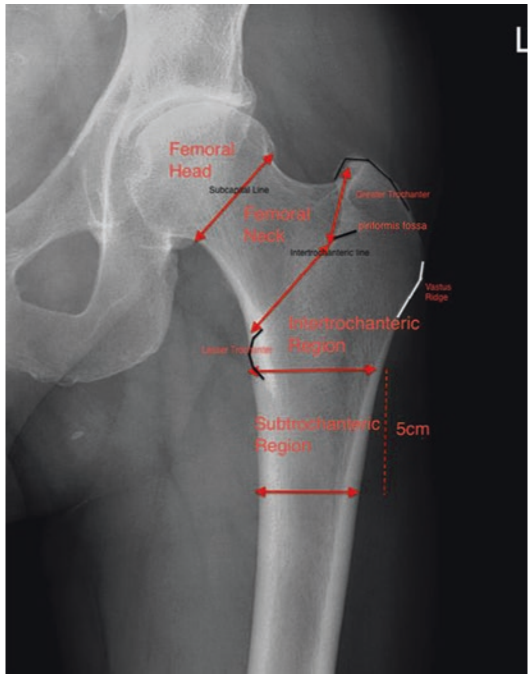


**Fig. 1.4** Plain AP radiograph of the left hip demonstrating various anatomic regions and landmarks

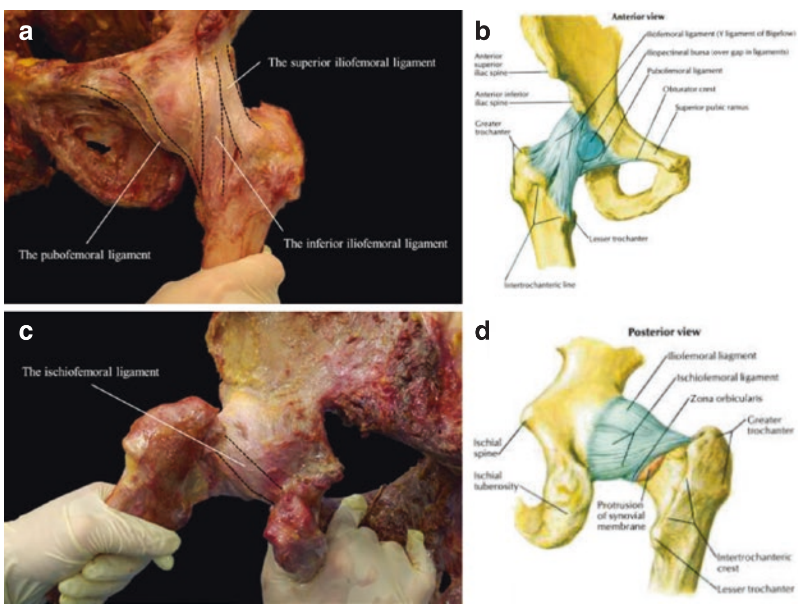


**Fig. 1.5** (**a** and **b**) Cadaveric left hip specimen and associated diagram with removal of overlying musculature revealing the superior and inferior iliofemoral ligament and pubofemoral ligament. Figures (**c** and **d**) with diagrammatic labeling of the ischiofemoral ligament (Adapted from Hidaka et al. [18] and Thompson JC. Netter's Concise Orthopaedic Anatomy, 2nd ed. Philadelphia: Saunders Elsevier; 2002.)

## Hip Capsule, Ligaments, Muscular Origins and Insertions, and Innervation Around the Proximal Femur

The hip capsule originates on the acetabulum of the pelvis. Anteriorly, it extends to the base of the femoral neck at the intertrochanteric line. Posteriorly, the lateral half of the femoral neck is extracapsular. The intracapsular portion of the femoral neck has no periosteum; therefore, intracapsular fractures must heal via endosteal healing.

There are three main ligamentous structures about the hip joint which are confluent with the hip joint capsule: ischiofemoral, iliofemoral, and pubofemoral ligament. The ischiofemoral ligament controls hip internal rotation in flexion and extension. The lateral aspect of the iliofemoral ligament has control of hip internal rotation in extension only and control of hip external rotation in both flexion and extension. The pubofemoral ligament controls external rotation in extension ([19]; Fig. 1.6).

On the anterior aspect of the proximal femur, the indirect head of the rectus femoris, innervated

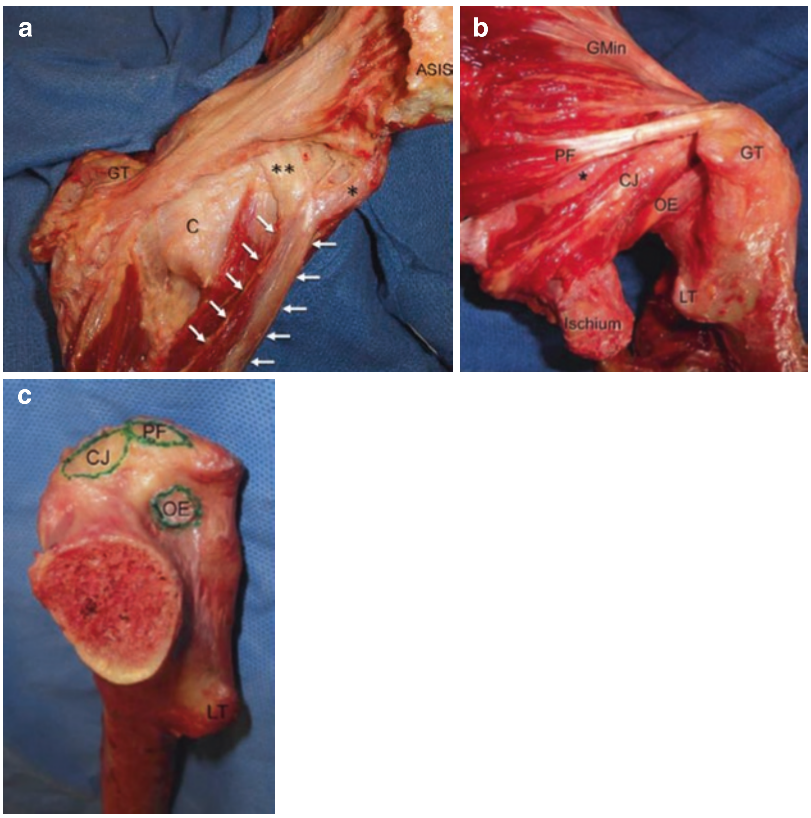


**Fig. 1.6** (**a**) Anterior view of the hip capsule [C] and surrounding pericapsular structures. The rectus femoris (*arrows*) is illustrated overlying the iliocapsularis muscles, along with its direct (*) and indirect (**) heads. The indirect head originates in part of the anterosuperior capsule at the acetabular rim. The tip of the greater trochanter (GT) and anterior superior iliac spine (ASIS) are labeled for orientation. (**b**) Posterosuperior view of the hip capsule (*asterisk*) with the overlying pericapsular muscles and tendons. Gluteus medius (Gmin), piriformis (PF), conjoint tendon of the obturator internus and gemelli (CJ), and obturator externus (OE) each have consistent capsular attachments. The ischium, greater trochanter (GT), lesser trochanter (LT), and capsule (*asterisk*) are labeled for orientation. (**c**) Medial view of the tendinous insertions onto the medial greater trochanter. The photograph was taken after the tendons were sharply removed from their respective insertion points (Figure and Caption Copyright Cooper et al. [20])

by the femoral nerve, originates from the anterior hip capsule. The vastus medialis and vastus intermedius, both innervated by the femoral nerve, originate at the superior aspect of the subtrochanteric region on the anterior aspect of the femur (Fig. 1.6).

On the lateral aspect of the femur, the gluteus medius and minimus, both innervated by the superior gluteal nerve, have a broad insertion over the superolateral aspect of the greater trochanter. The vastus lateralis, innervated by the femoral nerve, originates laterally on the vastus ridge, just inferior to the greater trochanter.

Posteriorly, the short external rotator muscles of the hip insert along the intertrochanteric line in a predictable order from superior to inferior. At the posterosuperior aspect of the greater trochanter, the piriformis (piriformis nerve) inserts followed by the obturator externus (obturator nerve), the superior gemellus, obturator internus, and inferior gemellus (all innervated by the nerve to obturator internus). The quadratus femoris (nerve to quadratus femoris) inserts along the inferior aspect of the intertrochanteric ridge posteriorly. The lesser trochanter is a posterior structure, and inserting onto it is the iliopsoas muscle (femoral nerve) (Fig. 1.6).

Along the posterior aspect of the proximal femoral shaft distal to the intertrochanteric ridge are the insertions for the gluteus maximus (inferior gluteal nerve), adductor magnus and adductor brevis (obturator nerve), and pectineus (obturator nerve).

**Conclusion**

In-depth understanding of proximal femoral anatomy including development, geometry, and muscular and ligamentous insertions is necessary to develop cogent treatment plans for fractures of the proximal femur.

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# Biomechanics of the Hip

# 2

Lorenz Büchler, Moritz Tannast,
Klaus A. Siebenrock, and Joseph M. Schwab

## Introduction

The hip joint plays a crucial role in the generation and transmission of forces during routine activity. To meet the requirements of ambulation, the hip differs in design from the more common hinge joints and is characterized by a large amount of inherent bony stability and extensive ligamentous and muscular support. Regardless of this stability, the hip joint maintains a wide functional range of movement. The great physical demands placed on the hip joint during athletic activities predisposes it to injury or chronic pathologic processes. Biomechanical considerations of the hip play a crucial role in understanding structural hip abnormalities and mechanisms of injury, and have important implications in the treatment of trauma-related injuries and reconstructive surgeries.

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## Evolution of the Human Hip

A common feature of the hip joints of *hominids* (great apes) is a spherical femoral head (*coxa rotunda*) with a long, narrow femoral neck [1]. This enables a wide range of motion of the hip joint, allowing the individual to sit, stand, and climb trees, and is ideally adapted for a jungle habitat. The obvious advantage is that the upper extremity is not exclusively used for locomotion, with hands that are free to grasp an object. The specific anatomy and biomechanics of the human hip joint is a consequence of the evolution from a sporadic to a permanent bipedal gait. It remains a matter of controversy as to why permanent bipedalism first emerged. A changing habitat—from jungle to open savanna—might have favored a predominantly bipedal running locomotion, allowing the eyes to look over tall grasses in the open savanna for possible food sources or predators. The earliest evidence includes fossil footprints similar to those of modern humans found at a site in Tanzania (Laetoli footprints). They are believed to have originated from *Australopithecus*, human ancestors that evolved in eastern Africa some 3.2 million years ago [2].

The most complete fossil of this species, "Lucy," shows pelvis and leg bones that are almost identical to those of modern humans. The brain and body size, however, are like those of a chimpanzee, indicating that bipedal gait evolved



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before the use of tools. Permanent bipedal gait required several mechanical and neurological adaptations [3]. The gluteus maximus muscle, a relatively minor muscle in the chimpanzee, was transformed into the largest muscle in the body as a hip extensor to stabilize an upright torso and major propulsive muscle in upright walking. The increase of forces exerted on the femoral neck favored a sturdier hip with a femoral neck less prone to fracture—which might explain the genetic basis for the relatively high prevalence of a *coxa recta* (cam morphotype) in the European male population [4].

## History of Research on Biomechanics of the Hip Joint

The earliest research on biomechanics of the hip dates back to the nineteenth century. Braune and Fischer published extensive research on human gait and biomechanics of the hips between 1895 and 1904 [5]. In contrast to earlier research on the subject, their approach was very analytical, involving the use of a camera apparatus to analyze human motion and determine the activity of muscles during ambulation. Using a three-dimensional coordinate system, the center of gravity in various phases of the gait cycle was defined. These findings were the foundation of the later fundamental work on the forces acting on the proximal femur and acetabulum by Frederick Pauwels [6]. Much experimental and clinical research using sophisticated methodology (e.g., ENMG, strain gauge prosthesis, finite element models) has since been conducted on this subject, generally confirming Pauwels's work.

## Anatomical Considerations

The demands on both stability and range of motion of the human hip joint are extraordinary. The anatomical properties of the acetabulum and proximal femur of a normal hip ensure a stable hip joint with an impingement-free range of motion during movements that are necessary in daily life.

### Acetabular Anatomy

The spatial orientation and size of the acetabulum can be described from radiographs by lateral center edge angle (LCE), the inclination of the weight-bearing surface (acetabular inclination or index AI), and the relation of the anterior and posterior wall on antero-posterior radiographs (retroversion index). Normal values are a cranio-caudal acetabular coverage of 78 ± 7%, LCE 26° ± 5°, AI 9° ± 4°, and an entirely anteverted acetabulum [7]. Lining the acetabular rim is the fibrocartilaginous labrum, which increases the functional size of the acetabulum and acts as a seal for joint fluid; it also significantly increases the functional stability of the joint [8]. Changes in the normal anatomy of the acetabulum have a great influence in the biomechanical properties of the hip joint. Acetabular undercoverage (dysplasia), overcoverage (pincer-type impingement), or malrotation (acetabular retroversion) can result in static overload and/or dynamic impingement of the hip, and is believed to be a cause of degenerative hip disease.

### Femoral Anatomy

The relative size of the femoral neck to the femoral head is a compromise between resistance to fractures and range of motion of the hip joint. The offset can best be described using the alpha angle. Normal values are 40–45°, allowing an impingement-free range of motion [9]. A reduced offset can lead to cam-type femoroacetabular impingement (FAI) that causes significant damage to the labrum and cartilage. Femoral antetorsion ranges from 30 to 40° at birth, and decreases progressively throughout growth. Normal values in adults show a wide range, with an average of 8° in males and 14° in females. While a higher antetorsion increases the lever arm of the gluteus maximus muscle, it decreases the lever arm of the abductors and can lead to posterior FAI [10]. The inclination between the femoral neck and shaft (CCD angle) also decreases during one's lifetime, with an average angle of 150° in newborns and 125 ± 5° in adults. A decrease in the CCD angle (varus hip) increases the lever arm of the abductors and thus decreases joint forces. On the other hand, the stresses on the femoral neck are increased. This partially explains why valgus-impacted femoral neck fractures have a better chance of healing.

### Muscle and Tendons/Ligaments

The hip is enclosed by a fibrous capsule. Intracapsular reinforcements (ilio-femoral, ischio-femoral, and pubo-femoral ligaments) stabilize the hip joint in the terminal range of motion. Numerous muscles are responsible for the motion of the hip joint. The iliopsoas, rectus femoris, sartorius, and tensor fasciae latae muscles contribute to hip flexion. The gluteus maximus and hamstrings extend the hip. Gluteus medius, gluteus minimus and tensor fasciae latae are hip abductors and internal rotators. Adductor magnus, -longus and -brevis muscles adduct the hip. External rotators are piriformis, gemellus superior and inferior, obturator internus and externus, and quadratus femoris muscles.

## Function of the Hip/Gait Patterns

### Range of Motion

The normal range of motion of a healthy adult hip measured with goniometric techniques shows significant variation: Mean hip flexion 120° (90–150, SD 8.3), extension 9.5° (range; 0–35, SD 5.3), abduction 38.5°(15–55, SD 7.0), adduction 30.5 (15–45, SD 7.3), internal rotation 32.5 (20–50, SD 8.2), and external rotation 33.6 (10–55, SD 6.8) [11]. Hip rotation appears to decrease by about 15–20° per decade during the first two decades of life, and about 5° per decade thereafter [12]. Measurements using dynamic ultrasound found lower values of passive ROM in the asymptomatic hip because it allows anatomic confirmation of terminal hip motion [13]. Joint motion varies with age, and is generally more restricted in the older age group [11, 12, 14]. In a normal hip, the joint capsule, ligaments, and musculotendinous units limit the terminal range of motion. In FAI, or generally hyperlax patients, this limitation is insufficient, leading to a bony abutment between the femoral neck and acetabular rim.

### Walking

In humans, the sequence of ambulation is composed of several successive processes: (1) double limb stance. The body weight is equally distributed across both hips; (2) anterior tilt of the pelvis in the sagittal plane (5° in walking, 15–20° in running), shifting of the center of gravity over the stance leg and hip extension 5–10°; (3) anterior rotation of the pelvis and weight release of the swing leg; and (4) rise of the pelvis 5–6° in the frontal plane and hip flexion 40–50° to elevate the swing leg. Propulsion with extension of the stance leg and plantar flexion of the ankle. A most energy-efficient gait is achieved at a mean velocity of 1.2–1.5 m/s (4-5-5 km/h), a step length of 0.65–0.75 m, and a cadence of 105–130 steps/min [15].

## Biomechanics of the Hip

The hip is a highly constrained ball and socket joint that attaches the lower limb to the rest of the body. The center of gravity is above the hip joints, and a continual muscular force must be applied to balance the body's mass on the hip. In contrast to many animals, standing is not a resting position for humans. To reduce energy consumption while standing, humans tend to shift weight from one leg to the other and position them in hyperextension to lock the hips onto the ilio-femoral ligaments.

Depending on the activity, the hip joint can see a peak force of up to eight times body weight (Table 2.1). This is primarily a result of muscular contraction across the hip joint that counteracts the weight of the body when attempting to stabilize the pelvis in single leg stance. A free body diagram of the hip joint shows how the moment arms acting on the hip joint can be used

**Table 2.1** Hip contact forces measured *in vivo* in patients with instrumented implants [16–18] (BW= Body weight)

| Activity | Typical peak force (BW) |
|---|---|
| Walking, slow | 1.6 ± 4.1 |
| Walking, normal | 2.1 ± 3.3 |
| Walking, fast | 1.8 ± 4.3 |
| Jogging/running | 4.3 ± 5.0 |
| Ascending stairs | 1.5 ± 5.5 |
| Descending stairs | 1.6 ± 5.1 |
| Standing up | 1.8 ± 2.2 |
| Sitting down | 1.5 ± 2.0 |
| Standing/2-1-2 legs | 2.2 ± 3.7 |
| Knee bend | 1.2 ± 1.8 |
| Stumbling | 7.2 ± 8.7 |

Table adapted from "The Adult Hip, Volume 1" Table 5-1, page 84. Callaghan, John J; Rosenberg, Aaron G; Rubash, Harry E (eds)

to estimate the joint reaction force (Fig. 2.1). This type of modeling is limited in that it assumes a single leg stance (i.e., no weight is being supported by the other extremities), that the abductors are the only source of muscular stabilization of the pelvis, that they are equally and simultaneously active to stabilize the pelvis, and that the entire system is not moving.

In a stable pelvis, the sum of all moment arms is 0 ($\sum M=0$). Assuming c-o is 1 and o-b is 3, then we can come up with the following equation

$$-M_y + 3K = 0$$

where $M_y$ is the vertical component of the abductor muscle moment arm and $K$ represents the body weight moment arm (minus the weight of the ipsilateral leg that corresponds to roughly 1/6 of the body weight). This equation then yields

$$M_y = 3K$$

Assuming the sum of all forces around the hip is also 0 ($\sum F_y=0$), then we can say that

$$-M_y - K + R_y = 0$$

which is to say that the vertical force created by the abductor muscle pull ($M_y$), the body weight ($K$), and the vertical component of the joint reaction force ($R_y$), must add up to 0. Substituting what we have already established is the relationship between $M_y$ and $K$, we are left with

$$R_y = M_y + K = 4K$$

$$R = \frac{R_y}{\cos 16}$$

$$\mathrm{R} = 4.2K$$

Since $K$ represents the force created by approximately 5/6 body weight (since the ipsilateral limb weight is not included), then the joint

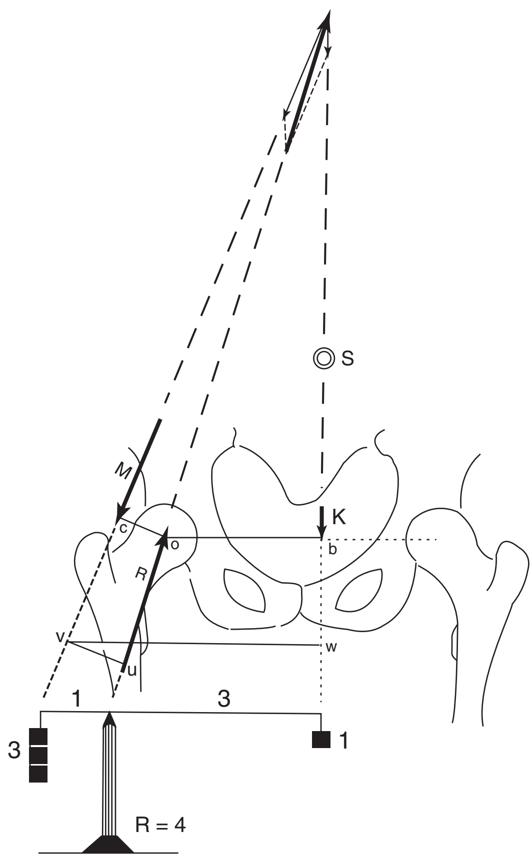


**Fig. 2.1** During static load of the hip joint in single leg stance, the lever arm between the center of rotation of the hip and the body center line (o-b) leads to a downward force towards the non-supporting leg. The hip abductors counteract this torque with the respective lever arm (c-o) and horizontally stabilize the pelvis. The sum of all forces acting on the joint is equal to zero. In normal conditions, the resultant force ($R$) passes through the center of the femoral head and forms an angle of 16° to the vertical. The respective magnitude of the total load ($R$) is dependent on the body weight ($K$) and the length ratio of the lever arms and results in roughly four times the body weight (original figures from Pauwels)

reaction force across a stable hip during single leg stance is approximately 3.5 times the body weight. Dynamic forces generated during walking additionally increase the load of the femoral head by 50%. Thus, the maximum applied pressure on the femoral head when walking is about 4.5 times the total body weight.

During Trendelenburg gait, the body weight is shifted over the affected hip, thereby decreasing the moment arm *K*. If the weight is shifted such that c-o remains 1, but o-b is reduced to ½, then the joint reactive force decreases to 1.7 K, or approximately 1½ times the body weight (Fig. 2.2).

The ratio of moment arms *M* and *K* can be influenced during surgery, and the resulting new ratio can either increase or decrease the effective joint reaction force. For instance, medializing or lateralizing the joint, such as during total hip replacement or periacetabular osteotomy, can lead to a respective decrease or increase in *R*. In addition, the *M*/*K* ratio can be influenced by surgically lateralizing the greater trochanter, or increasing offset with a longer neck prosthesis during total hip replacement, leading to a decreased R. Fixing a femoral neck fracture in relative varus or valgus will also change the M/K ratio and affect the associated joint reaction force.

It is also worth noting that placing a cane in the contralateral hand will produce an additional moment arm to the free body diagram that can reduce the joint reaction force by 50%, when just 15% of the body weight is put on the cane.

## Anatomical and Biomechanical Considerations in the Treatment of Proximal Femur Fractures

Both conservative and surgical treatment of fractures of the proximal femur can result in a variety of anatomical changes that can affect the biomechanics of the hip.

### Avascular Necrosis (AVN)

Originating from the A. *femoris profunda*, the medial femoral circumflex artery (MCFA) passes proximally from the trochanter into the M. *quadratus femoris*. At the level of the piriformis tendon, the vessel passes through the hip joint

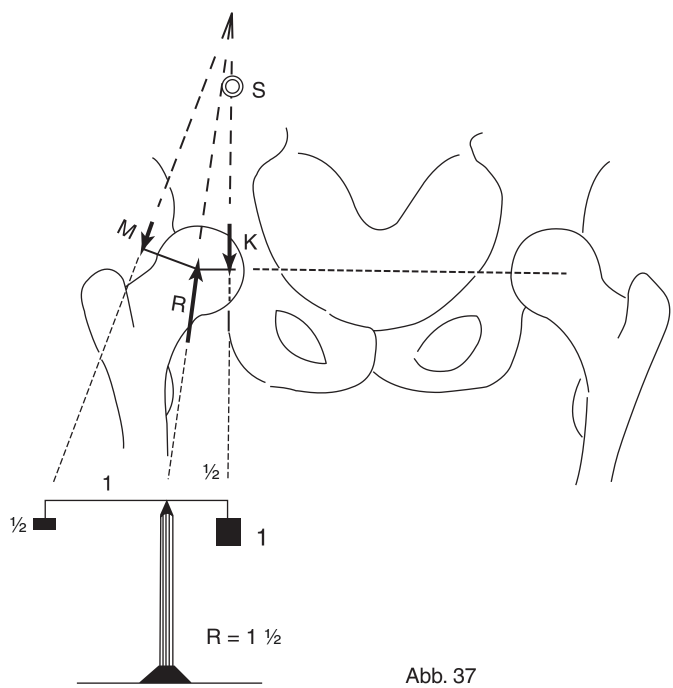


**Fig. 2.2** In the case of Trendelenburg gait, the patient inclines the upper body over the affected hip, thus shifting the center of gravity (*S*) closer to the center of rotation of the hip. The lever arm of the body weight is thereby shortened, and the necessary counteracting forces of the abductors are reduced. This significantly reduces the compressive stress of the hip joint to 1.5 times the body weight (original figures from Pauwels)

capsule. Splitting into several terminal branches, the vessel continues within the periosteum at the 11 o'clock position of the femoral neck. At the head-neck junction, the terminal branches penetrate the bone, where they first run relatively superficially before radiating into the femoral head. Femoral neck fractures or posterior ruptures of the capsule can lead to a rupture of these vessels during the initial trauma or reposition maneuvers. The too-medial insertion of a femoral nail can also cause injury to the vessels. Subsequent partial or complete AVN of the femoral head generally leads to pain and a severe limitation of hip joint mobility.

## Dislocation/Nonunion Trochanter Major

Dislocation of the greater trochanter significantly changes the biomechanics of the hip, due to a reduction of the lever arm and shortening of the abductor muscles. This can cause pain, weakness of the abductors and limping. Non-union of a fracture of the greater trochanter often causes pain, even in non-displaced fractures.

## Intra- and Extra-Articular Impingement

Dislocated femoral neck fractures may lead to intra-articular impingement similar to that seen in slipped capital femoral epiphysis (SCFE) due to the angulation of the femoral neck or callus formation. A dislocated greater trochanter or avulsions of the anterior inferior iliac spine can lead to extra-articular impingement. Torsional mal-unions of the femur can also lead to intra- or extra-articular impingement.

For patients with persistent pain or impaired function after a trauma to the proximal femur, appropriate imaging should be done, with a CT of the pelvis and knees to evaluate the torsion of the femoral neck. If there are anatomical misalignments, mal-unions or leg length discrepancy, the patients frequently benefit from corrective surgery.

**Conclusions**

Recognizing the biomechanical principles of the hip joint with the complex interaction of bony structures, muscles, capsules, and ligaments is essential for understanding normal hip function, and is the basis of all treatment concepts for congenital, traumatic, or degenerative hip diseases.

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# 3 Approaches to the Hip

Roy Davidovitch and Abhishek Ganta

## Introduction

Proximal femur fractures are a common injury and almost always require surgical intervention. Although many fracture types can be reduced indirectly, an open approach may be required to achieve an anatomic reduction. In addition, approaches to the proximal femur also need to be useful for an arthroplasty procedure, should one be required.

A number of approaches to the proximal femur and hip exist. In this chapter we describe the anterior and anterolateral approaches, as well as the posterior approach to the proximal femur and hip. A surgeon dealing with trauma to the proximal femur should be familiar with and comfortable performing these approaches in order to properly address these injuries.

| | |
|---|---|
| Anterior approach | Femoral neck fracture fixation |
| | Total hip arthroplasty |
| | Hemiarthroplasty |
| Anterolateral approach | Femoral neck fracture fixation |
| | Total hip arthroplasty |
| | Hemiarthroplasty |
| Posterior approach | Total hip arthroplasty |
| | Hemiarthroplasty |

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## Anterior Approach: Smith-Peterson

The anterior approach to the hip has been gaining popularity over the past decade, both for reduction of femoral neck fractures and for arthroplasty of the hip. Interest in the anterior approach has been increasing; it is a well-established surgical approach that was originally described by Carl Heuter in his text *Der Grundriss der Chirurgie* (*The Compendium of Surgery*), published in 1881 [1]. Smith-Peterson [2] described a similar anterior approach to the hip a number of years later, and is credited with spreading the anterior approach to the English-speaking world.

Differing from the Smith-Peterson approach, Heuter's does not require a tenotomy of the rectus tendon in order to access the hip. An additional advantage of the Heuter approach is that the lateral femoral cutaneous nerve is easily avoided and does not require direct visualization or retraction [1]. This approach is very useful for the reduction of a femoral neck fracture, although a separate lateral incision is needed for internal fixation; it can also be used for total hip arthroplasty or hemiarthroplasty if necessary. It should be noted that this approach is not useful for intertrochanteric/pertrochanteric fractures, as it is not easily extensile at this level, and, if fixation is required, access to the greater trochanter is limited.


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## Patient Positioning

The patient is placed in the supine position on an orthopedic table or a radiolucent operating room table per the surgeon's preference. If an arthroplasty is planned, it is important that the orthopedic table have the capability of extending the operative extremity. If a flat table is used for the arthroplasty, the patient should be positioned such that the hip is located just proximal to the break of the table so that the extremity can be extended by breaking the table.

For a femoral neck fracture, a closed reduction maneuver, as originally described by Ledbetter (1938), is performed as an initial step in order to attempt an adequate closed reduction [3]. If this fails, an open reduction needs to be performed prior to internal fixation.

## Surgical Anatomy and Approach

The anterior superior iliac spine (ASIS) and the greater trochanter are marked. A line is drawn from the center of the ASIS to the tip of the greater trochanter. A point 2 cm along this line from the ASIS marks the proximal extent of the incision. A vertical line of approximately 8 cm is then drawn distally along the direction of the tensor muscle belly towards the lateral aspect of the patella (Fig. 3.1).

**Fig. 3.1** The line drawn from ASIS to the tip of the greater trochanter is shown above. A point on this line—2 cm from the ASIS—is chosen and extended towards the lateral aspect of the patella, roughly 6–8 cm (courtesy of Dr. Roy Davidovitch)

Angling the incision in this direction (approximately 20° lateral to the midline) helps avoid the distal cutaneous branches of the lateral femoral cutaneous nerve. A separate 10 cm incision drawn over the lateral aspect of the greater trochanter is used for the insertion of hardware.

The dissection is carried down to the fascia overlying the tensor fascia latae. The direction of the underlying muscle fibers should be from ASIS to the lateral side of the knee. The fascia is then incised over the tensor muscle in the same direction as the fibers (Fig. 3.2).

The fascia is then gently elevated off the tensor muscle, using blunt finger dissection. The interval between the tensor muscle laterally, and fatty areolar tissue medially, is developed (Fig. 3.3). Developing the proper surgical interval is essential, as there are perforating vessels on

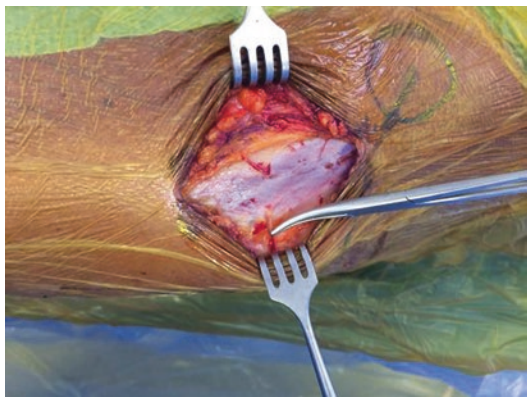

**Fig. 3.2** Correct location for incision in fascia that is 1 cm lateral to ASIS and 5 mm medial to perforators (courtesy of Dr. Roy Davidovitch)

**Fig. 3.3** Blunt dissection, with fascia medially and tensor muscle belly laterally (courtesy of Dr. Roy Davidovitch)

the fascia of the tensor muscle coursing from posterior to anterior; this helps identify the tensor muscle. Once the interval is developed, there should be muscle on the lateral side, and the fatty tissue on the medial side. If muscle is encountered on both sides there is a high liklihood that the surgeon is within the wrong interval.

The femoral neck is then palpated. Once it has been palpated, a blunt, narrow, curved Hohmann retractor is placed over the superior aspect of the femoral neck capsule. The interval between the tensor anda the rectus muscle is developed distally. Care is taken not to penetrate the loose layer of tissue septum underneath these muscles. The ascending branch of the lateral circumflex artery is located within this tissue and must first be identified. The vessels are then isolated, and electrocautery is used to achieve hemostasis (Fig. 3.4).

The fascial septum is incised and the anterior pericapsular fat pad comes into view. A plane between the anterior fat pad and the capsule is created, and the anterior hip capsule is clearly visualized. Next, a second blunt, curved Hohmann retractor is placed around the inferior femoral neck capsule. A cerebellar retractor is placed from cephalad into the wound to retract the tissue medially and laterally, directly overlying the femoral neck. A complete view of the anterior capsule is essential before the anterior capsulectomy is performed (Fig. 3.5). An anterior retractor placed over the anterior acetabular rim may help in this exposure, although it is not routinely used.

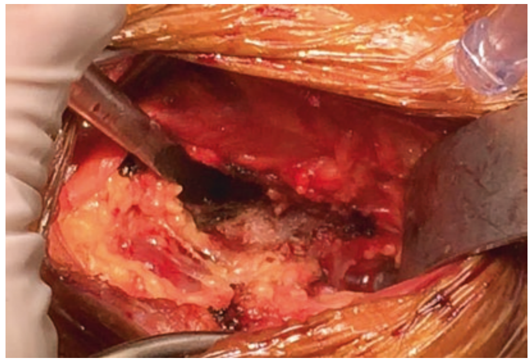

**Fig. 3.5** A complete view of the anterior capsule can be seen. Such a view is necessary before the anterior capsulectomy is performed (courtesy of Dr. Roy Davidovitch)

The capsule is then incised along the center of the femoral neck from the intertrochanteric line laterally to the labrum medially. The capsulectomy is then performed along the acetabular rim medially, both superior and inferior to the line of incision of the capsule if a total hip arthroplasty from this approach is to be performed. Labrum is also excised anteriorly to facilitate the extraction of the femoral head. The capsule is excised from the intertrochanteric line laterally, and the superior capsule is also released from the superior part of the trochanter. The position of the Aufranc retractors are then changed and placed directly around the femoral neck inside the capsule.

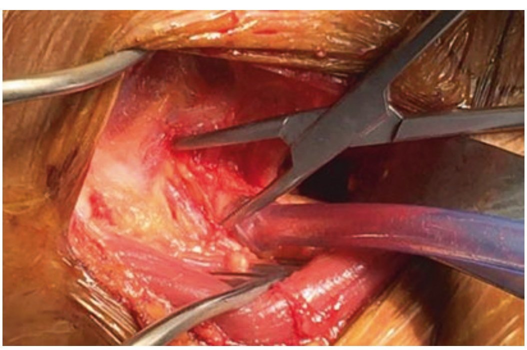

**Fig. 3.4** The location of the circumflex vessels is shown. It is necessary to locate and cauterize these vessels to achieve adequate hemostasis (courtesy of Dr. Roy Davidovitch)

## The Lateral Femoral Cutaneous Nerve and Possible Dyasthesia

The lateral femoral cutaneous nerve arises from the L2 and L3 nerve roots and merges on the lateral border of the psoas. It then travels under the inguinal ligament, overlying the sartorius and under the fascia, and it then divides into anterior and posterior branches. The anterior branch pierces the fascia about 8–10 cm below the ASIS and supplies the skin over the anterior and lateral part of the thigh. The posterior branch traverses posterior and supplies the skin of the posterior thigh. In the current surgical technique, the fascial incision is placed over the tensor muscle; this is lateral to the course of the nerve. The anterior sensory branch of the nerve may be subject to traction neuropraxia on the medial and distal end of the incision.

## Anterolateral Approach: Watson-Jones

The anterolateral approach allows access to both the femur and femoral neck for an indirect reduction. Since the interval places the surgeon more laterally on the femoral neck, hardware can be inserted through the same incision at the same time. Furthermore, this is an excellent approach for total hip arthroplasty if needed. The approach offers not only comprehensive exposure, but it can also be extended both proximally and distally if necessary.

This approach takes advantage of the intermuscular plane between the tensor fascia latae muscle (superior gluteal nerve) and gluteus medius muscle (superior gluteal nerve). The approach was described by Watson-Jones [5]. Watson-Jones's described interval is anterior to the abductors and posterior to the tensor fascia latae. However, in order to gain access to the femoral neck and acetabulum, the abductor mechanism needs to be neutralized, either by a trochanteric osteotomy, or by partial detachment of the abductors [6]. Like the anterior approach for hip arthroplasty, the anterolateral approach is fairly resistant to dislocation. In a review of literature of by Masonis and Bourne [7], the dislocation rate for the lateral approach is 0.55% compared to 2.03% for the posterior approach with capsular repair.

### Patient Positioning

The patient can be positioned in either the supine or the lateral position. Our preference is for a fracture table supine positioning during fracture repair, or supine on a radiolucent table for arthroplasty procedures. Supine positioning facilitates fluoroscopic imaging as well as leg length measurements during arthroplasty.

### Surgical Anatomy and Approach

The greater trochanter and proximal femoral shaft should be palpated and marked out. The length of the incision depends on the patient's body habitus, anatomy, and flexibility. The incision should begin approximately 3 cm lateral to the anterior superior iliac spine. The incision is carried in a curvilinear fashion along the anterior aspect of the greater trochanter down along the diaphysis of the femur.

Superficial dissection should proceed through the subcutaneous fat until the deep fascia is reached.

After identifying the tensor fascia latae, a cobb elevator can be used to push the subcutaneous fat back off the tensor. The tensor should be split in line with the incision through the fibrous portion of the fascia that appears white. If the fascia is split through the muscular portion of the tensor, it would be a more ideal incision for an anterior approach as discussed above, and would make exposure more challenging. The fascia is therefore split just anterior to the most lateral aspect of the greater trochanter fibrous portion, and carried both proximally and distally.

The fascial split can be retracted using a Charnley retractor. At this point, the gluteus medius should be identified and isolated; external rotation of the hip can help identify the most anterior aspect of the gluteus medius. The anterior third of the gluteus medius, the gluteus minimus, as well as the anterior capsule, can be elevated off as a single sleeve from the greater trochanter. The tendinous cuff is tagged with thick sutures and can be retracted anteriorly. This thick flap can be repaired back to restore the abductor mechanism of the hip, and access to the femoral neck is thus achieved (Fig. 3.6). Unlike the anterior approach discussed above, reduction of a femoral neck fracture through the anterolateral approach occurs indirectly via palpation and imaging. Unlike the anterior approach, the hardware can be inserted without requiring a separate approach for fixation.

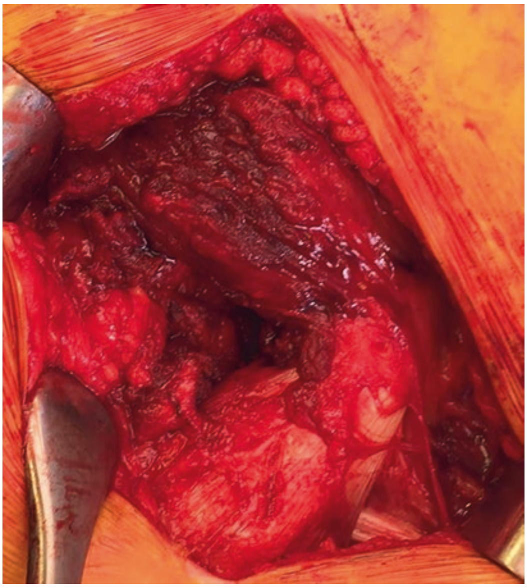

**Fig. 3.6** In this image, the gluteus medius is actually preserved without detachment. The hip gluteus medius is at the top of the image, and the vastus lateralis can be seen on the bottom. The left of the image is anterior with the hip retractors behind the tensor fascia latae, and to the right of the image, the gluteus maxiumus tendon can be seen (courtesy of Dr. Scott Marwin)

In an arthroplasty situation, whether for a total hip or a hemiarthroplasty, the leg is brought into a "figure four" position. The femoral head can now be dislocated for arthroplasty or an in-situ neck cut can be made. A napkin ring osteotomy can be performed if an in situ neck cut is needed for a femoral neck fracture. Access to the acetabulum is achieved with the extremity in neutral position, and femoral access is achieved with the extremity in a "figure four" position.

The procedure is typically concluded with repair of the tendinous cuff of the gluteus medius and capsule. This can be achieved by direct soft tissue repair; however, bone tunnels or suture anchors can occasionally be used for this purpose.

## Posterolateral Approach: Southern

The posterior approach was initially described by von Langenbeck and then by Kocher in 1873 and 1877, respectively [8, 9]. In 1980, Harris further modified the approach, in which the incision was curved posteriorly and extended distally to provide better access to the acetabulum and femur, respectively. This approach is commonly used for total hip arthroplasty and hemiarthroplasty and it is easily extensile, depending on the surgeon's need for exposure. The posterolateral approach is primarily useful for arthroplasty procedures and for posterior-based acetabulum fractures. The posterior approach, however, is not recommended for femoral neck fracture fixation, as it runs the risk of devascularizing the femoral head during the approach [10].

## Patient Positioning

The patient is positioned in the lateral decubitus position. It is the surgeon's preference in terms of which hip positioner is used; however, it is important to keep the pelvis as level as possible and to provide adequate padding for the bony prominences. The positioner should also be placed such that the leg can be fully flexed and brought through a range of motion to assess stability. An axillary roll is then placed distal to the axilla on the dependent chest wall to prevent upper extremity neuropraxias (Fig. 3.7). For acetabular fracture exposure, the patient is often positioned prone; however, this is beyond the scope of this chapter.

**Fig. 3.7** Depicted above is ideal positioning of the posterior approach to the hip. Note where the hip positioners are placed, allowing free range of motion of the hip intraoperatively (courtesy of Dr. Ran Schwarzkopf)

## Surgical Anatomy and Approach

The exposed field should include the ASIS and greater trochanter, and be distal to the knee. Being able to feel for the contralateral patella and foot over the drapes can help with determining leg lengths. The greater trochanter should be palpated and outlined. A longitudinal incision that is curvilinear posteriorly should be made over the posterior third of the greater trochanter for optimal exposure. Distally, the incision is in line with the femoral shaft, and proximally, the incision should be aiming towards the posterior superior iliac spine (Fig. 3.8). Again, as stated above, the size of the incision should depend on the patient's body habitus as well as flexibility.

The skin is incised and dissection is taken sharply down to the fasica latae. The posterior approach does not have a true internervous plane or intermuscular plane. The gluteus maximus can be split proximally up to the point when one encounters the perforating branches of the inferior gluteal nerve crossing the plane of dissection. This allows for adequate exposure. While splitting the gluteus maximus muscle, care should be taken to maintain hemostasis (Fig. 3.9).

A Charnley retractor can be placed to retract the fascia and the split fibers of the gluteus maximus. The trochanteric bursa, with its extension over the insertion of the short external rotators, is excised. The hip is placed in extension and slight internal rotation, which protects the sciatic nerve and places the short external rotators on tension.

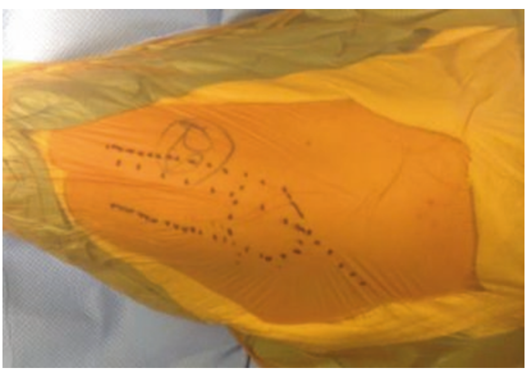

**Fig. 3.8** Depicted above is the incision that is used for the posterior approach. It is imperative to palpate and mark out all bony landmarks (courtesy of Dr. Ran Schwarzkopf)

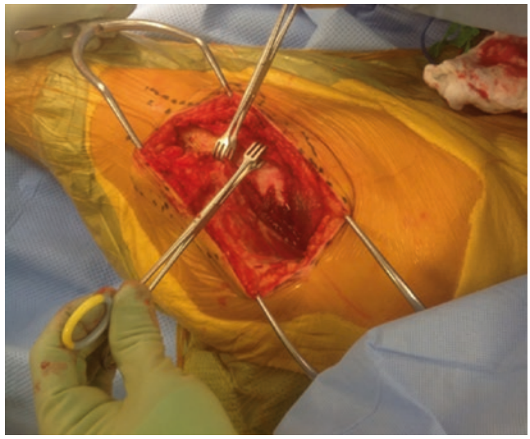

**Fig. 3.9** Depicted above is the fascial split with the gluteus maximus split at the proximal extent of the incision (courtesy of Dr. Ran Schwarzkopf)

A Cobb elevator can now be used to separate the gluteus minimus and piriformis tendon, and a Hohmann can be used to retract the abductors. The piriformis is now taken down from its insertion and often tagged. With further internal rotation, the short external rotators are taken down from their insertion on the proximal femur and dissection is carried distally to the quadratus femoris. It is the author's preference to dissect the short external rotators separately from the capsule, and tag these structures prior to capsulotomy. Often during this part of the exposure, the medial femoral circumflex may be cut, and hemostasis may be required; it is for this reason that this is not an ideal approach for fracture repair.

The hip capsule can be exposed, a capsulotomy can be performed in a T- fashion, and the edges tagged with thick sutures. The hip may be dislocated for access to the femoral head and neck (Fig. 3.10). The femoral neck cut is then performed, referencing the lesser trochanter. Access to acetabular prep is facilitated with the extremity placed in adduction and slight flexion. Access to the femoral neck is achieved with the extremity placed into hip flexion, internal rotation, and adduction.

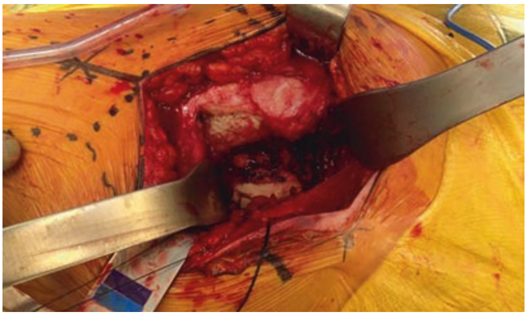

**Fig. 3.10** After tagging and taking down the short external rotators and the capsulotomy, the hip can be dislocated, allowing easy access to the proximal femur (courtesy of Dr. Ran Schwarzkopf)

For closure, the short external rotators and capsule can be repaired to the posterior edge of the greater trochanter using two drill holes and thick sutures. The gluteus maximus split is not repaired, and the fascia is repaired in a standard fashion.

## Structures at Risk

The anatomic structure that is at greatest risk during this approach is the sciatic nerve. While it does not necessarily have to be exposed during the procedure, it is important to keep in mind its proximity to the working area in terms of placement of retractors, or with excessive stretching or tension on the extremity. While there are anatomic variants, the sciatic nerve is typically deep (anteriorly) to the piriformis muscle, and then continues superficially (posteriorly) to the short external rotators.

Of note, while the femoral nerve is not in view, it is at risk from indirect and aberrant retraction anteriorly. Specifically, one should be cautious when inserting the anterior acetabular retractor during acetabular prep. It is imperative to remain on bone along the anterior acetabulum to prevent injury.

### Conclusions

Three surgical exposures to the hip and proximal femur are presented here. All approaches are amenable to arthroplasty options; however, only the anterior- based approaches are suitable for the reduction and fixation of fractures. Each approach poses its own risks and benefits, with the posterior approach arguably providing the most extensile approach for the purpose of arthroplasty. The anterolateral approach provides the most extensile approach for fracture fixation, and the anterior approach provides the most direct access to fracture reduction. It is up to the comfort level of the surgeon to determine the most ideal approach, based on the character of the fracture; however, all three should be in the armamentarium of the surgeon.

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# 4 Fractures of the Femoral Head

Axel Ekkernkamp, Dirk Stengel, and Michael Wich

## Introduction

Femoral head fractures represent a unique injury entity as they are regularly associated with other injuries to the femoral neck and acetabulum. The hip joint is inherently stable and resists significant forces up to 400 N. Thus, femoral head fractures typically result from high-energy trauma and are often observed in patients with multiple injuries [1, 2]. Six to 16% of posterior hip dislocations are associated with a femoral head fracture [3].

Femoral head fractures occur predominantly in young and middle-aged patients. In the elderly, the area of least resistance is the femoral neck, which will usually fracture before any injury of the acetabulum or the femoral head occurs.

The prognosis for patients with femoral head fractures depends on many variables. Some are inevitable, such as cartilage damage at impact and compromised femoral head vascularity. Modifiable management factors are early diagnosis and surgery, removal of intra-articular fragments, and, of course, accuracy of the reduction. Even if short-term complications such as avascular necrosis (AVN) and heterotopic ossification can be avoided, long-term outcomes of hip dislocation and femoral head fractures are difficult to predict. The incidence of unsatisfactory results, primarily as a consequence of post-traumatic arthritis, may exceed 50% [4, 5].

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## Surgical and Applied Anatomy Relevant to Femoral Head Fractures

The hip joint is a constrained ball-and-socket joint. We emphasize the role of the fibrous cartilage labrum that covers more than 10% of the femoral head and protects it by more than 50% during motion.

The capsule of the hip joint is reinforced by strong ligaments:

1. The *iliofemoral* (or Y) ligament originates from the superior aspect of the joint at the ilium and anterior inferior iliac spine. It runs in two bands inserting along the intertrochanteric line superiorly, and just superior to the lesser trochanter inferiorly.
2. The *pubofemoral* ligament inserts on the intertrochanteric line deep to the Y ligament.
3. The *ischiofemoral* ligament within the capsule originates at the junction of the inferior posterior wall with the ischium and runs obliquely lateral and superior to insert on the femoral neck.


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The large muscles surrounding the hip tend to force the femoral head into the acetabulum, taking advantage of its depth. All nerves to the lower extremity pass close to the hip joint. The sciatic nerve is at great risk during posterior hip dislocations and surgical procedures. The femoral nerve lies medial to the psoas muscle in the same sheath and can be injured with anterior dislocations.

In adults, the primary blood supply to the femoral head derives from the cervical arteries. These arteries originate from the extracapsular arterial ring at the base of the femoral neck.

In contrast to common belief, the foveal artery, a branch of the obturator artery within the ligamentum teres, contributes little to the nutrition of the femoral head in adults.

## Hip Dislocations

For the hip to dislocate, the ligamentum teres, and at least a portion of the capsule, must be disrupted. Labral tears or avulsions, as well as muscular injuries, are common in this setting. Pringle and Edwards [5] examined accompanying soft-tissue injuries in cadavers with experimental hip dislocations. They found that the capsule may be stripped as a cuff from either the acetabulum or femur by rotational forces, or be split by direct pressure (OTA Classification A1). A combination of these capsular injuries may occur, resulting in an L-shaped lesion [5].

In *posterior dislocations*, the capsule is torn either directly posteriorly or inferior-posteriorly, depending on the degree of flexion at the time of injury. The Y ligament remains generally intact, with the capsule stripped from its posterior acetabular attachment. In some cases, however, the Y ligament may be avulsed with a fragment of bone.

In *anterior dislocations*, the psoas muscle acts as the fulcrum of the hip, and the capsule is disrupted anteriorly and inferiorly. Although rare, in extremely high-energy injuries, the femoral vessels can be injured or an open hip dislocation can occur.

Associated femoral head injuries are common and may result from shearing, impaction, and, most frequently, avulsion. When the hip dislocates, a small fragment remains attached to the ligamentum teres (OTA B 31C1.1), avulsing from the head. These fragments, if small and within the fovea, are of minimal concern. More severe injuries to the head involve a shearing mechanism or an impaction force. Impaction is more common after anterior dislocation and may be quite large, similar to a Hill-Sachs lesion of the humeral head. Anterior dislocations with this pattern are at higher risk of AVN because the impaction occurs at the posterior-superior portion of the head-neck junction where the medial circumflex femoral artery (MCFA) vessels insert into the head. Shear injuries are usually the result of a posterior dislocation that occurs with less adduction and internal rotation, forcing the head against the rim of the posterior wall.

Hip dislocations and their accompanying injuries ultimately depend on the vector of the force and its magnitude. For example, minimal anteversion and internal rotation at impact tend to result in pure dislocations rather than fracture dislocation (Table 4.1).

## Injury Mechanisms Causing Fractures of the Femoral Head

Damaging the femoral head mandates destruction of its protective soft-tissue envelope first, which is most often accomplished through forceful dislocation of the hip joint. The vast majority

**Table 4.1** Position of the hip and leg during impact determines injury type

| Position of the proximal femur | Dislocation |
|---|---|
| Full flexion, adduction, internal rotation | Pure posterior dislocation |
| Partial flexion, medium abduction, internal rotation | Posterior fracture dislocation |
| Hyperabduction, extension, external rotation | Anterior dislocation |

of hip dislocations occur from high-energy motor vehicle accidents. Other mechanisms include falls, pedestrians struck by motor vehicles, industrial accidents, and athletic injuries [2].

Posterior dislocations outnumber anterior dislocations by approximately 9 to 1 [4, 6]. The typical mechanism for a posterior dislocation is a deceleration accident in which the patient's knee strikes the dashboard with both the knee and hip flexed. By vector analysis, Letournel demonstrated that more flexion and adduction of the hip during application of a longitudinal force through the femur increases the likelihood of pure dislocation [7].

Minimal adduction or internal rotation predisposes to fracture dislocation, which may occur together with a posterior wall fracture or a shearing injury of the femoral head. As the head impacts against the posterior wall, a fragment of the femoral head remains in the acetabulum, and the intact portion of the head connected to the femoral neck dislocates posteriorly.

The concept that the position of the femoral head at impact plays a large role in the type of injury was supported by Upadhyay and colleagues, who studied the effect of femoral anteversion in patients with hip dislocations and fracture dislocations [8, 9]. They saw that decreased anteversion of the femoral neck results in a more posterior position of the femoral head, similar to internal rotation, both tending to produce pure dislocation. In contrast, increased femoral neck anteversion and less internal rotation led to fracture dislocation.

The less common anterior dislocations are a result of hyperabduction and extension. This mechanism may be present in deceleration injuries in which the occupant is in a relaxed position during impact with the legs flexed, abducted, and externally rotated. This is a typical leg position in motorcycle accidents where the legs are frequently hyperabducted. Using cadavers, Pringle et al were able to cause anterior hip dislocations by hyperabduction and external rotation [5]. The degree of hip flexion determined the type of anterior dislocation, with extension leading to a superior pubic dislocation and flexion resulting in inferior obturator dislocation.

Femoro-acetabular impingement, either from decreased femoral head-neck offset (cam- type), or a deep acetabulum (pincer type), may be a risk factor of hip dislocation [10]. Insufficiency and stress fractures of the femoral head may occur, and their mechanism is often less comprehensible than high-energy trauma. They usually occur in patients with osteopenia, but also in healthy adults starting or intensifying exercise (e.g., in military recruits). They are reported as "subchondral impaction" or "insufficiency" fractures, but represent a significant injury to the femoral head [7, 11, 12].

## Associated Injuries

Patients with a hip dislocation and/or femoral head fracture typically sustain multiple injuries (including intra-abdominal, head, and chest trauma) that require inpatient management. Marymont et al showed that posterior hip dislocations may even signal thoracic aortic injuries because of abrupt deceleration [13]. Despite typical clinical findings, such as extremity deformation, the diagnosis of hip dislocation may be delayed due to life-threatening injuries.

Common accompanying skeletal injuries comprise femoral head, neck, or shaft fractures, acetabular fractures, pelvic fractures, and knee, ankle, and foot injuries. Knee injuries, including posterior dislocation, cruciate ligament injuries, and patellar fractures, are associated with posterior hip dislocations due to direct dashboard impact (Fig. 4.1).

Tabuenca et al identified major knee injuries in 46 out of 187 (25%) patients with hip dislocations and femoral head fractures [14]. Seven of these injuries were not diagnosed during the initial hospital stay. Associated injuries dictate treatment in most cases of hip dislocation. Among them, undisplaced femoral neck fractures represent a major diagnostic pitfall. High-resolution computed

**Fig. 4.1** Knee injury associated with posterior hip dislocation and femoral head fracture

tomography (HRCT) with fine cuts (2 mm) is needed to rule out occult femoral neck fractures before attempting closed reduction. In case of fracture lines at the level of the femoral neck, initial internal fixation must be considered.

Similarly, associated pelvic ring fractures may prohibit counter-traction, necessitating open reduction of the dislocation. Injuries to the knee are likely to be detected by careful clinical examination and conventional radiography.

Associated fractures of the hip itself, such as acetabular wall fractures and femoral head fractures, may require surgical intervention even if the hip dislocation can be reduced in a closed fashion. Femoral head fractures or intra-articular fragments may hinder closed reduction of the hip. Acetabular wall fractures may lead to instability – even after sufficient reduction – and then require fixation. Determining hip stability in the presence of a posterior wall fracture is important.

## Clinical Signs and Symptoms of Hip Dislocations and Fractures of the Femoral Head

In the scenario of interest, hip dislocations may be easily missed simply because other, potentially life-threatening injuries demand attention by the trauma surgeon in charge. Thus, no caregiver can be blamed for overseeing a hip dislocation and/or femoral head fracture in patients with multiple trauma. Whole-body MDCT has emerged as the imaging standard in most industrial countries and is likely to reveal unsuspected hip dislocations and femoral head fractures.

Still, clinical examination is valuable, and hip dislocations may occasionally be detected simply by the position of the patient's legs. Typically, the involved leg appears shortened and excessively rotated, either externally rotated in case of anterior dislocation, or internally rotated in case of posterior dislocation. If hip dislocation is suspected, palpation of all long bones and joints (specifically the knee) of the affected extremity and the pelvis (stability testing), along with a meticulous neurologic and vascular examination, are key. Documenting pre-reduction function of the sciatic nerve is important in posterior dislocations, as the nerve can be injured by reduction. Careful testing of all branches is required. For example, impaired foot eversion may indicate peroneal branch lesions. Posterior dislocations are associated with posterior knee dislocations (posterior cruciate ligament rupture). Anterior dislocations may injure the femoral vessels, necessitating a careful assessment of distal pulses and duplex ultrasound.

## Imaging and Other Diagnostic Studies for Hip Dislocations and Fractures of the Femoral Head

The first imaging available is usually the anteroposterior (AP) pelvis radiograph. This is usually taken as part of the initial trauma workup and helps direct treatment. The diagnosis of hip dislocation should be apparent on this single radiographic view (Fig. 4.2).

The key to the diagnosis on the plain AP pelvis is the loss of congruence of the femoral head with the roof of the acetabulum. On a true AP view, the head will appear larger than the contralateral head if the dislocation is anterior, and smaller if posterior. The most common finding, in the case of a

**Fig. 4.2** AP pelvis radiograph shows a posterior dislocation with a femoral head fragment left in the acetabulum

posterior dislocation, is a small head that is overlapping the roof of the acetabulum. In an anterior dislocation, the head may appear medial to or inferior to the acetabulum.

It is critical that the initial radiograph be of good quality and carefully inspected for associated injuries before a reduction is attempted. In particular, associated femoral neck fractures, which may be nondisplaced, must not be overlooked. Likewise, associated femoral head fractures are usually visible as a retained fragment in the joint (Fig. 4.3). Acetabular fractures and pelvic ring injuries are also visible on the plain AP radiograph. Additional radiographic assessment is not usually indicated before attempts at reduction unless a femoral neck fracture cannot be ruled out or there is a clinical suspicion of a femur, knee, or tibial injury that will affect the ability to use the extremity to manipulate the hip. In such cases, bi-planar radiographs of all questionable areas must be obtained.

The patient with a hip dislocation (including those with a femoral head fracture) has, in most of the cases, sustained a major trauma and will be subject to modern trauma management, which consists of an initial pan-CT-scan including angiography as a keystone of diagnostics (Fig. 4.3) [15]. Here, all relevant injuries

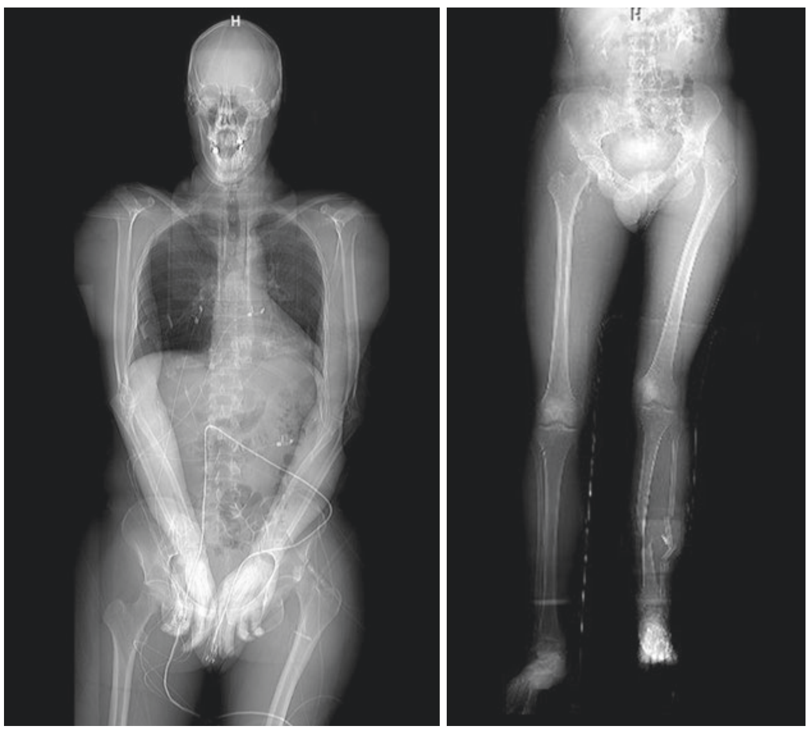

**Fig. 4.3** (**a**,**b**) Pan-CT as initial screening diagnostics in polytraumatized patient with posterior hip dislocation and femoral head fracture

can be detected within the first minutes of the patient's arrival at the trauma center.

A concomitant non-displaced femoral neck fracture and other adjacent injuries can be identified and have to direct the treatment. In the case of an unreducible hip, the CT scan has to be analyzed to identify the obstacle that prevents the femoral head from moving back into the acetabulum.

After reduction, five standard views of the pelvis should be obtained. These include the ap pelvis both Judet (45° oblique) views, and an inlet and outlet of the pelvis. Evaluation of the X-rays should focus on the concentric reduction of the hip. The use of the contralateral hip is necessary to answer this question. Using the relationship of the femoral head to the acetabular roof on each view, the congruency of the hip is evaluated by comparing it to the contralateral side. Any incongruency or widening of the joint space may indicate a loose body inbetween femoral head and the acetabulum.

After reduction of the hip, a CT scan with a minimum of 2 mm cuts through the hip is the diagnostic standard. The scan is more sensitive in detecting small, intra-articular fragments, femoral head fractures, femoral head impaction injuries, acetabular fractures, and joint incongruity. Hougaard et al reported six cases of minor acetabular fractures, and six cases of retained intra-articular fragments visualized on CT and not visible on plain radiographs after closed reduction of posterior hip dislocations [16]. The congruence of the hip is also easily evaluated using CT. The head should be in the center of the subchondral ring of the acetabulum as it becomes visible, appearing as a bulls eye. Impaction injuries and femoral head fractures are much more easily seen on the post-reduction CT. The quality of the reduction of femoral head fractures is also apparent and determines treatment. Besides the importance of meticulous diagnostics, the CT scan plays a major role in planning the operative intervention, when necessary, in cases of concomitant fracture, irreducible dislocation, or incongruent reduction. The location, size, and number of free intra-articular fragments and the location, The location and size of an acetabular fracture as well as the size and location of a femoral head fragment must be identified and will affect the treatment plan.

MRI is helpful in the evaluation of a traumatic osteonecrosis of the hip. MRI changes of AVN may not be present before 6 to 8 weeks. MRI studies can also help define soft tissue injuries following hip dislocations. Apart from its predictive values of AVN in the acute setting, MRI is the optimal study for evaluation of the soft tissues such as the external rotator tendons, the labrum, and cartilage. The traumatized hip from a dislocation will likely have an effusion, which will help identify any abnormalities of the labrum or capsule.

## Injury Classification Schemes

### Classification of Hip Dislocations and Fractures of the Femoral Head

Several classification schemes have been described for hip dislocations. All of these schemes include subtypes for important associated injuries. The first distinction is whether the hip dislocation is anterior or posterior.

Posterior dislocations are much more common than anterior dislocations. Two original classification schemes have been described for posterior dislocations. Thompson and Epstein and, subsequently, Stewart and Milford, both described systems incorporating associated fractures.

The Stewart and Milford scheme specifically addresses post-reduction stability in the case of acetabular fracture, which has prognostic implications. Epstein's type 5 dislocation includes a femoral head fracture. This type has been subdivided by Pipkin into four types (Table 4.2 and Fig. 4.4).

The Pipkin classification is commonly used and is important in decision-making.

A combined descriptive scheme has been suggested by Brumback et al and can be used for anterior or posterior dislocations with femoral head fractures (Table 4.3). Brumback's classification takes into account the size of the head fragment, the direction of the dislocation, and the resulting instability [18].

Finally, the Orthopaedic Trauma Association's comprehensive fracture classification scheme includes hip dislocations (Fig. 4.5).

The most important factors are whether there is an anterior or posterior dislocation, an associated fracture in the vincinity (acetabulum, femoral neck), and the stability of the hip after reduction (only the Brumback Classification [Fig. 4.6 and Table 4.3] takes all these relevant factors into account). In each scheme, the presence of an acetabular fracture requiring reduction and fixation is noted.

**Table 4.2** Pipkin classification

| | |
|---|---|
| Type I | Posterior dislocation with femoral head fracture caudad to the fovea |
| Type II | Posterior dislocation with femoral head fracture cephalad to the fovea |
| Type III | Femoral head fracture with associated femoral neck fracture |
| Type IV | Type I, II, or III with associated acetabular fracture |

## Treatment Options for Hip Dislocations and Fractures of the Femoral Head

### Non-operative Treatment of Hip Dislocations and Fractures of the Femoral Head

The initial management for almost all hip dislocations is an attempt at a closed reduction (Table 4.4). The reduction should be considered an emergent procedure and includes patients with

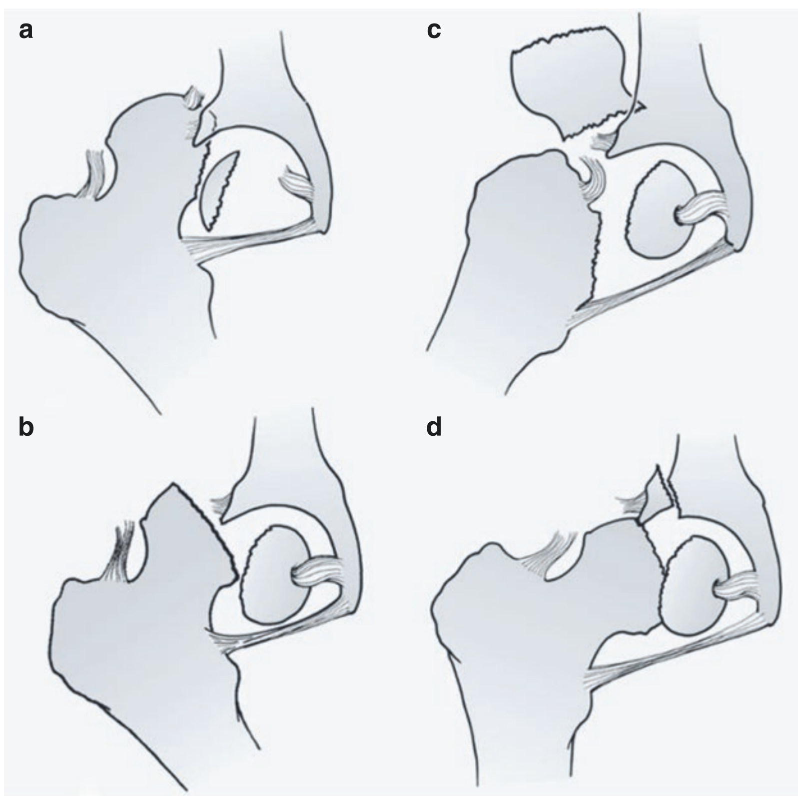


**Fig. 4.4** Pipkin classification. (**a**) Fracture inferior to fovea (**b**) Fracture superior to fovea(**c**) Fracture of femoral head and neck (**d**) Fracture of femoral head and acetabular fracture [17]

**Table 4.3** Brumback classification of femoral head fractures

| Type | Description |
|---|---|
| Type 1 | Posterior hip dislocation with fracture of the femoral head involving the inferomedial portion of the femoral head |
| Type 1A | With minimum or no fracture of the acetabular rim and stable hip point after reduction |
| Type 1B | With significant acetabular rim and stable joint after reconstruction |
| Type 2 | Posterior hip dislocation with fracture of the femoral head involving the supermedial portion of the femoral head |
| Type 2A | With minimal or no fracture of the acetabular rim and stable joint after reduction |
| Type 2B | With significant acetabular fracture and hip point instability |
| Type 3 | Dislocation of the hip (unspecified direction) with femoral neck fracture |
| Type 3A | Without fracture of the femoral head |
| Type 3B | With fracture of the femoral head |
| Type 4 | Anterior dislocation of the femoral head |
| Type 4A | Indentation type, depression of the superolateral surface of the femoral head |
| Type 4B | Transchondral type, osteocartilaginous shear fracture of the weight-bearing surface of the femoral head |
| Type 5 | Central fracture-dislocation of the hip with femoral head fracture |

From Stannard et al. [20]

concomitant femoral head fractures or acetabular fractures.

Contraindications to standard closed reduction are non-displaced femoral neck fractures and other associated injuries that exclude using the lower extremity to manipulate the hip.

A reduction is typically performed in the operating room, but can be performed in the emergency department if the patient is already intubated. Regardless of the direction of the dislocation, the reduction is attempted by traction in line with the femur and gentle rotation.

An Allis maneuver is next if the dislocation is posterior.

The patient must be under a full muscular relaxation, regardless of the technique used in order to achieve a closed reduction of the hip joint. The use of real-time fluoroscopy to aid the reduction is recommended. The position of the head with respect to the acetabulum can be easily visualized if there is difficulty reducing the hip, and adjustments based on the position can be made. It also allows for a thorough evaluation of hip stability or, if warranted, a stress exam following reduction.

The Walker modification of the Allis technique is performed if the dislocation is anterior (Fig. 4.7).

Anterior dislocations are also reduced using traction and counter-traction. For inferior dislocations, Walker described a modification of the Allis technique. Traction is continuously applied in line with the femur with gentle flexion. Along with a lateral push on the inner thigh, internal rotation and adduction are used to reduce the hip (Fig. 4.8). If the dislocation is superior, then distal traction is applied until the head is at the level of the acetabulum and gentle internal rotation is applied. Extension may be necessary when reducing anterior dislocations.

For all types of reduction, the surgeon should use steady traction. By using continuous distraction and gentle manipulation, the reduction is achieved while minimizing additional trauma. Sudden forceful movements can cause fractures of the neck and damage the articular surface of the femoral head. If the closed reduction is successful, then post-reduction diagnostics include AP and Judet views of the hip, and a CT with 2-mm cuts are obtained to determine the congruence of the reduction and the post-reduction position of any associated fractures or loose bodies. If there is no associated fracture and the hip is congruent with symmetric joint space to the contralateral hip on all plain films and the CT scan, then non-operative management is recommended. Sometimes a small fragment attached to the ligamentum teres is visible within the joint, but

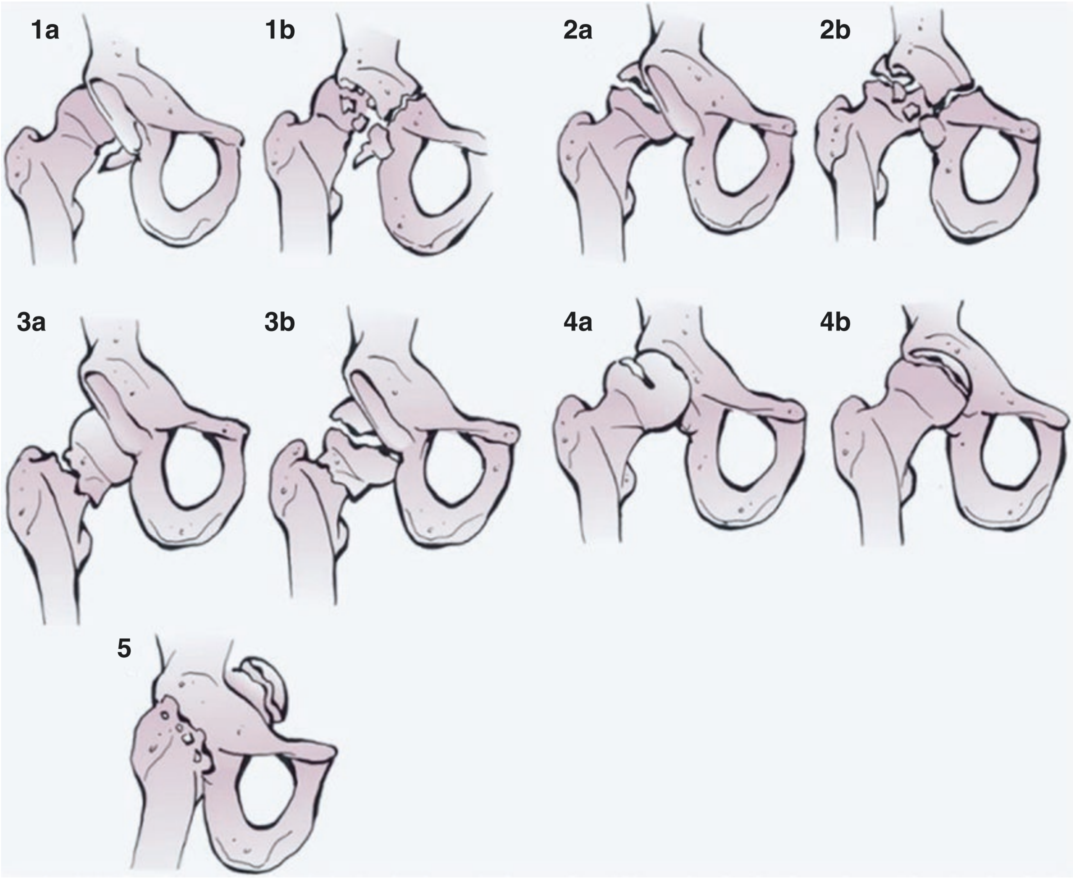


**Fig. 4.5** Brumback classification of hip dislocations and femoral head fractures

if positioned within the fovea, then it may be treated non-operatively, since it will not move due to its tether to the ligamentum teres.

In the early post-operative period, patients may experience groin pain or mechanical symptoms. These should be worked up with MRI and may be considered for operative management with hip arthroscopy.

## Fluoroscopic Evaluation of the Hip Following Closed Reduction

Definitive non-operative management is also indicated if there are fractures that do not require fixation or cause instability of the hip. Two types of injury fall into this category: Pipkin type I femoral head fractures, which do not create incongruity, and small posterior wall fractures that do not allow for instability. In cases of inferior femoral head fractures, the fragment does not affect the weight-bearing surface. These fracture fragments are not loaded during normal gait and therefore may be treated as loose bodies. If the fragments are well reduced or in a position that does not create an incongruent reduction of the hip, they can be left in place. Thus, fixation or excision is not necessary if the reduction of the hip is congruent. These injuries may be treated with the same non-operative protocol as a pure hip dislocation.

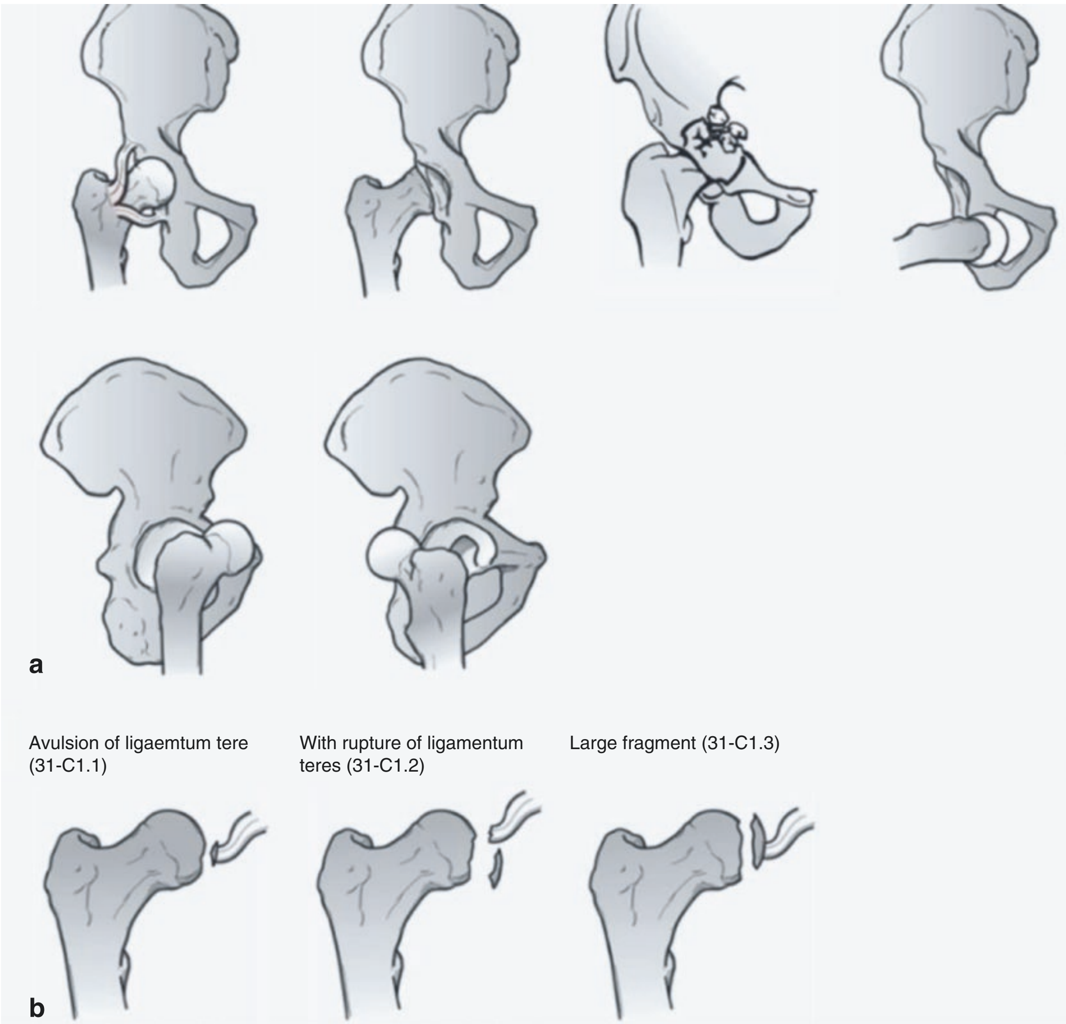


**Fig. 4.6** OTA classification classification of femoral head fractures with hip dislocation

**Table 4.4** Indications for non-operative treatment in hip dislocations with femoral head fractures

| Non-operative treatment after successful hip reduction | |
|---|---|
| Indication | Relative contraindication |
| Pipkin I | Pipkin III and IV |
| Pipkin II | Incongruent reduction of the head fragment |
| Congruent joint post reduction | Unstable joint |
| Small ligament teres fragment in the fossa | Loose bodies interfere with the joint surface |

The amount of posterior wall that can be affected without causing instability is debated. If greater than 35% of the posterior wall is affected, the loading pattern of the hip is altered and may lead to post-traumatic arthritis. On the basis of cadaveric studies, most authors would recommend ORIF of these fractures. If the posterior wall fragment is small enough that fixation may not be required, stability testing can be performed to ensure that the hip is stable.

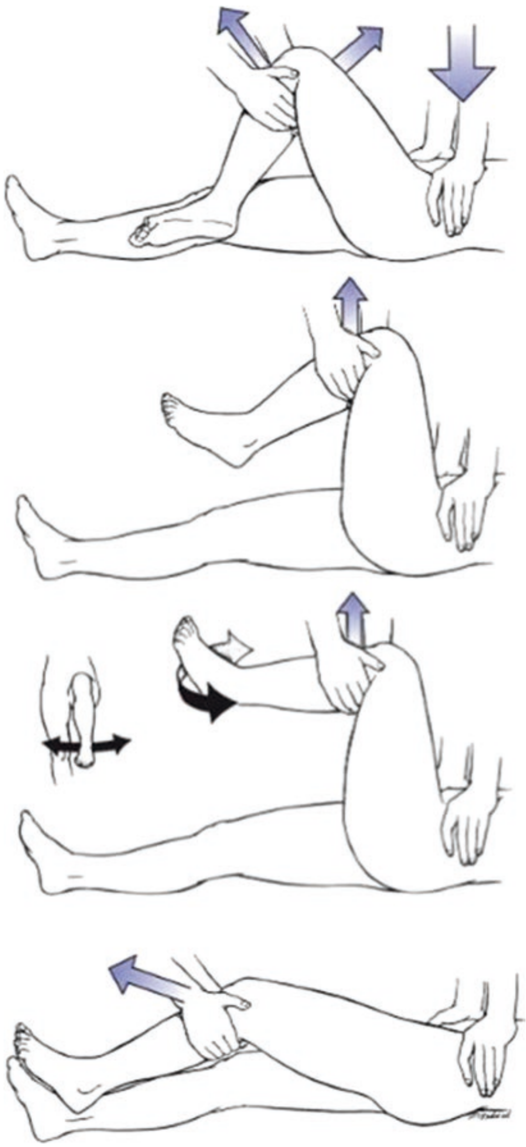

**Fig. 4.7** Allis maneuver for posterior hip reduction

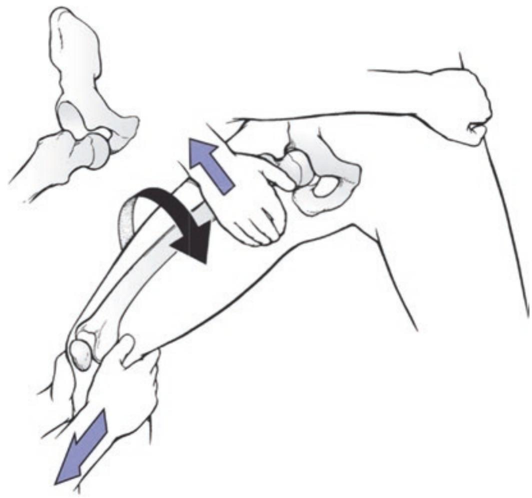

**Fig. 4.8** Walker maneuver for anterior hip reduction

In the face of an associated posterior wall fracture, if the hip reduction is incongruent, then an open reduction of the hip is necessary with removal of debris as described above. The posterior wall is fixed at the same time through the same incision.

## Operative Treatment of Hip Dislocations with Fractures of the Femoral Head

### Indications/Contraindications

Operative management is required if the hip joint is irreducible, or if there is an incongruent reduction; there is also a relative indication for operative management with sciatic nerve damage following an attempted reduction, and in some cases of fracture-dislocation. A secondary nerve lesion (after reduction) should lead to immediate, specific diagnostics to rule out a fragment or an interposition that is mechanically impinging. If mild traction during reduction has caused the nerve lesion in most cases, spontaneous recovery is to be expected.

Indications for operative treatment can be broken down into two treatment groups:

(1) Open reduction with or without debridement, and
(2) Open reduction and internal fixation.

If an open reduction is necessary to restore an articulating hip joint, then joint debridement and treatment of all associated fractures can be performed simultaneously. For example, a posterior wall fracture or Pipkin II fracture can be reduced and stabilized in the same session as loose bodies are removed from the joint.

In cases of a posterior wall and intra-articular debris, a surgical hip dislocation may be the best choice, as it allows 360° views of the head and acetabulum while preserving the blood supply to the head.

If the hip is reduced, but incongruent, then the offending structures need to be removed, which can be done arthroscopically or in an open fashion. For small intra-articular fragments, an arthroscopic approach is preferred. Large fragments can be extracted by surgical hip dislocation.

During the debridement of loose bodies, it is difficult to determine whether the joint is completely free of fragments; therefore, knowing the number, location, and sizes of bony fragments is imperative. If the labrum is avulsed from the acetabular rim, repair via suture anchors to a freshened cancellous surface may provide improved stability.

Post-op protocol for patients with hip dislocations and femoral head fractures include HO prophylaxis with NSARs (indomethacin) for 6 weeks; radiation is in most cases not favored due to the young population. In dislocations with fractures of the femoral head and open reduction with internal fixation, we allow immediate mobilization with movement of the hip joint and touch-down partial weight bearing, progressing to full weight bearing after 10-12 weeks.

## Open Reduction with or without Debridement and with or without ORIF

Irreducible dislocations require emergent open reduction. Approximately 2-15% of dislocated hips are irreducible via closed means. The offending structure may be a bony impingement or soft tissue interposition. Anterior dislocations are associated with interposition of the M. rectus femoris, the iliopsoas, the anterior hip capsule, or the labrum. Buttonholing through the capsule, and bony impingement in the obturator foramen, have also been reported. In posterior dislocations, the causes of irreducibility are buttonholing though the posterior capsule, and interposition of the piriformis, gluteus maximus, ligamentum teres, labrum, or large bone fragments.

Incongruent reductions occur if there are bony fragments or soft tissue interposed in the acetabulum. Free fragments located between the femoral head and acetabular articular cartilage must be removed. This may be an indication for arthroscopic debridement and evaluation of the hip joint, depending on the size of the fragment(s).

The post-reduction CT will show the location, size, and number of offending bony fragments, thereby allowing better planning of the procedure (Fig. 4.9). Fragments treated by debridement include avulsions from the femoral head, inferior femoral head fractures (Pipkin type I), loose fragments from the posterior wall, and cartilage fragments sheared from the femoral head.

In many cases, Pipkin type II fractures align well with reduction of the hip as the femoral head fragment is held in place by the ligamentum teres. A post-reduction CT of the hip joint, in conjunction with an AP and Judet views, will show any displacement. If the fragment is not anatomically reduced (step off >2 mm, gap >4 mm), then ORIF has to be considered. Fixation

**Fig. 4.9** Post-reduction CT scan with displaced head fragment

of these fractures can be challenging, as the fragment is frequently thin.

Many surgical approaches have been advocated for open reduction and internal fixation of femoral head fractures. Due to the most common mechanism of a posterior hip dislocation, the fracture fragment is often located anteromedially, as it was sheared off by the posterior wall. Although Epstein had recommended debridement of the joint via a posterior approach to utilize the already damaged capsule, this may not be the best approach for the treatment of femoral head fractures. To reduce and fix an anteromedial fracture of the femoral head from a posterior approach, the hip may require re-dislocation. Even with the femoral head out of the acetabulum, anatomic reduction may be difficult without disrupting the ligamentum from the femoral head fragment, potentially devascularizing it. Positioning the intact posterolateral head against the anteromedial fragment – without disrupting its soft tissue – is extremely difficult, and, at best, visualization of only a portion of the fracture is possible. In addition, the posterior approach may further compromise the medial femoral circumflex artery, the blood supply to the femoral head, making other surgical approaches more appealing.

An anterior approach (modified Smith-Peterson) allows for direct visualization of the femoral head fragment without re-dislocating the hip. External rotation of the hip allows for cleaning of the fracture bed and accurate reduction of the fragment. Since the major blood supply to the femoral head arises from the posterior cervical branches (MFCA), which may be damaged, there is a consideration for an anterior surgical dissection. Swiontkowski et al compared the anterior and posterior approaches in the management of femoral head fractures meeting operative criteria. The incidence of AVN was not increased in hips treated via the anterior approach vs. the posterior approach [19]; the anterior approach allowed for an easier reduction and better visualization. Stannard et al also found a higher rate of AVN after posterior than anterior approach for treatment of femoral head fractures. Four of five patients treated via a posterior approach developed AVN to some degree [20].

A trochanteric osteotomy with a surgical dislocation of the hip, described by Ganz et al, has also been described to treat these fractures. Massè et al reported on a series of 12 patients with femoral head fractures treated with surgical dislocation [21, 22]. In this group, 83% had good-to-excellent outcomes, compared to 56% of patients treated using other approaches (Watson-Jones, Smith-Petersen, and Kocher-Langenbeck). Other authors have also described this technique for femoral head fractures – in particular, those with combined posterior wall lesions. While this is a logical approach for the treatment of femoral head fractures, thus far only small numbers of patients have been reported on.

Fixation of the fragments is often difficult, due to the shallow nature of the fragment. Techniques that allow for subarticular fixation are necessary. These include the use of headless screws, countersunk screws, resorbable pin fixation, and suture repair. Regardless of the chosen technique, it is imperative that the fixation be within the subchondral bone and not protrude into the joint.

Lastly, large femoral head impaction may require operative fixation and restoration of joint congruity. Recent biomechanical studies have shown that a 2 $cm^2$ area must be present to significantly affect the contact force distribution in the hip. If such an injury exists, the impacted area can be elevated and grafted. This should be considered if there is an impacted area of 2 $cm^2$ and more in the weight-bearing portion of the head.

## Arthroscopic Technique in the Management of Hip Dislocations

The use of hip arthroscopy has increased substantially in the last decade. During this time, the instrumentation and techniques have improved, and therefore its use for the treatment of the injured hip has significantly increased. Several authors have now demonstrated that loose bodies, chondral injuries, and labral tears occur as a result of simple hip dislocation and are not detected by initial plain radiographs or fine-cut CT scans. Hip arthroscopy can be used for fracture-dislocations of the hip in which only a debridement of chondral damage or small loose bodies is necessary. There have been case reports of fracture fixation using arthroscopic methods, but this is not yet advocated as standard practice. Hip arthroscopy is contraindicated if there are fractures of the acetabulum that would allow fluid extravasation into the pelvis. The tear of the capsule after hip dislocation creates no obstacle if a modern fluid management system is used in arthroscopy.

## Complications

### Avascular Necrosis (AVN)

AVN is a common sequela of posterior hip dislocations and correlates with the time to reduction. AVN occurs in 1.7-40% of hip dislocations. If the hip is reduced within 6 h of the dislocation, the literature shows significantly lower AVN rates – between 0 and 10% [23].

The cause of AVN is thought to be multifactorial. In part, the cervical vessels to the head and the contributions from the ligamentum teres are damaged at the time of injury. Secondarily, an ischemic injury to the femoral head while it is dislocated affects the outcome.

Radiographic findings of an AVN are usually present within 2 years of the injury (Figs. 4.10, 4.11, and 4.12).

Diagnosis may be delayed until collapse is present. MRI is the most sensitive and specific imaging modality for AVN and is recommended if there are signs and symptoms. Treatment should involve initial weight-bearing restriction to prevent subchondral collapse.

### Arthritis

The most common complication after hip dislocation with femoral head fracture is post-

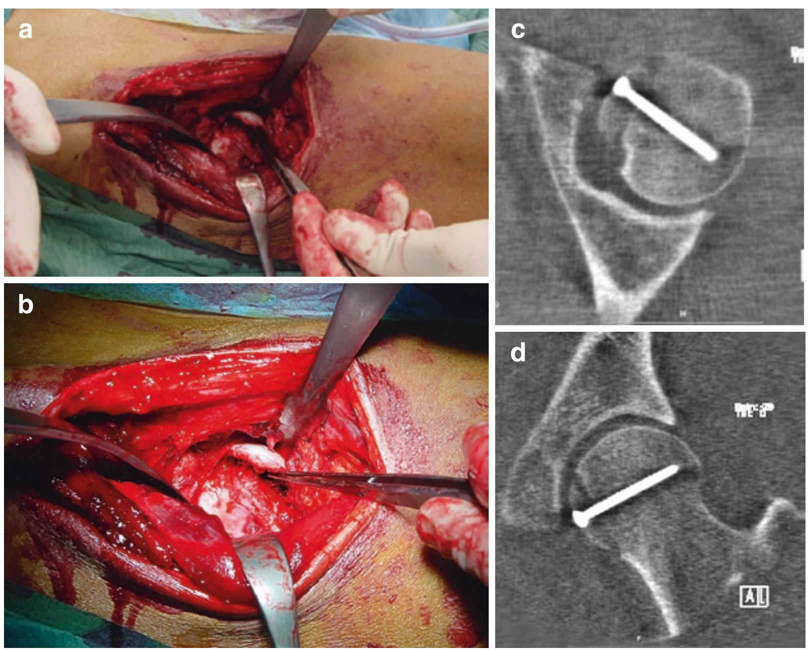


**Fig. 4.10** (**a**) Anterior approach to the hip joint showing a displaced femoral head fragment, after posterior fracture dislocation and initial closed reduction. (**b**) Mobilizing the fragment and performing the reduction. (**c**, **d**) Intraop 3-D imaging with C-Arm for control of fracture reduction and congruity of the hip joint

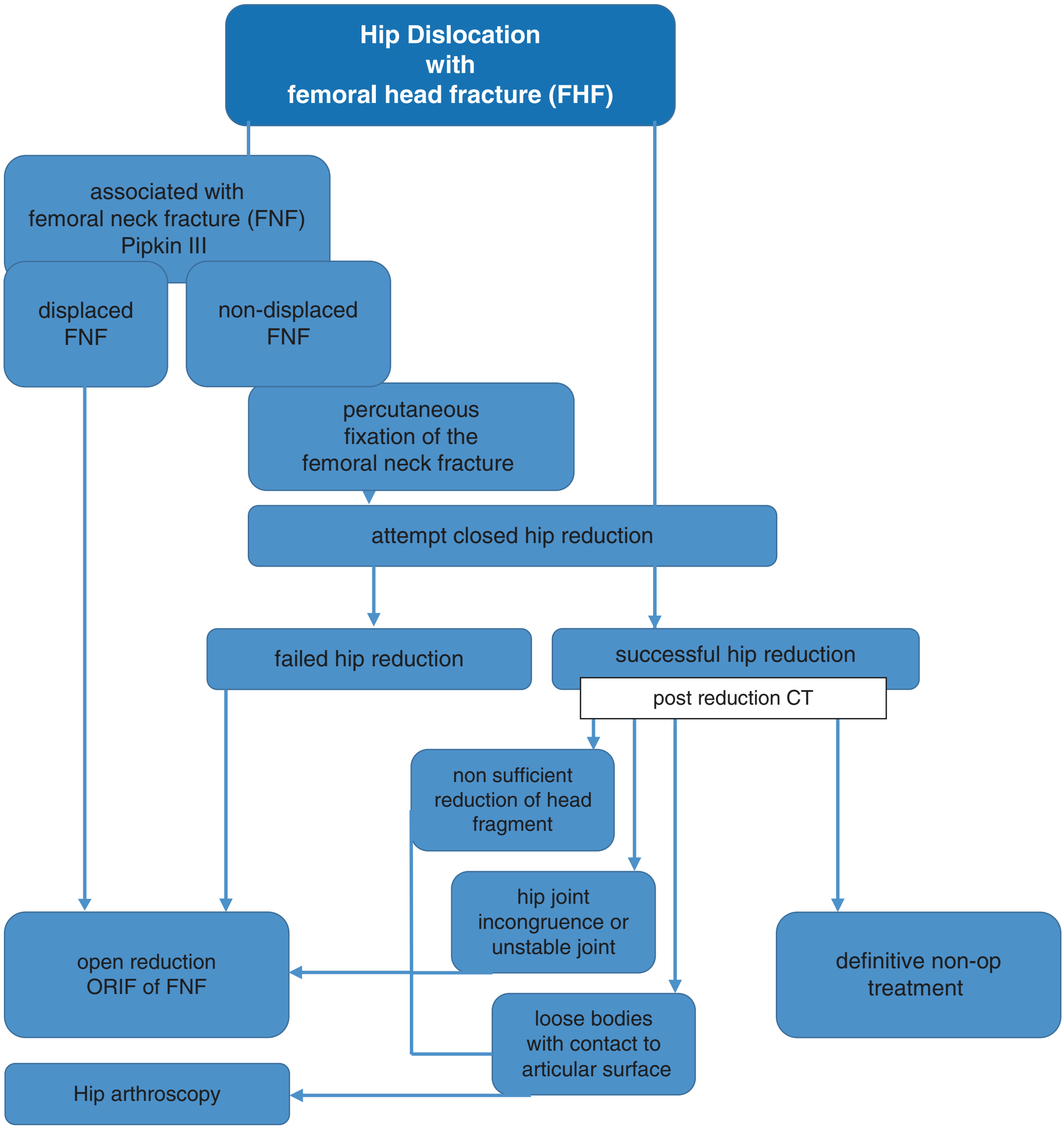


**Fig. 4.11** Treatment algorithm for dislocations of the hip with femoral head fragments

traumatic arthritis. Posterior dislocations have a higher rate of post-traumatic arthritis than anterior dislocations. Dislocations with associated femoral head fractures may develop arthritis in 50% of patients. The higher rates of arthritis in fracture dislocations may be in part due to chondrocyte damage, as marginal cartilage injury is common in cases of fracture dislocation. Repo and Finely were able to induce chondrocyte death by applying a 20-30% strain.

In addition, AVN does lead to arthritis. The incidence of primary arthritis is highest in severely injured patients. The effect of open reduction on later degeneration is not clear.

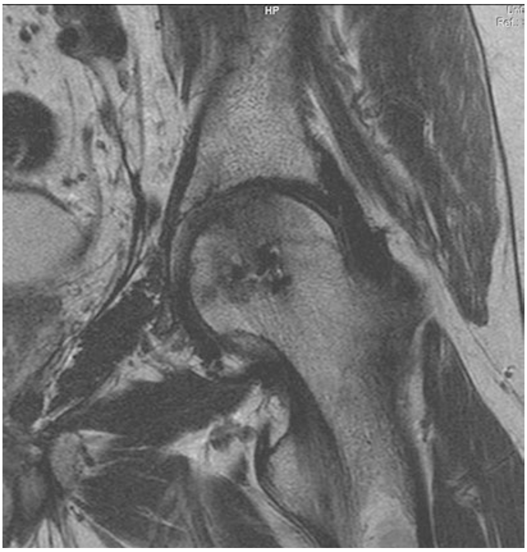


**Fig. 4.12** MRI 9 months after posterior hip dislocation with femoral head fracture and AVN of the femoral head

### Heterotopic Ossification (HO)

Heterotopic ossification is very common after posterior fracture dislocation (Fig. 4.12). It is most common after open reduction of a posterior dislocation. This complication is also commonly reported after posterior wall fractures. It is likely due to posterior muscle injury from the dislocation in combination with surgical trauma. In cases of femoral head fracture, Swiontkowski et al reported on a higher incidence of HO after ORIF via an anterior approach than a posterior approach [19]. In cases of posterior dislocation, the use of indomethacin may diminish the rate of clinically significant HO. Radiation therapy, usually a single dose with 700 Gy may be administered 24 h before, or within 48 h post-operatively. Data on the effectiveness of NSAIDs vs. radiation are inconsistent at best, and future large RTCs will need to identify the optimal prophylaxis [24]. HO development seems to be related to initial trauma impact. Pape et al reported a rate of 60% in cases that did not undergo surgical fixation [25].

### Malunion

Yoon et al reported on three patients who required late excision of an inferior femoral head fracture due to pain and limitation of motion. These patients were initially treated with non-weight bearing and then gradual ambulation. In each case, the inferior fragment was excised, thereby restoring motion.

### Sciatic Nerve Dysfunction

Late sciatic nerve dysfunction has been reported by several authors. It is usually from HO, either compressing the nerve or causing it to be stretched. It is important to continue to examine the nerve function at each post-injury visit, as early decompression may favor neurologic return.

## Outcomes After Femoral Head Fractures

### Outcome Measures

The assessment of patient outcome following hip dislocation or fracture-dislocations revolves around the patient's function and pain. Osteonecrosis, joint stiffness, and arthritis are the main limiting factors for patient outcomes; hence, evaluating outcomes using standardized hip scores, such as the Harris Hip score, WOMAC, and Merle d'Aubigné, are most commonly reported. These scores provide clinicians with insight into how the patients' hips are functioning, and they are used in combination with overall health scores such as SMFA and SF12.

### Evidence

The probability of identifying large-scale, high-quality randomized trials (RCT) on the management of femoral head fractures was very low. Given the rarity of this type of fracture, we accepted a broad scope of designs and individual study features to provide a rough estimate about the likely outcomes and, whenever possible, some guidance for individualized care to clinicians and patients.

To find the best available evidence, we first searched for systematic reviews and meta-analyses in Ovid Medline, Embase, and the Cochrane Library. We limited our search to reviews published between January 1, 2006 and January 1, 2016, appearing in English, French or German. Individual studies included in these reviews were identified, and by an iterative process and screening of reference lists, we further identified potentially relevant studies published at any time. To be included in this review, individual studies (whether full-text publications or conference proceedings) had to fulfill the following criteria:

1. The investigation included ≥10 patients (this was an arbitrary threshold).
2. The study reported functional outcomes using an accepted scoring system (e.g., Thompson-Epstein, Merle d'Aubigné, or others).
3. The study provided some information about the demography of patients, the classification of fractures (e.g., Pipkin type, AO/OTA grading), and surgical details.

We excluded case reports and technical notes. While we made efforts to retrieve full-text articles not available even from a major university library (Charité Medical University Center, Berlin, Germany) through other access options, we deliberately stopped at this stage. We are aware of missing one historical review because of this decision [18].

We identified three systematic reviews meeting our primary screening criteria [26–28]. These reviews included 12 original studies of 285 patients [19, 20, 28–38]. Table 4.5 summarizes key characteristics of the studies. Of note, there were two reports of small RCTs comparing operative and non-operative treatment of femoral head fractures [28, 29]. They may be based on a single RCT with individual results published for Pipkin 1 and 2 fractures. In addition, we identified a classic paper (including 41 fractures) published in 1992 [19].

The overwhelming body of evidence on the management of femoral head fractures comes from retrospective cohorts susceptible to almost all thinkable sources of bias. There is selection bias, bias by indication, an uncertain number of patients lost to follow-up, and so on. This must be taken into consideration when interpreting the results. Apart from cumulative data, nine reports [20, 28–33, 35, 37] offered individual patient data (IPD) on 175 participants, which is a strength which is a strong point in this kind of study.

For a first assessment of treatment effects, we used a random-effects model (metaprop procedure in STATA 11.0) to summarize the frequency of "excellent" and "good" outcomes, as assessed by the Thompson-Epstein scale. In a heterogeneous population with different baseline risks and different treatment approaches, about 72% (95% confidence interval [CI] 65-78%) of all patients achieved excellent or good results (Figs. 4.13 and 4.14).

ORIF (as compared to any other treatment option) was associated with

1. A higher relative risk (RR) of heterotopic ossification of any Brooker grade (RR 1.44, 95% CI 0.97–2.14)
2. A lower relative risk of AVN (RR 0.34, 95% CI 0.09–1.19)
3. A higher likelihood of excellent or good outcomes according to Thompson-Epstein criteria (RR 1.26, 95% CI 1.03–1.54)
4. A higher likelihood of excellent outcomes according to Thompson-Epstein criteria (RR 2.77, 95% CI 1.51–5.06

**Table 4.5** Study and patient profile of all included investigations

| Author | Year | n | Mean age, years (SD) | Male patients | Pipkin type | | | | Management | | | | Outcome, Thompson-Epstein score | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1 | 2 | 3 | 4 | ORIF | Excision | Arthroplasty | Non-op. | Excellent | Good | Fair | Poor |
| Chen et al [28] | 2011 | 16 | 37.5 (11.4) | 13 (81%) | 16 | 0 | 0 | 0 | 8 | 0 | 0 | 8 | 6 | 5 | 3 | 2 |
| Chen et al [29] | 2011 | 24 | 38.7 (11.0) | 17 (71%) | 0 | 24 | 0 | 0 | 12 | 0 | 0 | 12 | 7 | 8 | 7 | 2 |
| Guimaraes [30] | 2010 | 10 | 32.2 (12.6) | 7 (70%) | 6 | 3 | 0 | 1 | 10 | 0 | 0 | 0 | 6 | 2 | 1 | 1 |
| Henle [31] | 2007 | 12 | 39.8 (12.2) | 10 (83%) | 1 | 3 | 0 | 8 | 12 | 0 | 0 | 0 | 5 | 5 | 0 | 2 |
| Kokubo [32] | 2013 | 10 | 51.7 (16.1) | 6 (60%) | 5 | 2 | 0 | 3 | 4 | 4 | 0 | 2 | 2 | 7 | 0 | 1 |
| Marchetti [33] | 1996 | 33 | 33.6 (13.7) | 22 (67%) | 8 | 9 | 2 | 14 | 13 | 15 | 3 | 2 | 0 | 22 | 6 | 5 |
| Mostafa [38] | 2014 | 23 | 39.1 (8.8) | 14 (61%) | 5 | 18 | 0 | 0 | 23 | 0 | 0 | 0 | 18 | | 5 | |
| Norouzi [34] | 2012 | 28 | 33 (13) | 21 (75%) | 13 | | | 8 | 13 | 4 | 2 | 9 | 20 | | 8 | |
| Oransky [35] | 2012 | 21 | 42.0 (15.9) | 14 (67%) | 4 | 9 | 0 | 8 | 11 | 7 | 0 | 3 | 8 | 8 | 2 | 3 |
| Park [36] | 2015 | 59 | | | 15 | 28 | 9 | 7 | 23 | 25 | 7 | 4 | 34 | | 25 | |
| Stannard [20] | 2000 | 22 | 37.2 (15.2) | 14 (64%) | 4 | 9 | 0 | 9 | 12 | 10 | 0 | 0 | 7 | 4 | 3 | 8 |
| Yoon [37] | 2001 | 27 | 40.4 (12.8) | 22 (81%) | 5 | 18 | 4 | 0 | 14 | 12 | 1 | 0 | 7 | 15 | 4 | 0 |

**Fig. 4.13** Small heterotopic ossification 6 months after posterior dislocation of the hip and femoral head fractures with anterior approach

Individual findings are shown in Table 4.6.

Based on data from their systematic review, Wang et al concluded that "…the posterior approach decreased the risk of heterotopic ossification compared with the anterior approach for the treatment of Pipkin I and II femoral head fractures." [36] Unfortunately, this review cannot be reproduced using the information traced from original studies. There are multiple data extraction errors, and the presented summary estimates are erroneous. Stannard et al found no difference in Short-Form 12 physical component scores (PCS) between patients who underwent surgery by an anterior ($n$ = 9) or a posterior ($n$ = 13) approach. Mean PCS scores were 39.8 (SD 14.8) and 40.0 (SD 13.1), respectively [20].

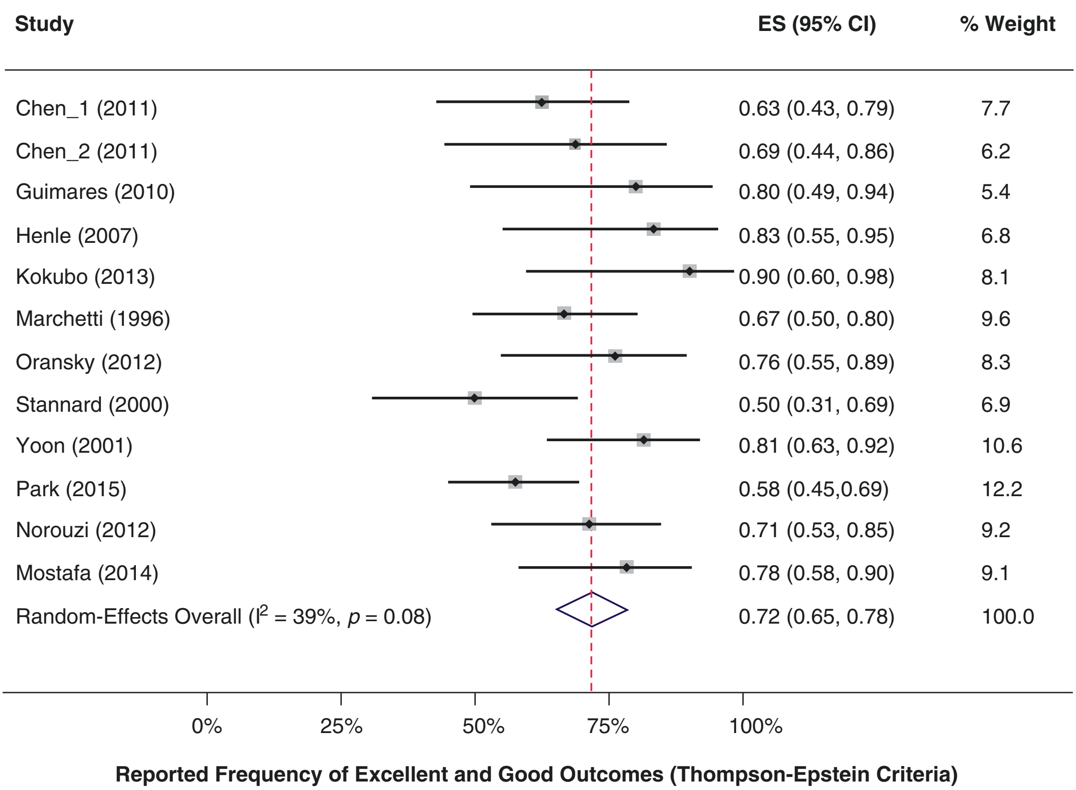


**Fig. 4.14** Meta-analysis of excellent or good outcomes (according to Thompson-Epstein criteria) in patients with femoral head fractures of any grade undergoing any type of treatment

**Table 4.6** Study and patient profile of included investigations

| | ORIF | Other options |
|---|---|---|
| *n* | 96 | 79 |
| Mean age, years (SD) | 35.8 (12.0) | 41.9 (15.4) |
| Gender | | |
| Male | 68 (71%) | 57 (72%) |
| Female | 28 (29%) | 22 (28%) |
| Pipkin classification | | |
| 1 | 22 (23%) | 27 (34%) |
| 2 | 46 (48%) | 31 (39%) |
| 3 | 2 (2%) | 4 (5%) |
| 4 | 26 (27%) | 17 (22%) |
| Dichotomized Pipkin class | | |
| 1/2 | 68 (71%) | 58 (73%) |
| 3/4 | 28 (29%) | 21 (27%) |
| Complications | | |
| HO | | |
| *n* | 60 | 56 |
| Brooker grade | | |
| 0 | 26 (43%) | 34 (61%) |
| 1/2 | 22 (37%) | 14 (25%) |
| 3/4 | 12 (20%) | 8 (14%) |
| Any HO | 34 (57%) | 22 (39%) |
| AVN | | |
| *n* | 56 | 50 |
| Any AVN | 3 (5%) | 8 (16%) |
| Thompson-Epstein | | |
| *n* | 96 | 79 |
| Excellent | 37 | 11 |
| Good | 38 | 38 |
| Fair | 10 | 16 |
| Poor | 11 | 14 |
| Excellent/good | 75 (78%) | 49 (62%) |
| Fair/poor | 21 (22%) | 30 (38%) |

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# 5 Femoral Neck Fractures in the Young

Ewan B. Goudie, Andrew D. Duckworth, and Timothy O. White

## Introduction

Hip fractures in young adults are uncommon injuries; however, the complications can be severe. The rate of nonunion is approximately 10%, and that of AVN is 23% in young adults with displaced intracapsular neck of femur fractures [1]. Secondary salvage procedures such as osteotomy have associated risks and a notable failure rate, whilst the longevity of a hip arthroplasty and the potential need for revision surgery are problematic given the young age and higher level of function in this patient group. In order to achieve good outcomes, it is essential to understand the differences in treatment principles between elderly, frail patients and their physiologically young and active counterparts.

In contrast to the elderly population, hip fractures in young adults are often caused by high-energy injuries, resulting in fracture comminution and disruption of blood supply to the femoral head. Associated skeletal and visceral injuries are common. Anatomic reduction and stable fixation are imperative for a good outcome. However, controversy remains regarding the role of ancillary techniques such as capsulotomy, as well as the timing of surgery and the device choice and configuration. The aim of this chapter is to summarize the main management principles, outcomes of treatment and potential complications in young adults with hip fractures.

## Epidemiology

Younger patients constitute a small proportion of those presenting with femoral neck fractures, accounting for 3% of all hip fractures [2–5]. A significant force is usually required to fracture the femoral neck of a physiologically young adult. This most often is a result of an axial load with external rotation of the hip in an abducted position [4, 6]. The anterior capsule holds the femoral head fixed, whilst the hip rotates externally, and the posterior cortex of the neck impinges on the lip of the acetabulum. The anterior cortex fails in tension and the posterior cortex is compressed, often producing comminution that can result in a problematic reduction and stable fixation [7].

Common high-energy mechanisms of injury include road traffic accidents, sporting injuries or falls from height. This is in contrast to the elderly population, where low-energy fractures usually result from a fall from a standing height [7]. The literature does highlight a significantly lower mean age of males when compared to females for displaced fractures of the femoral neck in young patients, with high-energy trauma

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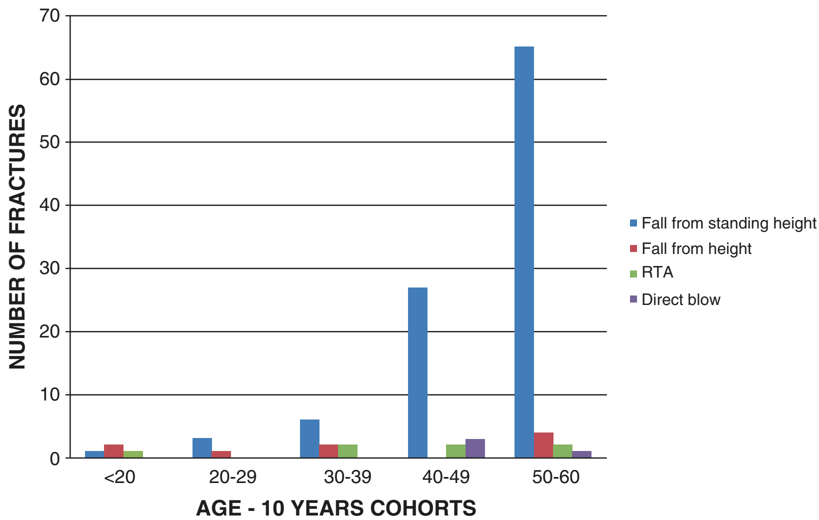


**Fig. 5.1** The distribution of young hip fractures by 10-year cohorts according to mechanism of injury, as presented by Duckworth et al. [5] (Reproduced with permission and copyright © of the British Editorial Society of Bone and Joint Surgery. From Duckworth AD, Bennet SJ, Aderinto J, Keating JF. Fixation of intracapsular fractures of the femoral neck in young patients: risk factors for failure. J Bone Joint Surg Br. 2011; 93–B:811–16 (Fig. 5))

commonly the mode of injury in patients under the age of 40 years (Fig. 5.1) [2, 5, 8]. These findings, in conjunction with data showing that up to 85% of young hip fractures are seen in patients over the age of 40 years following a low-energy fall, suggest that a large proportion of these injuries are fragility fractures associated with poor bone quality in patients with a high rate of chronic disease and comorbidities, e.g. alcohol excess [5, 8]. This not only increases the risk of sustaining a hip fracture at a younger age but is also associated with an inferior outcome.

## Classification and Anatomy

The vascular anatomy of the proximal femur forms the basis for the classification of hip fractures and determines management. The major blood supply arises from the lateral and medial circumflex femoral arteries, which are branches of the profunda femoris artery [9]. At the inferior margin of the femoral neck, these vessels form an extracapsular anastomotic ring. Retinacular vessels arise from this, pierce the hip capsule, run onto the neck under the synovium and ascend in a medial direction to penetrate the head [10, 11]. The main retinacular vessel lies on the posterosuperior aspect of the neck. Additionally, there are a small contribution from the medullary canal and a negligible contribution from the ligamentum teres in adults [12].

The hip capsule inserts into the intertrochanteric line (anteriorly) and the intertrochanteric crest (posteriorly) in the region of the vascular ring [13]. Intracapsular fractures lead to injury and disruption of the retinacular vessels, leaving the blood supply to the femoral head at risk. This can result in AVN of the femoral head [14]. In contrast to this, extracapsular fractures rarely affect the blood supply to the femoral head, and hence the management is different. Classification systems commonly used include:

- The Garden classification (intracapsular fractures) describes four patterns based on the degree of fracture displacement on the AP radiograph [15]:
  - Poor inter- and intraobserver agreement between subgroups [16, 17].
  - Identification of displacement and the risk of retinacular vessel disruption (Garden 3 and 4) is the important clinical point [18, 19].

  - Fracture displacement on the lateral hip radiograph is not considered by the Garden classification. Angulation at the fracture site, which usually involves posterior tilt, of more than 10° is routinely considered displaced.
- The Pauwels classification (intracapsular fractures) that is determined by the vertical orientation of the fracture (30°, 50°, 70°), with reference to the horizontal on an AP radiograph of the hip [20]:
  - Most young high-energy fractures are a type 3 pattern with a more vertical orientation [21].
  - Most elderly low-energy fragility fractures are type 2.
- Modified Evans classification (extracapsular fractures) describes the fracture type, e.g. basicervical or reverse oblique, and can be used as a guide to the appropriate surgical management [22].

## Diagnosis

In the major trauma setting, patients are assessed and managed according to routine protocols, e.g. advanced trauma life support (ATLS). There may be significant associated injuries, which must be excluded through both the primary and secondary survey. Management of the neck of femur fracture should only be carried out after other life- and limb-threatening injuries have been effectively dealt with.

### Clinical Presentation

Although the majority of young patients will present few or no comorbidities, factors that might mitigate against successful stable fixation, such as chronic disease predisposing to osteoporosis (e.g. steroid use) or osteomalacia (e.g. renal failure, alcohol abuse), should be identified, especially in the presence of a low-energy injury or if the patient is older than 40 years of age [5]. In the setting of an undisplaced fracture, there may be no obvious deformity with the only finding a painful and reduced range of motion at the hip. For displaced fractures, the injured leg will classically be shortened and externally rotated. Open fractures and neurovascular injury are uncommon but should always be excluded. Associated fractures of the femoral shaft and acetabulum also need to be ruled out.

### Imaging

Hip fractures are often seen on routine plain radiographs, consisting of an anteroposterior (AP) and a lateral radiograph of the hip. In approximately 2% of patients, it is not possible to determine the presence of a fracture on plain radiographs. When the diagnosis is in doubt and an occult fracture is suspected, CT or magnetic resonance imaging (MRI) may be required [23, 24]. This may have already been carried out as part of a routine CT trauma scan. Ipsilateral femoral neck fractures occur in around 5% of all femoral shaft fractures and can be easily missed [25–28], particularly if the neck fracture is undisplaced or if there are poor-quality radiographs. Meticulous assessment is essential in all cases.

## Management

### Initial Management

Once the primary and secondary surveys (where possible) are complete, patients with multiple injuries and those who are physiologically unstable may require ongoing resuscitation and monitoring in a critical care setting. It is essential to provide appropriate pain relief, which routinely includes systemic analgesia and regional anaesthetic blocks, e.g. fascia iliaca block, which can reduce the opiate requirements of the patient. The femoral nerve (anterior), the lateral cutaneous nerve of the thigh (lateral) and the obturator nerve (medial) lie within and on the psoas and iliacus muscles as they pass under the inguinal ligament, and the fascia iliaca covers this neurovascular bundle. As the three nerves lie in the same fascial compartment, they can be blocked by a single injection. In day-to-day practice, the femoral and lateral cutaneous nerves are regularly blocked effectively, whilst the obturator nerve is variable. An important point to consider is that the femoral branch of the genitofemoral nerve, which supplies the skin at the groin crease, lies in a different compartment and is not affected by this technique.

Historically, the application of skin traction to the affected limb was a routine practice in patients with fractured neck of the femur. The rationale was that this might provide pain relief, reduce the extent of soft tissue injury as well as aid in fracture reduction. However, traction is now not routinely recommended as these proposed benefits have not been substantiated by comparative trials in the field [29–33].

## Intracapsular Fractures

### Nonoperative

There are very few indications for nonoperative treatment of intracapsular hip fractures due to the significant risk of complications. Nonoperative treatment involves protected weight bearing using crutches for routinely 6 weeks. In one study comparing nonoperative treatment with surgery for undisplaced femoral neck fractures, there was a 20% rate of displacement in the group treated nonoperatively and no failures in the surgery group [34]. Additionally, fixation was associated with a reduced length of hospital stay and a shorter time to full weight bearing. Other studies have reported displacement rates as high as 46%. For these reasons, nonoperative treatment should only be considered in patients unfit for surgery (which is rare in the younger patient) or possibly in those asymptomatic patients with a delayed presentation following fracture [35, 36].

### Operative

#### Undisplaced Intracapsular Fractures

The management choice in the vast majority of patients with undisplaced fractures, irrespective of age or other factors, is internal fixation. This is best achieved with either a cannulated screw system or a sliding hip screw device with a short plate. In a meta-analysis, there was a single nonunion (0.9%) in 118 young adults with undisplaced intracapsular femoral neck fractures managed with internal fixation [1]. The same study found the overall rate of AVN to be 5.9%, highlighting the need for patients to be kept under review for up to 2 years to detect this [37–39]. Most patients with healed fractures have a good functional outcome and can return to their pre-injury level of mobility.

#### Displaced Intracapsular Fractures

The majority of intracapsular neck of femur fractures are displaced, and the management principles are very different in physiologically younger and active patients when compared to their frailer elderly counterparts. For an elderly patient, the goals are to restore mobility with early weight bearing and to reduce the complications seen with prolonged bed rest. This is often best achieved with a hemiarthroplasty or total hip replacement. For a physiologically young and active patient, the aims are to preserve the femoral head, achieve union and prevent AVN. Other than in patients with a very limited life expectancy, these injuries are not amenable to nonoperative treatment. Anatomic reduction and stable robust internal fixation are essential for a good outcome [40].

The important factors to consider when deciding whether to undertake an open reduction and internal fixation of a displaced femoral neck fracture are the patient's chronological and biological age, pre-injury level of activity, medical comorbidities and the fracture morphology. Anatomic reduction and internal fixation are the treatment of choice for most young patients with a displaced femoral neck fracture, with good results achieved in the majority of patients. Rates of nonunion are between 0% and 15.6% and AVN between 10% and 46% (Table 5.1). A meta-analysis reported the overall rates of nonunion and AVN to be 8.9% and 23%, respectively, with a rate of 6.0% and 22.5%, respectively, for displaced fractures [1]. Patients can anticipate a good functional out-

**Table 5.1** The documented nonunion and AVN rates from recent large studies following reduction and internal fixation of *displaced* femoral neck fractures in patients younger than 60 years of age

| Author | Year | Total number (displaced fractures) | Mean age (range) | Nonunion (%) | AVN (%) |
|---|---|---|---|---|---|
| Haidukewych et al. [41] | 2004 | 73 (51) | 36 (15–50) | 9.8 | 27 |
| Damany et al. [1][a] | 2005 | 500 (382) | 28 (15–50) | 6.0 | 22.5 |
| Duckworth et al. [5] | 2011 | 122 (122) | 49 (17–60) | 7.4 | 11.5 |

Table adapted from Goudie EB, Duckworth AD, White TO. Hip fractures in young adults. Orthop Trauma. 2017; 31(2):76–85

[a]Meta-analysis

come with a healed femoral neck fracture that does not progress to AVN [41–47]. The ability to achieve a good outcome by attaining an anatomic reduction and avoiding fixation failure depends on several factors that the surgeon can control [45, 48–50].

### Physiologically Older Patients

As already noted, approximately half or more of young patients with displaced femoral neck fractures are between 40 and 60 years of age. This patient group may have medical comorbidities predisposing them to hip fractures including chronic diseases associated with osteoporosis and osteomalacia [8]. Smoking is a significant risk factor for hip fractures in women under 65 years of age [51]. A large study from Edinburgh determined the risk factors for failure after internal fixation in patients under the age of 60 with displaced intracapsular neck of femur fractures [5]. In a retrospective series of 122 patients, union occurred in 83 (68%), with failure more frequent in patients aged between 40 and 60 years (37/104, 36%) than those under 40 years (2/18, 11%). The authors identified respiratory disease, alcohol excess and renal disease as independently predictive of failure on multivariate analysis. In younger patients with a history of alcohol abuse or significant other medical comorbidities, arthroplasty can be considered.

### Surgical Timing

There is controversy surrounding the timing of surgery for displaced intracapsular fractures in young adults. In theory, early reduction and stabilization should allow timely re-establishment of the retinacular vessels to potentially restore blood flow to the femoral head and minimize the potential risk of AVN. However, some would argue any damage to the vessels is done at the time of injury and early intervention may not improve this.

One study compared fixation within 12 h of injury with delayed fixation (>12 h) and reported the rate of AVN to be 16% in the delayed group compared with 0% in the early fixation group [52]. However, Barnes et al. found that the timing of surgery did not affect the rates of nonunion and AVN in patients treated with reduction and fixation within the first week post-injury [14]. Experimental studies have also demonstrated that whilst cellular changes occur in the femoral head within the first 6 h postfracture, osteocyte cell death occurs more slowly and may not be apparent until 2–3 weeks following injury [53]. In the face of contradictory evidence, a sound and safe approach is to operate as soon as an appropriately skilled surgeon and equipped theatre are available. This may be on the day of injury or the following morning but probably need not be in the middle of the night. Fixation should still be considered in patients who present late (up to 1 or 2 weeks following injury), although an imperfect reduction may have to be accepted.

### Surgical Protocol

To reduce the fracture, gentle traction and internal rotation are applied to the leg. Fracture reduction is assessed on both the AP and lateral images, with the convex femoral head-neck junction producing an S-shaped curve in all planes. There is a debate about what represents an adequate reduction, but a 20° varus malreduction is associated with a 55% risk of failure, and less than 10° of posterior angulation is recommended to minimize this complication also [54, 55].

There is a relationship between quality of reduction and AVN. The risk is lowest with an anatomic reduction and increases with either valgus or varus malreduction [56]. An open reduction is sometimes necessary if an acceptable reduction cannot be achieved with closed techniques. This is most conveniently done on traction. A two-incision approach is recommended:

1. An anterior Smith-Peterson approach is used to expose the fracture and femoral head. Two large (2-mm) guide wires are placed in the femoral head to act as joysticks, allowing reduction of the rotational and angulatory components of the displacement (a and b on Fig. 5.2).
2. A lateral incision is used to fix the reduced fracture using either cannulated screws or a sliding hip screw with a short plate (c and d on Fig. 5.2).

Post-surgery, patients can be mobilized touch weight bearing for a total of 6 weeks. Union of a femoral neck facture is slow and routinely takes longer than 6 months in most cases [14]. AVN is a late complication, usually presenting postfracture union, and is most common in the second year after injury [14]. It is recommended that patients should be kept under clinical review with regular radiographs for 2 years to detect this complication.

### Role of Capsulotomy

There is a rise in intracapsular pressure due to the haemarthrosis that arises from an intracapsular fracture, and this can cause a tamponade effect which might impede blood flow to the femoral head [57–59]. For this reason, aspiration or capsulotomy to decompress the haemarthrosis seems a sensible option [40]. Despite this, the efficacy of these techniques has not been clearly demonstrated in clinical studies, and whilst there remain advocates, aspiration or capsulotomy is now rarely recommended [14, 60, 61].

### Implant Selection and Positioning

There is no definitive consensus on the optimal device for fixation of displaced intracapsular fractures in young patients, with either cannulated screws or a sliding hip screw commonly used. Both these techniques allow controlled linear compression at the fracture to promote union. More rigid methods of fixation, such as blade plates and locked plate systems, have an increased risk of cut-out with repetitive loading [62]. The disadvantage of implants that allow compression is that shortening of the femoral neck can occur and this may have an effect on abductor biomechanics, joint reaction force and ultimately gait. Stockton et al. reported on 65 patients under the age of 60 years old who underwent internal fixation, with 32% having leg shortening of more than 1 cm [63]. Femoral neck shortening and loss of offset may be associated with poorer functional outcomes in younger patients [64, 65].

Three cannulated screws are more stable than two, but there is no additional advantage known

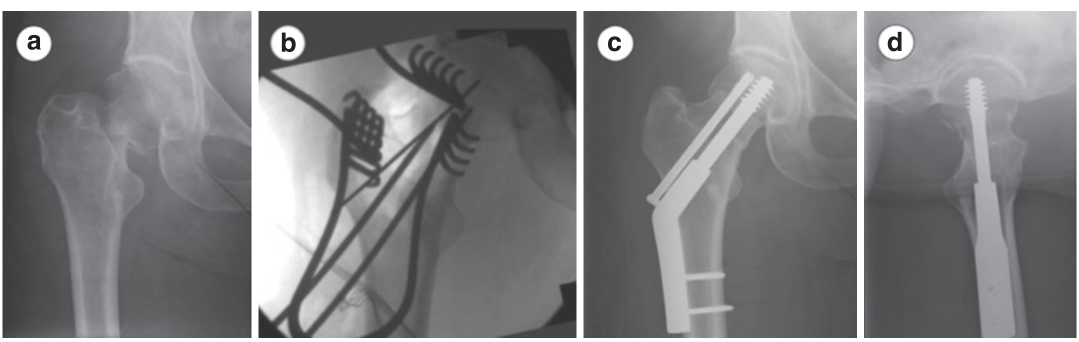


**Fig. 5.2** Surgery for displaced intracapsular fractures in the young. See text for details (Reproduced with permission from McRae's Orthopaedic Trauma 3rd Edition by White et al.)

in using four [66, 67]. There is controversy regarding the optimal position of screws, particularly whether they should be divergent or parallel, but there is no strong evidence to prove that position greatly influences outcome. However, we advocate the use of three partially threaded cannulated screws in the configuration found in Fig. 5.3. It has been suggested that a fully threaded posterior screw could improve stability in a commonly comminuted and length-unstable region of the fracture. This would prevent posterior angulation and give controlled compression in the anteroinferior region. Schaefer et al. performed a biomechanical study using a saw bone femora and reported this proposed construct to have higher bending stiffness and less failure compared to three partially threaded screws, although there are no clinical studies analysing this [68]. Vertically orientated Pauwels' type III fractures have a tendency to fail through shear, and there is some evidence that they should be fixed with a sliding hip screw and a short plate rather than with cannulated screws [21].

## Ipsilateral Femoral Neck and Shaft Fractures

An associated femoral neck fracture occurs in approximately 5% of femoral diaphyseal fractures, and the injury may be missed. Risk factors for missing an associated injury are if the hip fracture is undisplaced or if the radiographs of the proximal femur are inadequate or are of poor quality [25–28]. There are three common clinical scenarios in which an ipsilateral femoral neck and shaft fracture occur.

The first is if when the femoral neck fracture is diagnosed preoperatively and is undisplaced. Although a cephalomedullary nail could be used to fix both factures with one implant, there is a risk of hip fracture displacement during nailing, and it is therefore essential to place heavy guide wires across the fracture to minimize this risk. This risk can be prevented altogether by first addressing the hip fracture with the most suitable implant, e.g. a sliding hip screw and plate, and then treating the femoral shaft fracture with a secondary implant, e.g. a retrograde intramedullary nail (Fig. 5.4). Otherwise, if plate fixation of the shaft is preferred, a sliding hip screw with a long plate may be used.

The second scenario is one where the femoral neck fracture is recognized after nailing and the fracture remains undisplaced. Access to the fracture is often impeded by the proximal end of the nail, but it is usually possible to stabilize the fracture with cannulated screws placed anterior and posterior to the nail. Otherwise, the nail can be removed and replaced with one of the options above.

The final scenario is when the femoral neck fracture is displaced, whether this is recognized preoperatively or postoperatively. The fracture needs to be anatomically reduced and stabilized without delay to protect the viability of the femoral head. An open reduction, e.g. through a Smith-Peterson approach, and fixation with a sliding hip screw system are preferred, with either a retrograde nail or a plate for the fracture of the shaft.

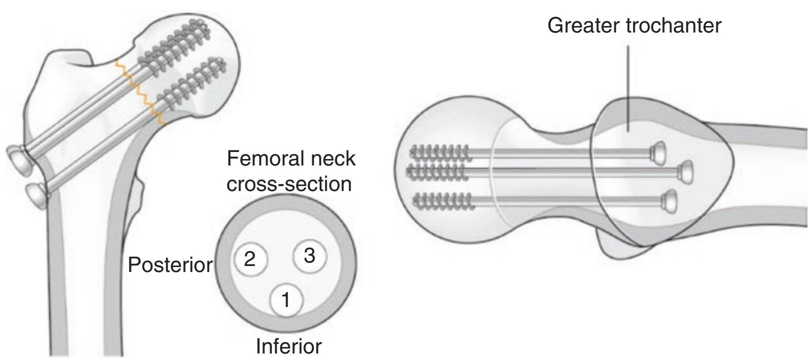


**Fig. 5.3** The author's preferred configuration for cannulated screw fixation (Reproduced with permission from McRae's Orthopaedic Trauma 3rd Edition by White et al.)

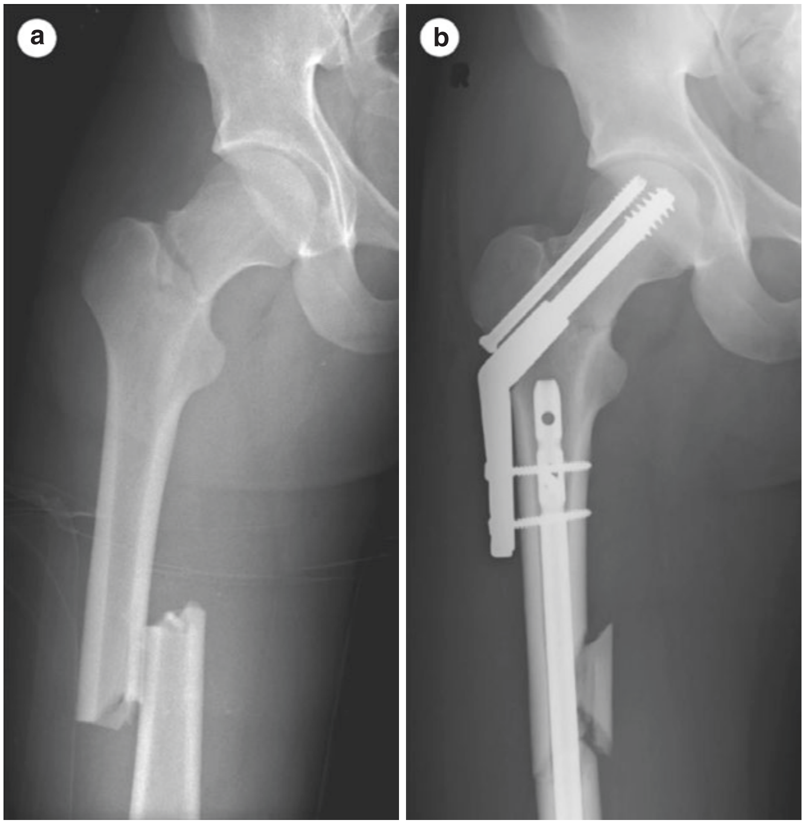


**Fig. 5.4** Ipsilateral femoral neck and shaft fracture treated with a sliding hip screw system and a retrograde femoral nail (Reproduced with permission from McRae's Orthopaedic Trauma 3rd Edition by White et al.)

## Intertrochanteric Fractures

In young adults, intertrochanteric fractures of the proximal femur are best managed with anatomic reduction and internal fixation. Nonoperative is very rarely considered and is only for when a patient is considered to be unwell to survive anaesthesia and surgery, which is very unlikely in the young patient. There are meta-analyses and prospective randomized trial comparing different implants and techniques, but despite this controversy persists [69, 70]. The two most frequently used implants are a cephalomedullary interlocking nail or sliding screw and plate, with no consensus on the superiority of one device over the other. A majority of studies have demonstrated comparable outcomes with regard to mortality, functional outcome at 1 year, implant mechanical failure rates and length of inpatient stay [69, 71–73].

Despite this, there is an exception when cephalomedullary interlocking nail is preferred. The reverse oblique fracture types, where the orientation is inherently unstable, will progressively displace following sliding hip screw fixation [74]. Hwang et al. reviewed the outcome in 66 patients under the age of 40 years with an intertrochanteric fracture of the proximal femur and found that all fractures united at an average of 10 weeks post-surgery and that the functional outcome, which was good in most patients, was largely determined by the associated injuries sustained [75].

## Subtrochanteric Fractures

These fractures are very unstable as stress concentrations in the subtrochanteric region mean a large compressive and rotational force on the medial cortex when the patient weight bears. Due to the high rate of comminution at the fracture site, these deforming forces often result in collapse; thus, subtrochanteric fractures should routinely be treated with a cephalomedullary nail [76–81].

## Complications

As would be expected, the reported outcomes are suboptimal in patients who go onto develop complications following an intracapsular neck of femur fracture, with a high rate of revision surgery documented in these cases. Failure of fixation and nonunion are the primary modes of failure following surgery for displaced neck of femur fractures in young adults. These two complications can be difficult to distinguish as most displaced fractures take a prolonged time to heal, which increases the chance of failure. Such problems often present with increasing hip pain, different leg lengths due to shortening secondary to femoral head collapse and loss of reduction. Radiological evidence of failure is apparent (Fig. 5.5). Although the clear option in older patients is conversion to arthroplasty, a head salvaging procedure might be preferable in younger patients. This could include revision of fixation, vascularized bone graft or a valgus osteotomy if the nonunion or failure is recognized before complete displacement of the head has occurred [82].

## Avascular Necrosis

AVN is a well-documented complication following fixation of intracapsular femoral neck fractures in young patients. Patients often present with hip pain and shortening, and the diagnosis can be confirmed using a combination of radiographs and/or MRI. The classical radiographic changes may not be apparent for 1–2 years following surgery, whilst MRI will detect AVN earlier (Fig. 5.6), although this is not helpful in the early weeks following surgery. The development of AVN does not always lead to functional problems severe enough to warrant intervention, with the management still debated. Barnes et al. reported that 24.3% of patients were asymptomatic and 46.4% had an acceptable level of disability [14], with the 29.3% reporting significant disability but only 60% undertaking further surgery. In patients without subchondral collapse, and in the absence of symptoms, no further treatment may be required. For younger patients with clear segmental collapse of the femoral head requiring further intervention, the best salvage option is a total hip arthroplasty.

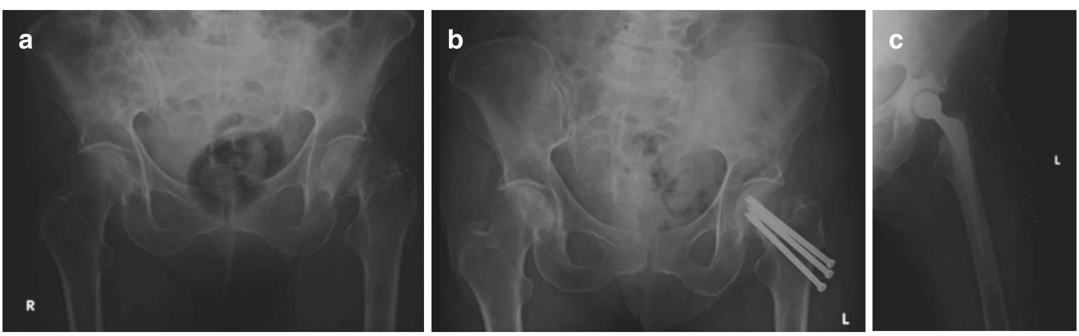


**Fig. 5.5** (**a**) An AP pelvis showing a displaced left intracapsular neck of femur fracture in a 57-year-old patient with a background of alcohol excess (>200 units/week). (**b**) An AP pelvis showing fixation failure at 1 month following cannulated screw fixation. (**c**) This was revised at 4 months following injury to a cemented total hip replacement

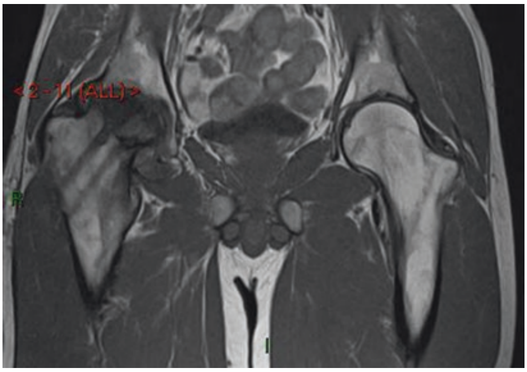

**Fig. 5.6** An MRI scan of the pelvis showing failure due to AVN of the right femoral head, subchondral sclerosis and segmental collapse. Metalwork removal is apparent (Reproduced with permission and copyright © of the British Editorial Society of Bone and Joint Surgery. From Duckworth AD, Bennet SJ, Aderinto J, Keating JF. Fixation of intracapsular fractures of the femoral neck in young patients: risk factors for failure. J Bone Joint Surg Br. 2011; 93–B:811–16 (Fig. 3))

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# 6 Femoral Neck Fractures in the Elderly

Christian Macke and Christian Krettek

## Abbreviations

| | |
|---|---|
| ASA | American Society of Anesthesiologists |
| DHS | Dynamic hip screw |
| HA | Hemiarthroplasty |
| HHS | Harris hip score |
| IF | Internal fixation |
| OTA | Orthopedic Trauma Association |
| THA | Total hip arthroplasty |

## Introduction: Definition of Elderly and Epidemiology

The incidence of femoral neck fractures has consistently increased because of the aging population [1, 2]. In 1990, 1.66 million hip fractures occurred, and new conservative estimates project 6.26 million hip fractures in 2050 [1]. This increase represents a significant burden and challenge to the healthcare system, as the estimated cost of a hip fracture is around $21,000 in the first year [3]. The lifetime risk for a fracture of the hip at age 50 in the U.S. is 17.5% for women and 6% for men; in other countries, it varies from 11.4–22.9% and 3.1–10.7%, respectively [2, 4].

Major obstacles for an evidence-based treatment approach for this fracture are the heterogeneity of the patient population and the exact definition of an elderly patient. Some studies define elderly as age ≥60 , while others quote ≥65, and yet others ≥70. Some studies exclude patients ≥85 or ≥90 as too frail and not representative, whereas others emphasize their inclusion as being very important.

Furthermore, nearly one-third of hip fracture patients suffer from dementia or other mental conditions. These comorbidities significantly affect outcome, and thus should be grouped into their own sub-group to further understand their rehabilitative potential [5]. Unfortunately, as most studies exclude patients with dementia or other cerebral comorbidities, only limited recommendations can be offered for this cohort. Owing to the copious literature on femoral neck fractures, we attempted to compile a concentrated evidence-based algorithm; however, because of the sheer magnitude of the literature, our review may be occasionally selective and biased.

The main focus of this chapter is on elderly, active, and lucid patients ≥65 years old with femoral neck fractures. Separate recommendations for the other cohorts are provided within the chapter. Furthermore, we highlight the main recommendation in an algorithm at the end of the chapter.

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For better legibility and understanding, the chapter is subdivided into three parts: stable versus unstable fracture, where stable fracture means an impacted, undisplaced femoral neck fracture of Garden type I or II, and unstable means a displaced femoral neck fracture, Garden type III–IV. In the last part, the patient's blood management is discussed, as it is a crucial factor in this patient cohort.

## Stable Fractures

### Conservative Treatment versus Osteosynthesis

Particularly in the elderly, there are good reasons to prevent surgical procedures and the anesthesia that goes with them: cardiovascular disease, pulmonary disease, multimorbidity, and local factors such as mycosis or other skin problems. It is indisputable that displaced femoral neck fractures have to be repaired surgically, [6] but the question remains whether stable femoral neck fractures can be treated conservatively (Figs. 6.1a–f and 6.2a–d). Unfortunately, the existing data do not support a clear treatment protocol, although most authors recommend percutaneous osteosynthesis. In 1996, Cserháti et al. [7] published a series of 247 undisplaced femoral neck fractures, predominantly Garden I. A total of 122 patients were primarily treated non-operatively, and 125 underwent primary operative stabilization—mostly with three cancellous screws and an "inverted key-hole plate." The results were significantly better for hospital stay (1 week shorter) and beginning full weight-bearing (11 days earlier) in the surgery group. Moreover, just one-quarter of the conservative patients were able to walk unaided at the time of discharge vs. two-thirds of the surgically treated group. Within 6 weeks, 20% of the conservative group required another operation due to displacement. Furthermore, there were slightly more survivors in the operation group after 1 year, though this was not significant.

Another interesting approach to this field was published by Buord et al. in 2009 [8]. They treated 57 Garden I fractures in patients age 65 and older (the mean was 82), with a standardized

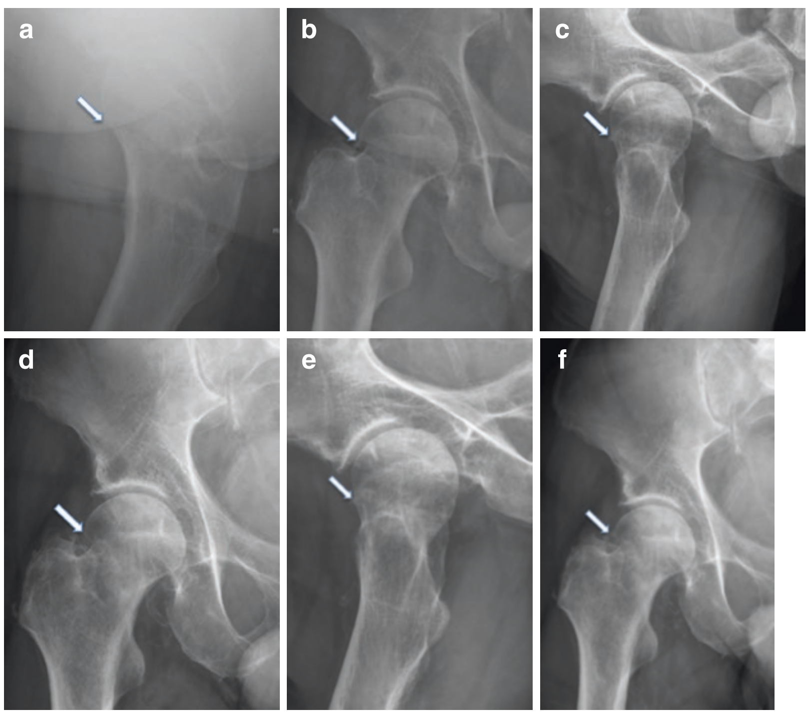


**Fig. 6.1** Stable femoral neck fracture on the right side in a moribund patient, axial view (**a**) and pelvis ap (**b**). Patient was bedridden due to spinal stenosis and multiple cardiovascular diseases. (**c**) and (**d**) showing the same patient after 3 months and (**e**) and (**f**) after 6 months. The fracture is healed, the patient has no pain. Arrows indicate the fracture

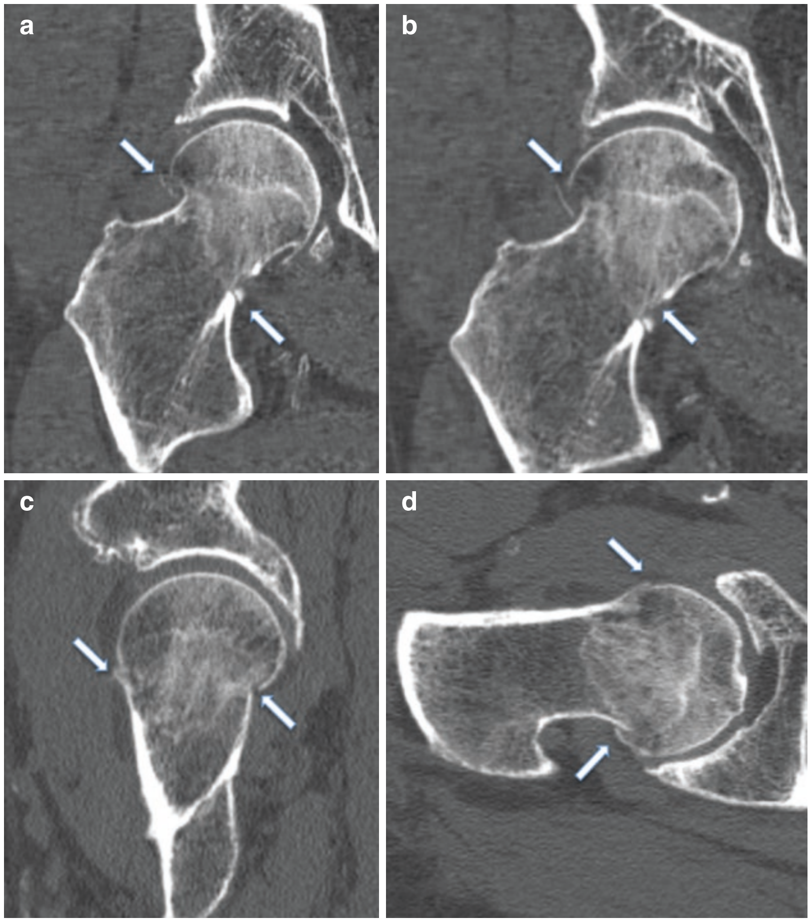


**Fig. 6.2** CT-scan of the right hip from the same patient as in Fig. 6.1, (**a**) and (**b**) showing the frontal, (**c**) the sagittal, and (**d**) the axial plain at the time of injury. Arrows indicate the fracture

"early functional training" with full weight bearing and frequent radiographic follow-up on post-injury days 2, 7, 21, and 45, and months 3, 6, and 12 to evaluate the predictive factors of displacement and the results of the functional training. If displacement occurred, then arthroplasty was performed. One-third of the patients had a displacement at a mean of 10 days; in fact, they reported comparable results in the functional successful vs. the arthroplasty group with Parker Score (6.9 vs. 7) and Harris Hip Score (HHS) (82 vs. 85), but one has to admit that the arthroplasty "control" group was the failed functional training group. Unfortunately, they were unable to identify predictive parameters for displacement, such as age, gender, side, fracture type, inclination angle, degree of outward displacement, sagittal displacement, and general status. In view of the missing predictive values and the disadvantages of secondary arthroplasty after primary osteosynthesis, [9] the approach with this trial-and-error management could be an option for borderline patients, as early mobilization has multiple advantages. However, as long as there is no clear evidence for this kind of treatment, conservative treatment should be an individual decision, especially for moribund patients, and the standard should be the osteosynthesis.

## Type of Implant for Osteosynthesis in Stable Femoral Neck Fractures

Choosing the type of implant leads directly to the next step. Usually, there are two implant types that are feasible: two or three parallel cannulated screws, and fixed-angle devices such as the sliding hip screw (SHS) or cephalomedullary nails [6, 10–13]. Most authors prefer cannulated screws, as they are a fast, inexpensive method.

In 112 consecutive patients, Krastman and colleagues reported positive results for stable and undisplaced femoral neck fractures if treated with two cannulated screws, but the patient collective was very heterogeneous due to age and fracture type [6]. In addition, Manohara concluded that the cancellous screw fixation for undisplaced femoral neck fractures in the elderly is associated with relatively few complications and revision rates [11]. However, he found longer hospital stays and a higher mortality rate in the >75 years patient collective.

Unfortunately, there is no significant evidence-level study comparing the outcome of the two internal fixation (IF) methods, especially not in the elderly. In 2008, Liporace et al. tried to compare the fixed-angle devices with cannulated screws in 76 displaced high vertical femoral neck fractures (Pauwels Type 3, Orthopaedic Trauma Association (OTA) type 31 B2.3) and found a non-union rate of 19% in the cannulated screw treated group vs. 8% in the fixed-angle device group, although this was not significant [14]. Siavashi et al. demonstrated significantly better results for the DHS compared to the cannulated screws after 1 year in the young with no fixation failure in the DHS group vs. an 18% failure rate in the cannulated screw group ($p < 0.001$) [15]. It seems that the fixed-angle devices provide better stability, but further research is necessary, since any comparative study is in displaced and/or young patients. Figure 6.3a–d shows an example of DHS fixation.

However, there are some interesting considerations regarding the biomechanics, which allows for cautious recommendations. First of all, the question remains whether two screws are enough,

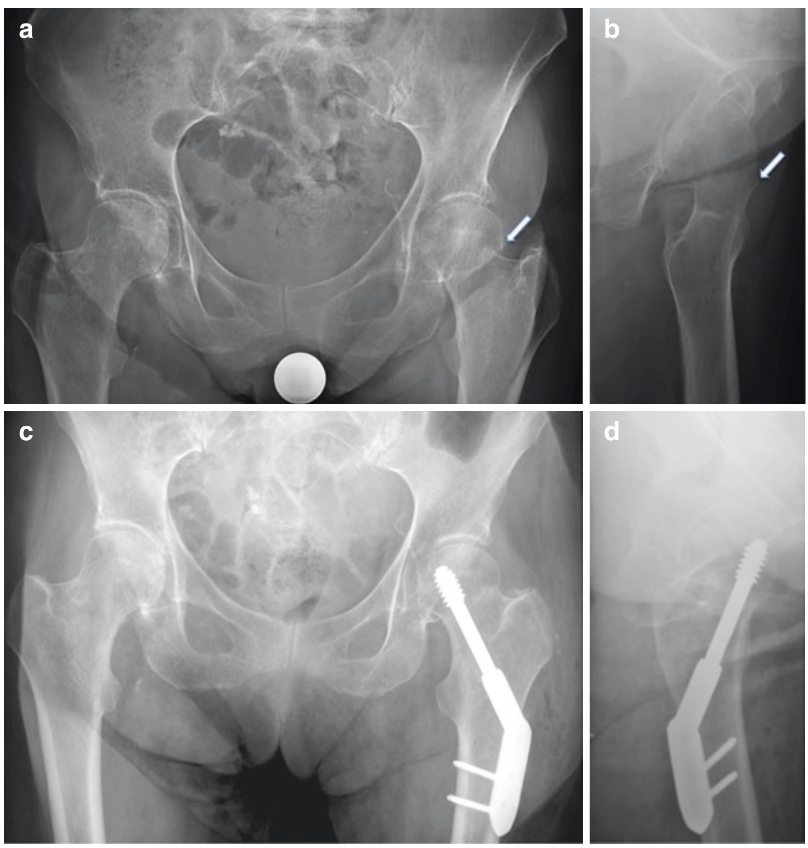


**Fig. 6.3** Garden II femoral neck fracture in an active patient on the left side with a posterior tilt of 30° (see Fig. 6.5), pelvis ap (**a**) and axial view (**b**). Same patient after treatment with DHS, pelvis ap (**c**) and axial view (**d**). Arrows indicate the fracture

or whether a third one is necessary. Maurer et al. tested, in a cadaveric model, the anterior loading, incremental axial loading, and cycling loading of two and three screws in two matched pairs of human cadaveric femurs with femoral neck fractures and found that three screws yield better results, with greater resistance to anterior loading, less inferior femoral head displacement, and less superior gapping at the osteotomy site [16]. Furthermore, Yang and colleagues evaluated the influence of the relative screw position of three screws in young patients with femoral neck fractures and found a significantly better union rate for the "inverted triangle configuration" (91 vs. 77%, $p = 0.018$) (Fig. 6.4a–d) which means one screw placed distally near the calcar femoris, and two screws parallel above it anteriorly and posteriorly to form an inverted triangle [17].

As it is known that for trochanteric fractures, the so-called "tip-apex" distance of the sliding hip screw should be less than 25 mm [18], one could assume similar results for the femoral neck fracture, but there is as yet little data on the exact screw position in relation to the head for the undisplaced femoral neck fractures [19]. In 2009, Palm et al. described the posterior tilt for the undisplaced femoral neck fractures [13]. They treated 113 patients ≥60 years old with Garden I

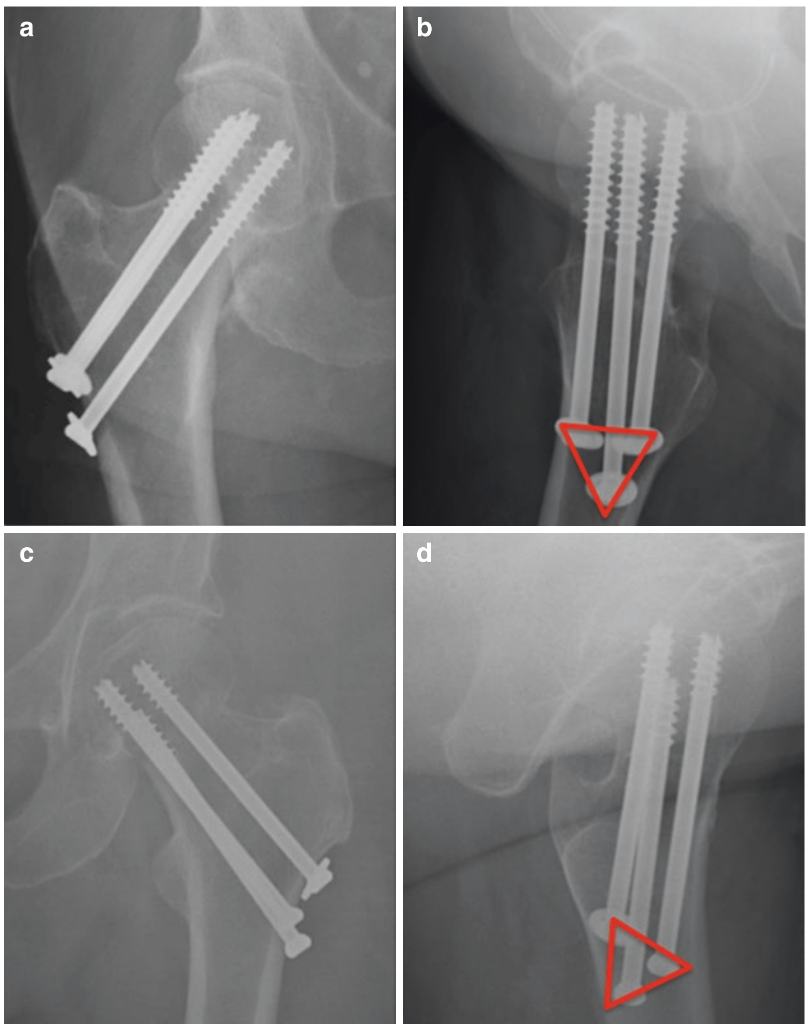


**Fig. 6.4** Stable femoral neck fracture on the right side treated with three cannulated screws in the inverted triangle, hip ap (**a**) and axial view (**b**). One screw lies in a steep angle near the calcar femoris, two screws are parallel above it, forming an inverted triangle highlighted in (**b**). In (**c**) and (**d**) there is a stable femoral neck fracture on the left side treated with three cannulated screws not lying in the preferred triangle configuration

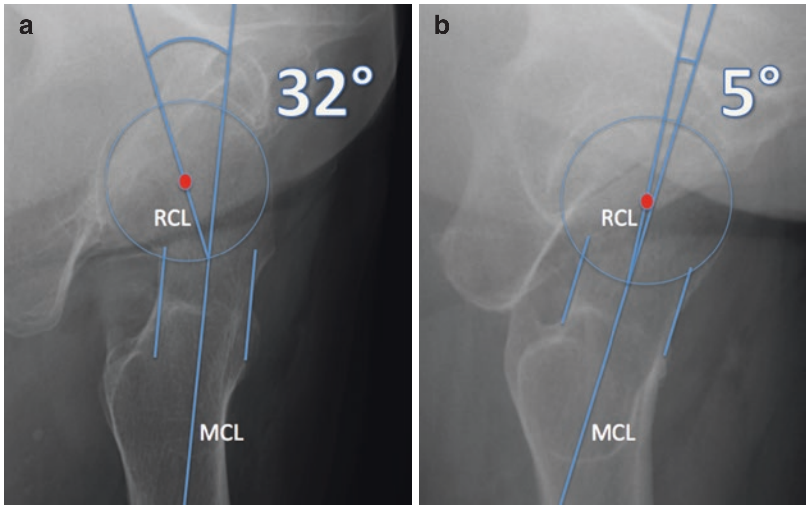


**Fig. 6.5** Stable femoral neck fracture on the right side, axial view (**a**). A posterior tilt of 32° is shown. In (**b**) there is a stable femoral neck fracture on the right side, axial view, a posterior tilt of 5° is shown. The posterior tilt is the angle between the mid-collum line (MCL) and the radius collum line (RCL) defined at the line from the head center to the crossing of the MCL with the radius of the head [13]

and II fractures with two cannulated screws and found that the posterior tilt (Fig. 6.5a, b) was a predictor for reoperation with a rate of 14/25 to 12/88 if the posterior tilt was ≥ 20° ($p < 0.001$). Clement and colleagues proved that the posterior tilt ≥20° was an independent predictor of internal fixation failure in 162 elderly patients; moreover, they found the ASA (American Society of Anesthesiologists) grade to be an independent predictor for failure [12]. The reason for this finding is not clear; one possible explanation could be the higher rate of osteoporotic bone. In a biomechanical in vitro study, Paech et al. found better results for polymer-augmented sliding hip screws in osteoporotic bone with a decrease of failure in terms of cut-out [20]. However, there are still no studies regarding cement-augmented cannulated screws for femoral neck fractures.

Overall, the implant situation is not clear, and in some ways disappointing. There are some new implants, such as the angular stable multiple screw fixation (Targon FN) that has yielded good results, [21] but other studies have shown no difference for this implant against cannulated screws [22]. In our opinion, the treatment of the stable femoral neck fracture in the elderly should be pragmatic: If there is no posterior tilt and good bone stock, then three cannulated screws in an inverted triangle should be used. If there is poor bone stock and/or posterior tilt ≥20°, then a sliding hip screw with additional anti-rotational screw should be used, augmented with bone cement eventually, depending on the bone quality.

## Unstable Fractures

### Internal Fixation vs. Arthroplasty

Although there have been multiple discussions on the best implant for femoral neck fractures in the young patient, it is beyond dispute that a primary reduction and fixation should be obtained in a timely, acceptable manner [23]. In the elderly population, the discussion on the best strategy for displaced femoral neck fractures has been going on for ages. The general considerations are about early mobilization, failure rate, functional outcome, mortality, and socioeconomic costs. Since many patients in this group have numerous diseases, and since internal fixation is mostly performed with a sliding hip screw or 2–3 cancellous parallel screws, it is understandable that surgeons perform such small, fast operation [24, 25]. Many studies have shown that internal fixation takes less operating time, there is less blood loss and fewer needs for transfusion [25, 26]. However, the problems occur post-operatively (Fig. 6.6a–h): high failure rates with the necessity for reoperation in 30–43% [9, 24, 25, 27], compared with

6–11% for hemiarthroplasty (HA) [9, 28, 29], and there is a high rate of avascular necrosis of the femoral head in the internal fixation group [9]. Despite these data, internal fixation is still a common treatment for patients with severe comorbidities—and especially dementia. One reason could be the expected higher mortality of hemiarthroplasty (HA) vs. internal fixation (IF), but many studies could not confirm this in active elderly patients [9, 25, 27]. A small exclusion has to be made: Parker et al. found a tendency towards improved survival after IF in patients aged 90 or above, and in those with a low mobility score, although this was not statistically significant [26]. Figure 6.7a–d shows the treatment of a displaced femoral neck fracture with HA.

As nearly one-third of the patients with femoral neck fracture suffer from dementia or other mental deficiencies, in following the post-operative treatment protocols, the question emerges as to whether this group would benefit. However, Olofsson et al. found no differences in mortality between patients

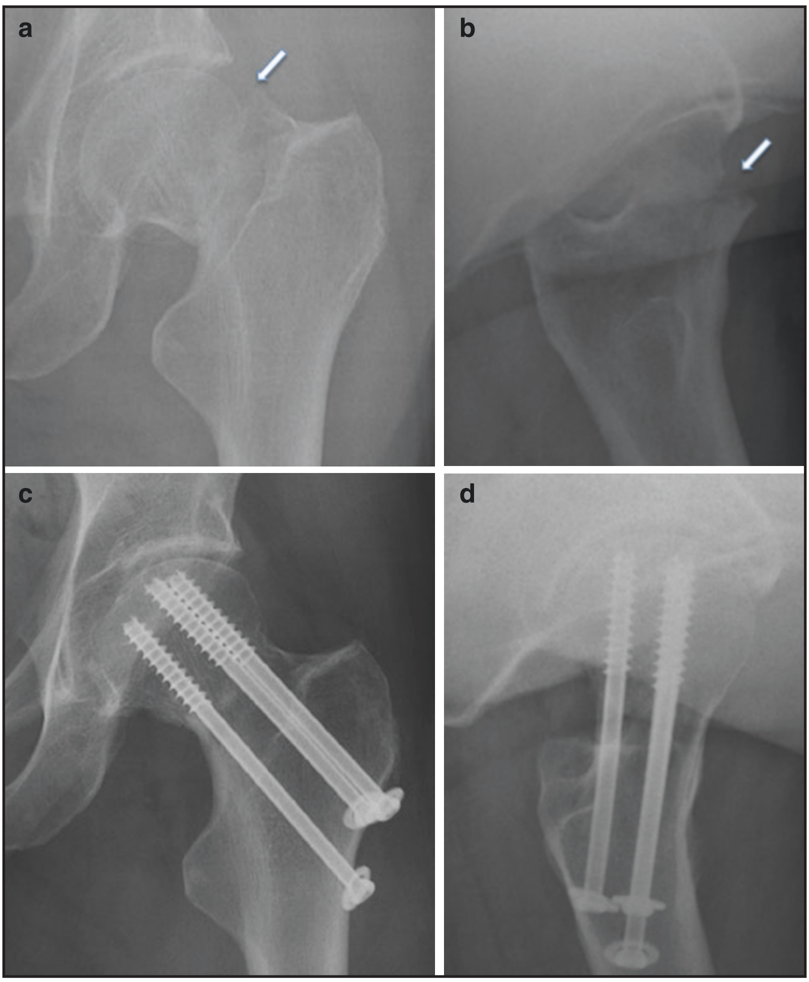


**Fig. 6.6** Unstable and displaced femoral neck fracture on the left side, hip ap (**a**) and axial view (**b**), arrows indicate the fracture. Treatment was with three cannulated screws, (**c**) showing the post-operative hip ap view (**d**) the axial view. Although the treatment was done in an adequate technique, there was internal fixation failure after 6 weeks with shortening and a bad functional result (**e**, **f**). Arrows indicate the screw movement in relation to the washer. After 6 months (**g**, **h**), the fracture is still visible and the head collapses, resulting in a revision with hemiarthroplasty

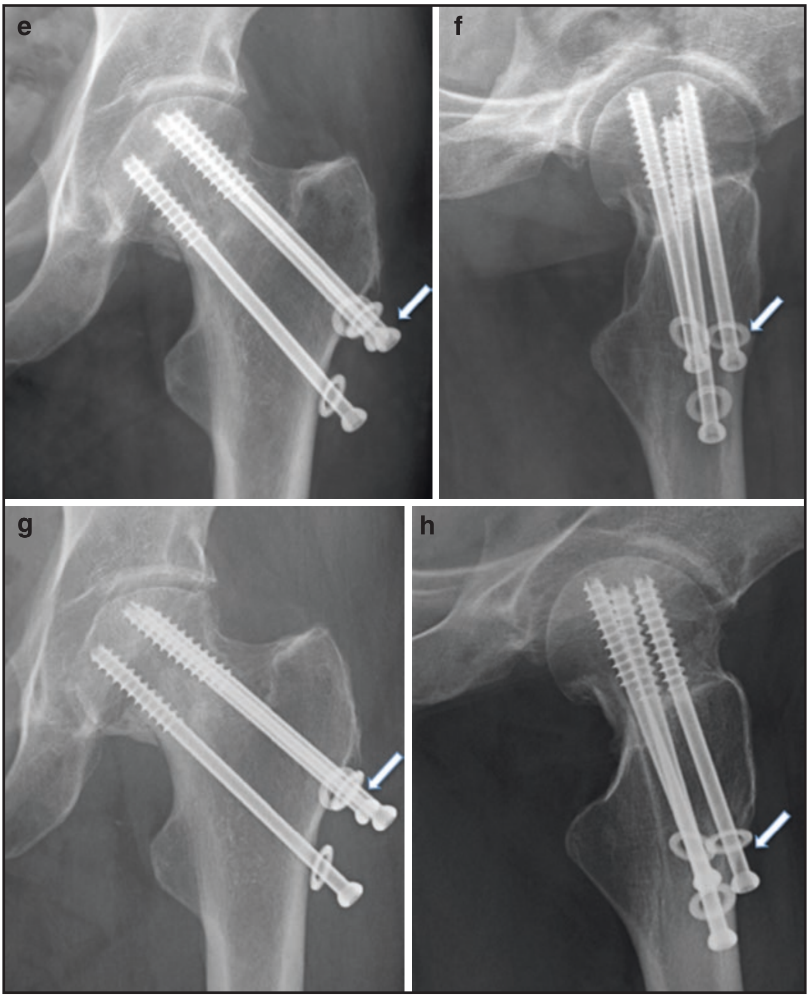


**Fig. 6.6** (continued)

with or without dementia treated with IF or arthroplasty, and all patients with arthroplasty had better functional results after 4 months and 1 year [5]. In 2014, Johansson published long-term results of 146 fractures and included 38% mentally impaired patients in his study [30]. The failure rate for the IF was very high, with 55% for the lucid and only 16% for the mentally impaired, whereas failure was defined as early redisplacement, non-union, symptomatic segmental collapse, or severe infection. For arthroplasty, the failure rates were 5% and 16% respectively, whereas failure was defined as two dislocations or more, implant loosening, severe infection, or a periprosthetic fracture. Most of the complications occurred within the first 2 years. Unfortunately, this study has a high bias due to patient loss. After 2 years, only 50% of the mentally impaired patients were still alive, and after 5 years 13% ($n = 7$); this makes interpretation of the data on the mentally impaired very difficult. Further research is needed to highlight this large, increasing patient population, although the trend is toward arthroplasty even in this cohort.

With regard to functional outcome, many studies show either equal [24] or better results for arthroplasty [9, 25, 26, 31, 32]. Furthermore, a secondary arthroplasty after failed IF seems to have worse results for hip function [33].

Blomfeldt et al. compared the outcomes of 43 patients with a primary hip due to femoral neck fractures with 41 patients with secondary arthroplasty due to IF failure; both the hip function and the health-related quality of life were significantly better after hip arthroplasty [33]. In contrast, Parker et al. found in one of the largest long-term studies (with 455 patients), no difference in the outcomes of IF vs. HA after 11 years [26]. Due to the study design, uncemented stems were used, and no THA control group was evaluated. Also Ravikumar and Marsh showed—in 290 patients after 13 years—equally poor outcomes with regard to function for IF and HA, but they had good functional results for the total hip arthroplasty (THA) group, which will be discussed in the HA vs. THA section [27].

Some studies dealt with the socioeconomic outcome and performed a cost effectiveness analysis of IF vs. HA or THA. Obviously, the sheer costs of the implants and the shorter operating time for IF speak for themselves, but if one keeps the higher failure rate and necessity for reoperations in mind, this recommendation may change. Bjørnelv et al. made a cost effectiveness" analysis alongside a randomized, controlled trial in Norway, and found that besides a better health-related quality of life for HA, there were higher

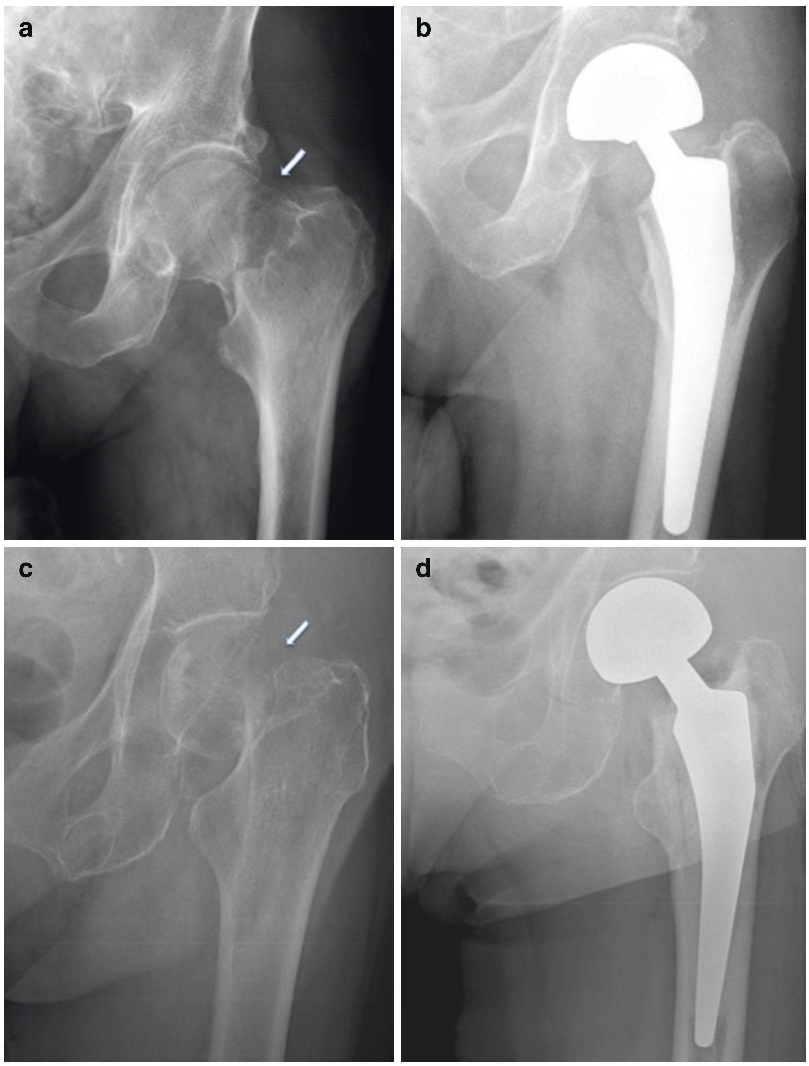


**Fig. 6.7** Unstable and displaced Garden III femoral neck fracture in active patients with no radiological osteoarthritis on the left side **(a)** before and **(b)** after surgery with hemiarthroplasty with cemented stem and bipolar head. (**c**) and (**d**) showing the same for a Garden IV femoral neck fracture. Arrows indicate the fractures

overall costs for IF in comparison with HA [34], whereas Johansson and colleagues found no difference in the costs for 143 patients receiving either THA or IF in addition to better results for the THA group for the Harris Hip Score [35].

To summarize, regarding the actual evidence on unstable femoral neck fractures in view of treatment with internal fixation or arthroplasty, one has to conclude that the internal fixation with the high failure rate and the worse functional and health-related results cannot be recommended as the implant of first choice for the active elderly. In our opinion, an HA or THA should be performed for the elderly and active, whereas the internal fixation can be considered to be a fast and gentle tool for moribund and bedridden patients. For the active mentally impaired elderly, there is no clear evidence as yet, but the tendency is towards hemiarthroplasty.

## Uni- vs. Bipolar Head

As noted, the HA still remains the "work horse" in the treatment of displaced femoral neck fractures in the elderly. However, depending on the region and economic considerations, the decision to use a uni- or bipolar head varies. The basic idea to use a bipolar head is the reduction of the acetabular erosion, as the movement mainly takes place in the bipolar head rather than in the joint, and thereby reduces pain levels and increases the clinical outcome [36, 37]. Unfortunately, the evidence in the existing literature varies as much as the real treatment. In a randomized control trial study of 120 patients, Hedbeck and colleagues found that at a mean age of 86 years, there was an almost identical clinical outcome after 1 year, but a significantly higher incidence of acetabular erosion in the unipolar HA group. As they found trends towards worse Harris Hip Scores (HHS) in patients with acetabular erosion, they concluded that a bipolar HA should be the preferred treatment [37]. In contrast, Calder et al. reported no difference in clinical outcomes and complication rates between both groups [36]. They evaluated 250 patients with a median age of 85, and found significantly better results for the unipolar group in view of the return to pre-injury state, in comparison to the bipolar group. In summary, current evidence is not able to provide a conclusive recommendation for or against unipolar or bipolar hemiarthroplasties in octogenarians.

But the question remains of whether the "young" old patients would benefit from a bipolar head. It was again Calder et al. evaluating a questionnaire from a randomized control trial of a group of 110 patients age 65–79 who were treated with either hip screw, unipolar, or bipolar arthroplasty [38]. The bipolar arthroplasty group showed a trend towards better results in almost all questionnaire values in this patient collective. But in 2001, Davison et al. showed in a prospective, randomized control trial of the treatment of 280 displaced fractures of the femoral neck (187 patients had had arthroplasty, and 93 sliding hip screws) in patients aged 65–79, that there was no advantage to the bipolar over the unipolar head [24]. So again, there is no clear evidence for or against one of the two options. Theoretically, younger patients would have a higher acetabular erosion rate due to longer survival, although the existing literature does not support the use of the four times higher costs of bipolar head in the 65 to 79-year-old age group [39]. Moreover, the actual trend goes toward total hip arthroplasty in this group, under certain circumstances.

## Cemented vs. Uncemented Stem

Today, there are many studies that deal with this subject, and there is convincing evidence in favor of cemented or uncemented stems. The reason for choosing cement, or an uncemented implant, depends mostly on the surgeons' experience, education, and personal preference. Surgeons who use uncemented implants are afraid of the revision surgery, and the rare, but severe cardiopulmonary effects of cement in this patient cohort; the other group (who use cement) may worry about early loosening with pain and worsening function [40]. Figved and colleagues found no difference in HHS scores after 3 and 12 months in 220 patients (112/108 cemented/uncemented stems, 83.4/83.0 years) [41]. Also, DeAngelis et al. found no differences in mortality and various activities of daily living post-operatively and after 12 months in a prospective control trial with 125 fractures [42]. However, there are many more studies that show better results for the cement group in this cohort. It seems that cemented stems have better function and mobility results in the short-term [43], that the patients have statistically less pain, lower rates of complication [44], and lower periprosthetic fracture rates [45]. Furthermore, the results regarding walking ability, the use of walking aids, and activities of daily living were statistically better [40]. In 2010, a Cochrane Systematic Review dealing with this topic was published [39]. Many studies were included, but most had weaknesses in form and content. Nevertheless, the Cochrane Review corroborated the better results for cemented stems.

In the last few years, new models of the hydroxyapatite-coated stems have come on the market, and it remains to be seen whether they are associated with similar results. In 2014, Bell and colleagues showed, in a case-control study of nearly 180 patients, better results for the hydroxyapatite-coated Corail stem (DePuy Ortho- paedics Inc., Warsaw, Indiana) in view of further surgery, less operating time, and lower peri-prosthetic fracture rates in comparison with a cemented Exeter stem (Stryker Howmedica, Newbury, United Kingdom) [46]. Whether this is a really new way, or just a trend, cannot be assessed yet. Hence, the recommendation today should be a cemented stem for treating femoral neck fractures in the elderly.

## Hemiarthroplasty vs. Total Hip Arthroplasty

As highlighted above, arthroplasty is the recommended treatment for active patients with unstable femoral neck fractures. However, the question increasingly emerges about whether active patients should receive a THA (Fig. 6.8a–d) rather than an HA. Van den Bekerom et al. found in 252 patients (>70 years) who had either cemented HA ($n$ = 137) or THA ($n$ = 115), that there were no differences in the modified HHS, revision rate of the prosthesis, local and general complications, or mortality [47]. Furthermore, they reported lower intra-operative blood loss for HA (7% > 500 ml) than for THA (26% > 500 ml), shorter surgery for HA (12% > 1.5 h vs. 28% > 1.5 h). and no dislocations of any HA, but 8 dislocations of the THA during their 1- and 5-year follow-ups. Because of the dislocation rate, they concluded that they would not recommend THA for these patients in the absence of advanced radiological osteoarthritis or rheumatoid arthritis of the hip [47]. But is the higher dislocation rate a factor for recommendation, or should we rather ask the patients whether they are satisfied? In 2013, Leonardson et al. showed—in a national survey of 4467 patients—better results for those below and above 70 years of age who were treated with THA; they had less pain and more satisfaction compared with those treated with IF or HA [48]. This shows the conflict in the debate about the best strategy for or against THA pretty well. Finally, it is a question of outcome parameter definition.

But maybe osteoarthritis itself is an indication for THA? A recent study by Boese and colleagues addressed this question in 126 elderly patients treated with HA. They saw no significant differences in the HHS score ($p$ = 0.545), the timed up and go test ($p$ = 0.298), the Tinetti test ($p$ = 0.381), or the Barthel Index ($p$ = 0.094) between patients with preoperative Kellgren and Lawrence grades 3 or 4 osteoarthritis and patients with grades 0–2 after 12 months [49]. Unfortunately, they had only a short-term follow-up that included 40% of the initial patients, thereby substantially limiting the evidence. After all, the question still seems to be unsolved.

The theoretical idea for THA rather than HA is that acetabular erosion due to HA lowers the outcome in comparison to THA in the long run, and one could assume that an already degenerated joint has a worse outcome with hemiarthroplasty, but there is only scant secondary data that deals with this. It was Ravikumar et al. who presented one of the largest long-term studies for THA in femoral neck fractures [27]. They evaluated the difference for IF, HA and THA in 290 patients over 13 years and found revision rates of 33% for

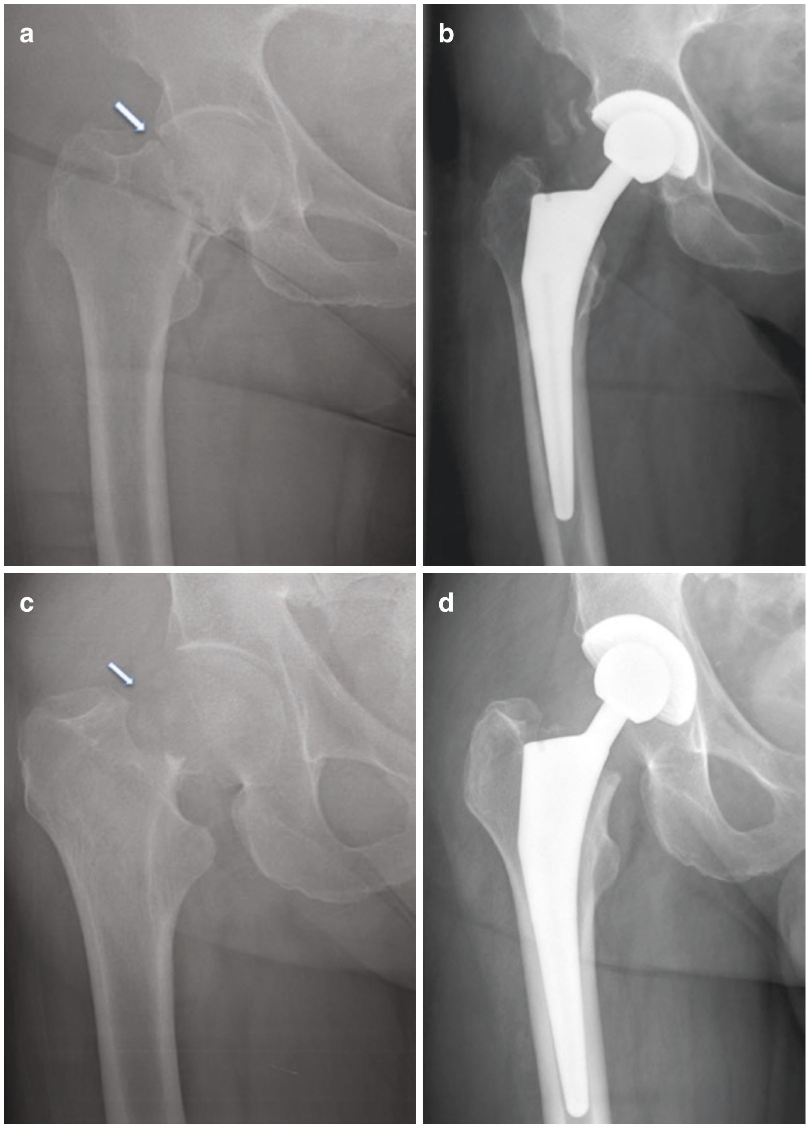


**Fig. 6.8** Unstable and displaced Garden III femoral neck fracture in active patients with no radiological osteoarthritis on the right side before (**a**) and after (**b**) surgery with THA. (**c**) and (**d**) showing the same for a Garden IV femoral neck fracture. Arrows indicate the fractures

IF, 24% for HA, and only 6.75% for THA. The dislocation rate was 13% for HA and 20% for THA, whereas the HHS score was 62 (IF), 55 (HA), and 80, which was much better for THA. Furthermore, the IF and HA had poor results in pain and mobility levels. However, one limitation remains: the HA group had an uncemented stem in contrast to the THA group; this probably affects the outcome, but it seems that the THA has better results in the long-term in active patients. In addition to this, Macaulay et al. showed no difference in pain levels and functional outcome for HA vs. THA in 41 patients after 6 months, but the THA group was better in pain levels, the timed “Up & Go” Test, and functionally independent life after 12 months [50]. Moreover, Keating and colleagues reported better results for THA in comparison to IF or HA after 24 months in 298 patients [31]. Additionally, they undertook a cost effectiveness analysis and found—after evaluating all complications and readmissions—a cost advantage of £3000 per patient for THA vs. HA.

In 2009, Heetveld et al. published a meta-analysis of all accessible studies with the focus of IF vs. arthroplasty and HA vs. THA for displaced femoral neck fractures [51]. They concluded that THA should be considered in any elderly active patient and in patients with pre-operative osteoarthritis or rheumatoid arthritis, but to date, no high-powered study has compared HA with THA in the long run, even though in 2011 Hedbeck and colleagues published a Level I randomized controlled trial with 120 elderly patients (60 HA vs. 60 THA), with a follow-up at 12, 24, and 48 months [52]. At 12 months, the THA had better hip function in the HHS score (mean score: 87 vs. 78, $p < 0.001$), and this increased up to 4 years (mean score: 89 vs. 75, $p < 0.001$). Furthermore, the health-related quality of life had a tendency to better values for the THA after 12 and 24 months, becoming significant at 48 months ($p < 0.039$).

To summarize the results: THA is a good option for active lucid elderly patients with displaced femoral neck fracture, since in the long run the outcome parameters of the HA decreases. But one possible influence parameter is not yet highlighted, neither in this chapter nor in the literature: the surgeon's experience. As most femoral neck fractures will be treated by a traumatologist with possibly less experience with THAs than HAs, the recommendation for or against THA as the treatment of choice for a certain patient has to be made individually, and it must include the surgeon's experience.

## Patient Blood Management

### Transfusions

A critical aspect in the treatment of elderly patients with femoral neck fractures is preoperative anemia and intraoperative blood loss. Many of the patients in this cohort have cardiovascular disease and few possibilities for compensation, so the relevance for the outcome seems obvious. Potter et al. found in their 2014 review that *anemia* at the time of hospital admission in patients with hip fractures was associated with increased mortality (RR 1.64, $p < 0.0001$), with anemia defined at <100 g/L hemoglobin [53]. The transfusion itself had no influence on mortality, but the transfusion level at <80 vs. <100 g/L led to a relative risk from 1.67 ($p = 0.05$) for myocardial infarction. In 2011, Carson et al. published the largest randomized control trial study, with 2016 hip fracture patients at cardiovascular risk, in which they found no difference in mortality between a liberal-strategy group that received transfusions of red blood cells at <100 g/L or a restrictive-strategy group that only received a transfusion for symptoms of anemia or at the physician's discretion at <80 g/L [54]. Furthermore, there were no significant differences in mortality or the inability to walk at the 60-day follow-up. In 2015, Brunskill et al. addressed this matter within the context of a Cochrane Collaboration Review and found, with low-quality evidence, no difference in mortality, functional recovery, or post-operative morbidity between a liberal-strategy and restrictive-strategy group in patients who had hip fracture treatment [55]. Overall, there are low-evidence levels for a clear preference of restrictive or liberal transfusion strategies, but it seems reasonable to undertake a restrictive strategy in the transfusion of red blood cells both during and after hip fracture treatment. Patients with chest pain and/or a history of cardiovascular disease should receive transfusions rather verified to clinical symptoms and severity of cardiovascular disease than to a hemoglobin level of <80 g/L.

### Delay Due to Anticoagulants

As mentioned, most elderly patients with femoral neck fractures have additional diseases, and so it is not surprising that a relevant percentage of the patients take platelet inhibitors or other anticoagulants, such as warfarin [56, 57]. Patients treated with warfarin are a relevant proportion (about 8%) of patients with hip fractures, but it is beyond dispute that the warfarin has to be antagonized with vitamin K or fresh-frozen plasma prior to surgery [57], although for platelet inhibitors like aspirin or clopidogrel, it is not that clear. A major problem is the long-lasting effect of the drugs, and the only reasonable possibility to antagonize them would be a platelet transfusion. One question could be: Can we wait with surgery until the effect of the platelet inhibitors is gone? Maheshwari et al. evaluated the 1 year mortality and complications in 30 patients with proximal femoral fractures on clopidogrel [58]. After a mean of 8.4 days' delay, they found that there was still a need for transfusion in 7 patients, and post-operative complications in 43% of them. A multi-regression analysis showed that delaying surgery ($p = 0.03$) was the only independent predictor of one-year mortality. Thus, waiting does not seem to be an option. Manning and colleagues found in 32 patients with femoral neck fractures who take aspirin, that there was a higher transfusion rate but no effect on peri-operative blood loss, or change in hemoglobin concentration or hematocrit, in comparison to 57 patients who did not take aspirin [56]. Moreover, the transfusion rate seems to be an effect of a pre-operative lower hemoglobin concentration and hematocrit.

But perhaps it is possible to identify the patients with a high risk of bleeding by measuring the platelet function. It was Thaler et al. who reported the effects of measuring it in 462 patients with hip fractures, 120 of them with platelet inhibitors (98 aspirin, 22 clopidogrel) [59]. They found no difference in mortality, major bleeding, red blood cell requirement, or drainage blood loss. Moreover, they reported no correlation of the peri-operative blood loss with either a history of platelet inhibitor intake or measured platelet function. In 2012, Hossain et al. showed that in 102 patients (50 vs. 52) with or without clopidogrel and femoral neck fracture treated with HA, there was no difference in pre- and post-operative hemoglobin, ASA grade, comorbidities, operating time, transfusion requirements, length of hospital stay, wound infection, hematoma, and reoperation rate [60]. Overall, there are no clear disadvantages found in the literature for early operation in this cohort, but there are clear disadvantages for delay. Related to these findings, a delay in surgery due to platelet inhibitors intake does not seem reasonable.

## Summary and Recommendations

In consideration of the restrictions mentioned in the introduction, the actual recommendations for treating femoral neck fractures in the elderly can be summarized thus:

1. Stable fractures:
   - The standard should be three cannulated screws with the inverted triangle technique.
   - If there is poor bone stock and/or posterior tilt ≥20°, then a sliding hip screw with an additional anti-rotational screw should be used.
   - Augmentation with bone cement in osteoporotic bone.
   - Conservative treatment according to individual decision, especially for moribund patients.
2. Unstable fractures:
   - Hemiarthroplasty with cemented stem for physically or mentally impaired elderly patients.
   - Unipolar head for very elderly patients is possible.
   - Bipolar head rather for the "younger' elderly," but no clear recommendation.
   - Pre-operative osteoarthritis or rheumatoid arthritis: THA.
   - THA for active and mentally healthy elderly patients.
3. Patient blood management:
   - Restrictive strategy for transfusion (<80 g/L hemoglobin level).
   - Early surgery with antagonizing warfarin.
   - Early surgery independent of platelet inhibitors.

For the future, there are still many challenges to further randomized studies with enough power.

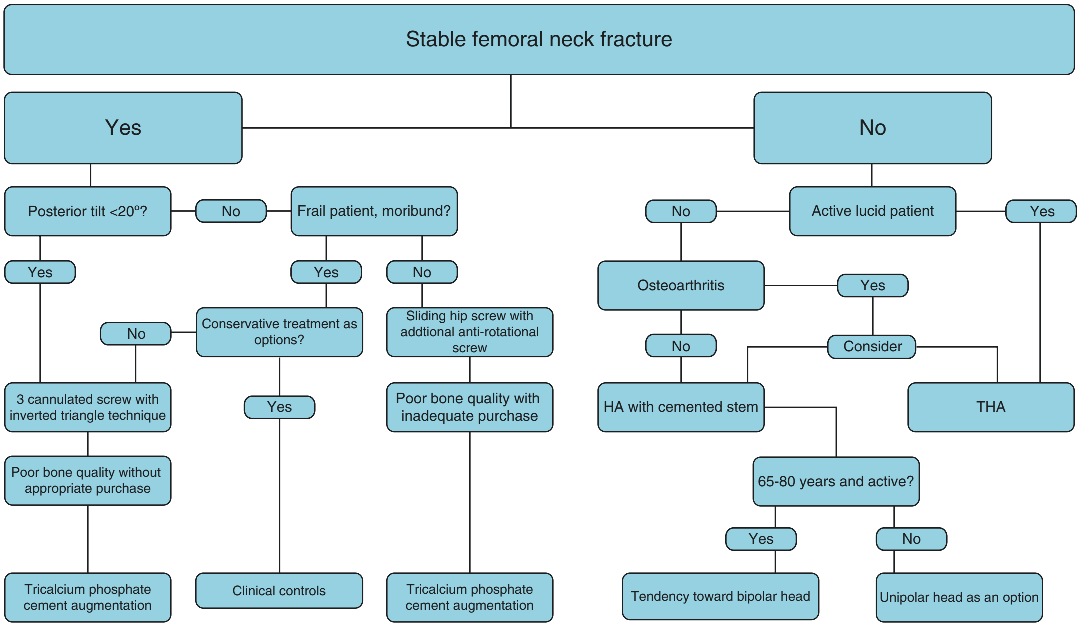


**Fig. 6.9** Simplified algorithm for femoral neck fractures in the elderly on the basis of the existing evidence data. It has no claim for completeness as this is not possible due to the many influences described in the text, but it could influence the decision of the surgeon facing the problem in the OR

The focus must be on the various patient cohorts and the outcomes in the long run, especially in patient-related outcomes such as satisfaction, mobility, pain level, and function. Nevertheless, the surgeon facing the problem in the OR still has to consider many individual factors—such as age, ASA grade, general condition, or the drugs taken. With that in mind, we developed a treatment algorithm that may help make the decision (Fig. 6.9).

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# Intertrochanteric Femur Fractures: Plates and Screws

7

Frank A. Liporace and Nirmal Tejwani

## Epidemiology and Mechanism of Injury

In general, the number of hip fractures is rapidly increasing with the increasing life expectancy and the rapidly increasing elderly population. By 2050, it is postulated that there will be over 500,000 hip fractures in the United States with a similar ratio of femoral neck and intertrochanteric fractures [1, 2]. Ninety percent of elderly hip fractures result from a low-energy fall. Women who sustain an intertrochanteric fracture, as opposed to a femoral neck fracture, are more likely to be older, more dependent in activities of daily living, and home ambulators [3, 4]. It is important to determine which intertrochanteric fractures are appropriate candidates for sliding hip screw with side plate fixation since a recent review of the American Board of Orthopaedic Surgeons applicants has shown an overwhelming increase in the use of intramedullary devices with a concomitant decrease in the use of sliding hip screws with side plates [5].

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## Radiographic Analysis, Classification, and Determining Stability

Judicious use of implants with specific inclusion and exclusion criteria is important to deliver cost-effective, appropriate care. The sliding hip screw is likely the most cost-effective implant for AO 31.A1 or 31.A2 intertrochanteric fractures (Fig. 7.1) [6, 7]. Identifying radiographic stability is the key to success when determining surgical treatment.

Initial diagnostic studies should include an AP and cross-table lateral radiograph of the hip and an AP radiograph of the pelvis. If the diagnosis remains in question, a traction-internal rotation view of the hip (AP radiograph of the hip as it is held in 15° of internal rotation with axial traction) can be helpful by allowing visualization of the entire femoral neck in the absence of anteversion to decipher between questionable femoral neck and intertrochanteric fracture patterns. When no fracture is evident after standard radiographs, an MRI (within 24 h of injury) or bone scan (within 48–72 h of injury) can aid in diagnosis [8, 9]. Patterns that are non-displaced or border femoral neck fractures are usually appropriate to be treated by screws with side plates. Fractures with



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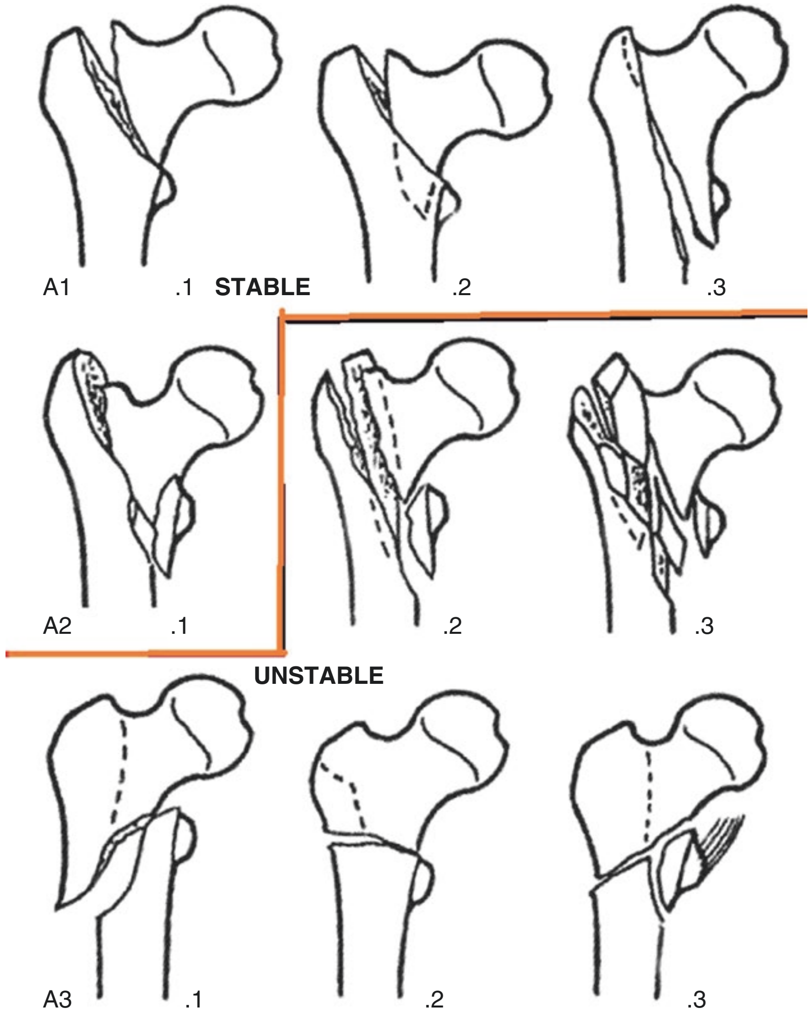


**Fig. 7.1** Evans classification of intertrochanteric hip fractures; division of stable fractures suitable for plates and screws and unstable fractures

questionable instability can be confirmed with a lateral radiograph when evaluating posteromedial cortical integrity and sagittal displacement. The ability to determine which fractures are appropriate to be treated with screws and side plates will be defined throughout this chapter.

A variety of classifications of intertrochanteric hip fractures include the Evans classification, the AO classification, and the OTA classification [10, 11]. Traditionally, classification and treatment of intertrochanteric fractures have been based on determination of stability (Fig. 7.1). Stable patterns can be treated with either plates or intramedullary devices with cephalomedullary fixation. Instability patterns have been defined as including loss of ability to maintain a stable posteromedial buttress, reverse obliquity patterns, and presence of subtrochanteric extension [10, 11]. Fracture instability dictates the use of intramedullary nails (IMNs) with cephalomedullary fixation, which is discussed in the following chapter.

Stable patterns with intact lateral wall, including those with posteromedial comminution, are best treated with a sliding hip screw [12–14]. Fixation with a sliding hip screw in these stable patterns is associated with equivalent functional outcomes compared to cephalomedullary nails with decreased cost and lower perioperative complication rates [12–14]. In AO 31.A1 or 31.A2 fractures, patients treated with sliding hip screws with side plates have similar functional recovery scores compared to patients treated with cephalomedullary nails [15]. In a recent analysis of 4432 patients treated with sliding hip screws and cephalomedullary nails that looked at 30 day outcomes, operation time, rate of hospital readmission, and operating room time did not differ between groups although those treated with cephalomedullary nails had a 1 day shorter hospital length of stay, possibly negating the higher implant cost for the cephalomedullary nail [16].

More recently lateral wall competency has been considered as a mitigating factor to instability, as well. Lateral wall incompetency may be a result of comminution at the time of injury or iatrogenic comminution during side plate application with the use of the triple reamer [17]. At a point 3 cm distal to the vastus ridge, if the lateral wall thickness is less than 20.5 mm, there is an increased predilection for failures and reoperations when a sliding hip screw with side plate is used [17].

## Plate Function, Technical Considerations, Limitations, and Options

Sliding hip screws with side plates work on the basic function of compression across a fracture in a dynamic mode. Historically, the sliding hip screw has been the implant of choice for the treatment of both stable and unstable intertrochanteric fractures. Sliding hip screw side plate angles are typically available in 5° increments from 130° to 150°. The 135° plate is most commonly utilized. This angle is easier to insert in the desired central position of the femoral head and neck than higher angle devices and creates less of a stress riser in the subtrochanteric region. In the past, biomechanical studies have shown no advantage of four screws over three to stabilize the side plate [18]. Recently, both biomechanical and prospective consecutive series supported the use of a two-hole side plate for stabilization of appropriate intertrochanteric fracture patterns [19–21].

## Technique of Sliding Hip Screw with Slide Plate

Most frequently, the patient is placed on a fracture table with a well-padded perineal post. The unaffected leg is placed in a well-leg holder in flexion, abduction, and external rotation or padded and placed in hip extension and adduction while being secured to the leg-holding device.

Gentle traction is applied with the table and with subsequent rotation to match the distal to the proximal fragments. Various reduction maneuvers including traction in flexion or extension with external rotation to “unlock” the fragments followed by internal rotation will allow satisfactory reduction of the fracture. Confirmation of reduction must be done on both AP and lateral fluoroscopic views. The lateral will also show if there is excessive posterior sagging of the distal fragment. If present, this must be corrected and maintained throughout the procedure. This may be corrected externally with a support (crutch) or after dissection with the aid of reduction instruments.

An incision is made from the level of the vastus ridge, distally, for approximately 4 fingerbreadths. The iliotibial band is incised in line with the skin incision, and the vastus lateralis is elevated at the vastus ridge and then distally from posteriorly to anteriorly to expose the lateral femoral cortex. With the aid of the chosen angled guide (based on preoperative assessment of the femoral neck-shaft angle of the unaffected side), the guide wire is inserted through the lateral cortex, into the femoral head to a point within 1 cm of the center-center location on both the AP and lateral views. AP and lateral fluoroscopy is used to confirm position of the start point, the trajectory, and the end point. The tip-apex distance (the sum of the distance from the tip of the lag screw to the apex of the femoral head on the AP and lateral views, corrected for magnification) has been shown to be predictive of screw cutout after intertrochanteric fracture. If the tip-apex distance is ≤25 mm, the risk for screw cutout and resultant loss of fixation will be minimized [22].

Measurement of the proposed lag screw length is done, and then the triple reamer is inserted over the guide wire. Based on bone quality, tapping may be considered with the guide sleeve, followed by lag screw insertion. Screw insertion should ideally be within 1 cm of the subchondral bone. Subsequently, the side plate is applied over the lag screw to the lateral femoral cortex. Bicortical shaft screw fixation through the side plate is then

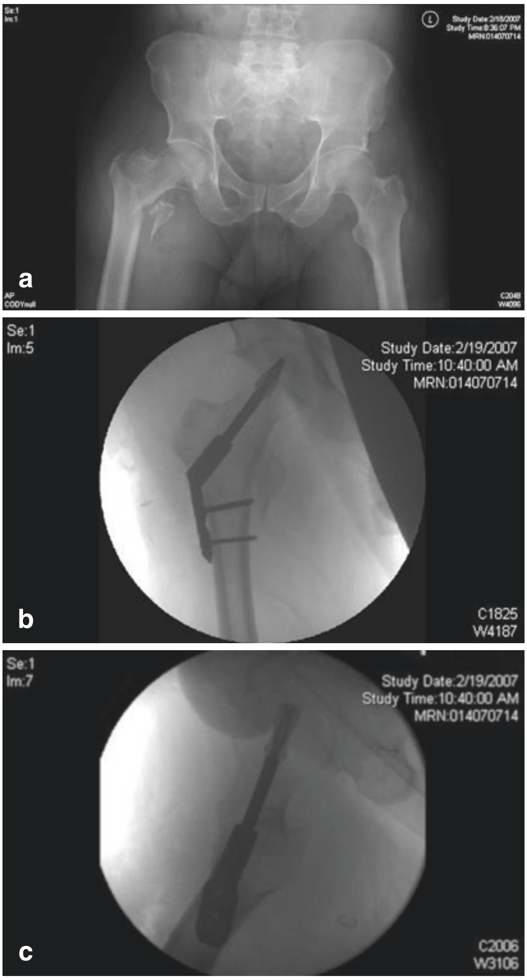


**Fig. 7.2** (**a–c**) Stable intertrochanteric hip fracture treated with a sliding hip screw demonstrating center-center position with a tip-apex distance of <25 mm

performed, and if further acute compression is desired, the compression screw can be applied with concomitant release of traction and then subsequently removed (Fig. 7.2a–c).

## Alternatives to Standard Sliding Hip Screw with Side Plate

The variable angle hip screw (VHS) (Zimmer Biomet, Warsaw, IN) is a sliding hip screw side plate device that allows angular adjustment of the side plate barrel to conform to different neck-shaft angles. This can allow for freehand guide wire insertion but should not be used to have excessive angular insertion of the guide wire for the main lag screw. A recent biomechanical study with the VHS has shown that mean compressive failure load was significantly higher in specimens dialed into a valgus angle of 150° compared to 135°. When load was applied to the two constructs, the 135° group exhibited more bending and shear, while the 150° group displayed more compression [23].

## Unstable Fracture Patterns

With unstable intertrochanteric fracture patterns, failure occurs by excessive femoral shaft medialization and significant loss of offset. This can result in catastrophic mechanical failure, nonunion, and increased propensity for decreased ambulatory function even in the setting of union. Multiple studies have suggested that >15 mm of slide can increase the risk of these unwanted complications [24–28] including limb shortening, limp, and poorer outcome measures, especially in younger patients.

Excessive sliding occurs in reverse obliquity patterns, in subtrochanteric patterns, and with lateral wall incompetence because here, the sliding hip screw slides in line with the main fracture line, not perpendicular to it, therefore resulting in excessive displacement and shear stress at the fracture site (Fig. 7.3). The absence of the lateral wall results in a situation similar to that seen in the other unstable patterns discussed [29]. This is different from the expected normal sliding in an intertrochanteric hip fracture (type A1 or 2) (Fig. 7.4).

Recent studies have shown that the excessive slide and concomitant lateral wall incompetence are directly related to patient age, iatrogenic comminution, and postoperative comminution seen. These factors are more predictive than gender, Singh index, implant position, or even quality of reduction [30]. Even in the setting of a tip-apex distance (TAD) of <25 mm, if lateral wall incompetency is present at the time of injury or created intraoperatively, this can lead to a seven times greater reoperation rate than in cases with an appropriate TAD and intact lateral wall [31].

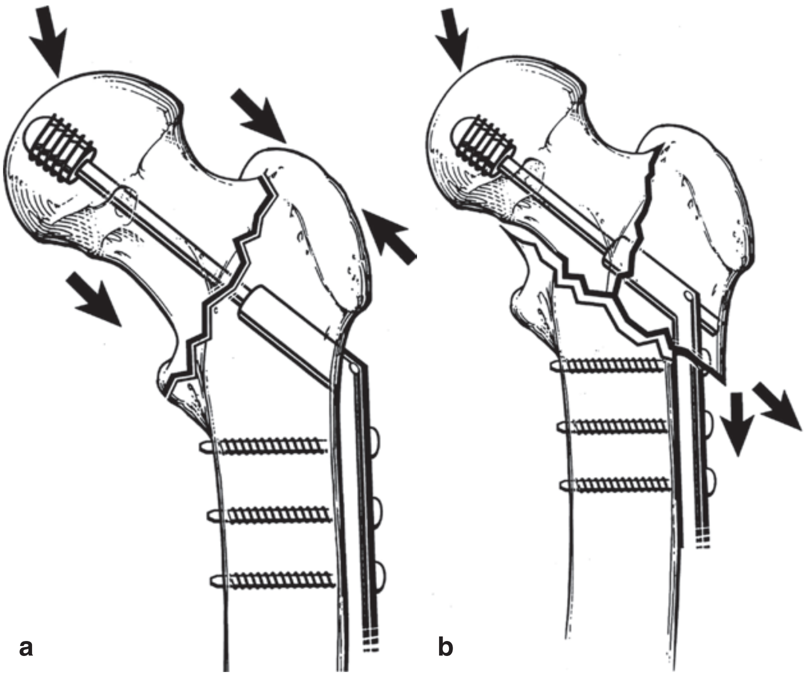


**Fig. 7.3** (**a**, **b**) Reverse obliquity fractures are not suitable for sliding hip screw fixation as the fracture will slide along the screw and allow medialization of the shaft and significant shortening (From: Reverse obliquity fractures of the intertrochanteric region of the femur Haidukewych GJ, Andrew Israel T, Berry DJ. J Bone Joint Surg Am. 2001;83(5):643–50)

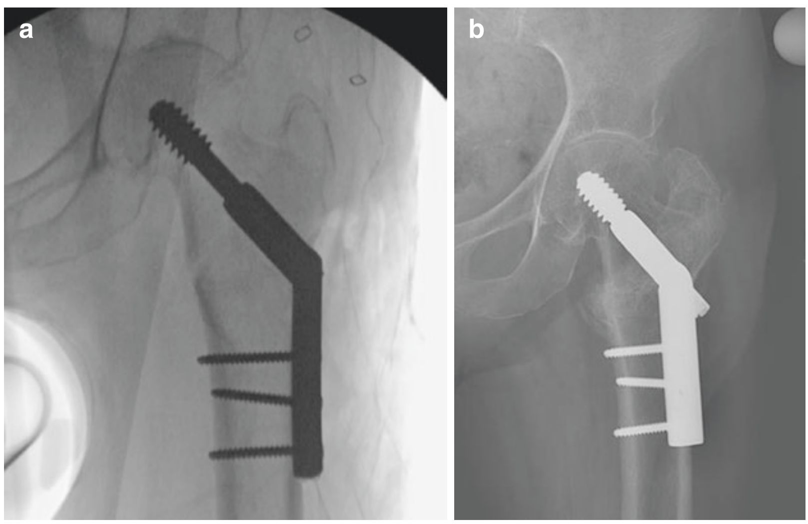


**Fig. 7.4** (**a**, **b**) Expected fracture compression with a sliding hip screw may lead to shortening

Many additions/variations to the plate and screw implants have been developed to deal with instability. Some commonly used ones include the percutaneous compression plate (PCCP), trochanteric stabilization plate, and proximal femoral locking plates (PFLP).

The percutaneous compression plate (i.e., Gotfried plate) (Instrument Makkar, Okemos, MI) has two smaller diameter lag screw/barrel components which stabilize the femoral head and neck; this device was designed to be inserted through a minimally invasive surgical technique (Fig. 7.4 – PCCP). Theoretically, these two lag screw components (9.3 mm and 7.0 mm diameters) provide greater rotational stability of the proximal fracture fragment. Other theoretical advantages provided by the use of two smaller diameter screws are preservation of the remaining lateral wall of the distal fragment. In unstable fracture patterns, it is the remaining lateral wall of the distal fragment which prevents excessive fracture collapse and subsequent fracture deformity. Placement of a large diameter single lag screw creates a larger defect in the lateral wall of the distal fragment that increases the risk of lateral wall fracture [32]. Early studies showed a decreased intraoperative blood loss and postoperative transfusion requirement than the standard sliding hip screw with side plate [32–34]. Also, smaller diameter drill device required for implant insertion has significantly decreased the potential of iatrogenically created lateral wall incompetence when compared to dynamic hip screws (DHS) even in three- and four-part intertrochanteric fractures [35].

The trochanteric side plate (DePuy Synthes, Paoli, PA) was introduced as a way to increase stability and decrease excessive slide compared to a standard DHS. This implant requires the use of a four-hole side plate and is attached to the superficial surface of the side plate. It is secured via three of the side plate screws traversing this implant and the side plate of the DHS into the femur. It has a proximal extension to stabilize the greater trochanter, functionally creating a lateral wall and limiting the amount of slide that can occur in an unstable scenario. Madsen had shown that it prevented slide of >20 mm as reliably as certain intramedullary nail devices [36]. Some have criticized the implant for its increase in operative time, dissection, intraoperative blood loss, and postoperative symptomatic hardware compared to a sliding hip screw with side plate, alone [37]. Biomechanically, the implant has been shown to provide similar resistance to medial displacement when compared to the intramedullary hip screw [38]. When a previously unrecognized lateral wall incompetence is detected intraoperatively, the use of a trochanteric side plate has been shown to decrease the reoperation rate by 13 times compared to that of patients who were treated with DHS alone [39].

Locking plates have shown increased stability in a variety of areas of the body. In the proximal femur, there are many reports of increased complication rates when proximal femoral locking plates (PFLP) are used in the setting of unstable pertrochanteric/intertrochanteric fractures. Complication rates have been shown to be between 37 and 41% in some recent series [40–42]. Large moment arms, excessive rigidity that prevents any bony apposition, and inherent weak areas in the device have been cited as reasons for the high complication rates and catastrophic failure.

PFLPs were originally postulated to be acceptable alternatives to intramedullary nailing in the setting of an unstable intertrochanteric fracture; however, they have been shown to have statistically significant greater operative time, blood loss, use of fluoroscopy, and failure rate. Additionally, patients treated with PFLPs compared to intramedullary nails have lower Harris Hip Scores and SF-12 scores [43].

## Summary

Intertrochanteric hip fractures are common injuries, especially in the growing, aging population. The impact of appropriate surgical intervention has a great impact on patient function, morbidity, mortality, and societal economics. Identifying potential instability is paramount when determining what device would appropriately and cost-effectively treat these patients. Potential lateral wall incompetency, reverse obliquity patterns, subtrochanteric fractures, and posteromedial comminution are contraindications to the use of a sliding hip screw with side plate alone and are most often best treated with cephalomedullary nails. When presented with an intraoperative situation of unexpected instability, the addition of a trochanteric side plate can increase stability but comes with its own mitigating factors. PFLPs, although theoretically have advantages to sliding hip screws with side plates, have very high complication rates and should be considered with caution for pertrochanteric/intertrochanteric hip fractures.

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# 8 Intertrochanteric Hip Fracture: Intramedullary Nails

Benedikt J. Braun, Jörg H. Holstein, and Tim Pohlemann

## Epidemiology

The incidence of hip fracture varies considerably among various populations [1], but it is estimated that as many as 1.7 million people worldwide suffer from hip fractures each year, and this number has been increasing by about 25% each decade [2]. Even though recent trends have shown a slight decrease in overall hip fracture incidence rates in the U.S., in part because of better treatment for osteoporosis [3], the growth of the elderly population worldwide will lead to an increase of osteoporosis-related fractures in the coming years [4]. The current number of Americans with osteoporosis is estimated to double by 2020, reaching over 60 million people [5]. Of all hip fractures, the portion of extracapsular fractures that can be considered for intramedullary treatment varies between 40 and 50% [1, 6]. Statistically, more than three-quarters of these hip fracture patients are female, and over 90 percent are over 70 years of age [7]. When compared with patients with femoral neck fractures, those with intertrochanteric fractures are significantly older, more likely to be limited to home ambulation, and more dependent on help for activities of daily living [8]. The comorbidity rate increases with increasing age of these intertrochanteric fracture patients, and over 90% of all patients have at least one major comorbidity [3].

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## Classification

Several classification systems for intertrochanteric hip fractures exist. In 1949, Evans [9] developed a classification system for intertrochanteric hip fractures based on the direction of the fracture line, number of fractured fragments, fragment dislocation, and stability. The fractures are divided into five main types, with type 1 being the most stable, and type 5 the most unstable (type 1: stable, no comminution; type 2: stable, minimally comminuted but displaced; type 3: unstable, lack of lateral support; type 4: unstable, lack of medial support; type 5: unstable, lack of medial and lateral support). Further classification systems by Boyd and Griffin [10] and Kyle et al. [11] were published thereafter. The most commonly used classification system for intertrochanteric femur fractures for clinical and research purposes is the AO classification system that was introduced in 1990 [12].

In the AO classification system, intertrochanteric femur fractures are classified as extracapsular fractures of the proximal femoral joint region (31-A.X). Fractures with an intact medial cortex, without fracture displacement of the lesser trochanter, are classified as A1. Sub-classification between



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1.1 and 1.3 is based on the medial fracture line, with either a supra-, trans-, or sub-trochanteric exit (Fig. 8.1a). Fractures with more than one medial fracture line end are classified as A2 fractures and are sub-classified based on lesser trochanter displacement and comminution (Fig. 8.1b). Fractures with lateral starting points beneath the greater trochanter and a main fracture line running between the greater and lesser trochanter in a horizontal or reversed fashion are classified as A3. Sub-classification is based on the horizontal orientation of the fracture line and displacement of the lesser trochanter fragment (Fig. 8.1c).

Several studies have shown superior intra- and inter-observer reliability for the AO classification system, when compared to all other, major classification systems, especially in experienced surgeons. This is based on classification for intertrochanteric fracture main types 31-A1 through 31-A3 (mean kappa value 0.82) that allow sufficient prediction of fracture stability and required implant type. AO sub-classification is less reliable, and reaches kappa values comparable to the other classification systems (mean kappa value 0.54) [13]. No classification system with sub-groups can be used reliably to

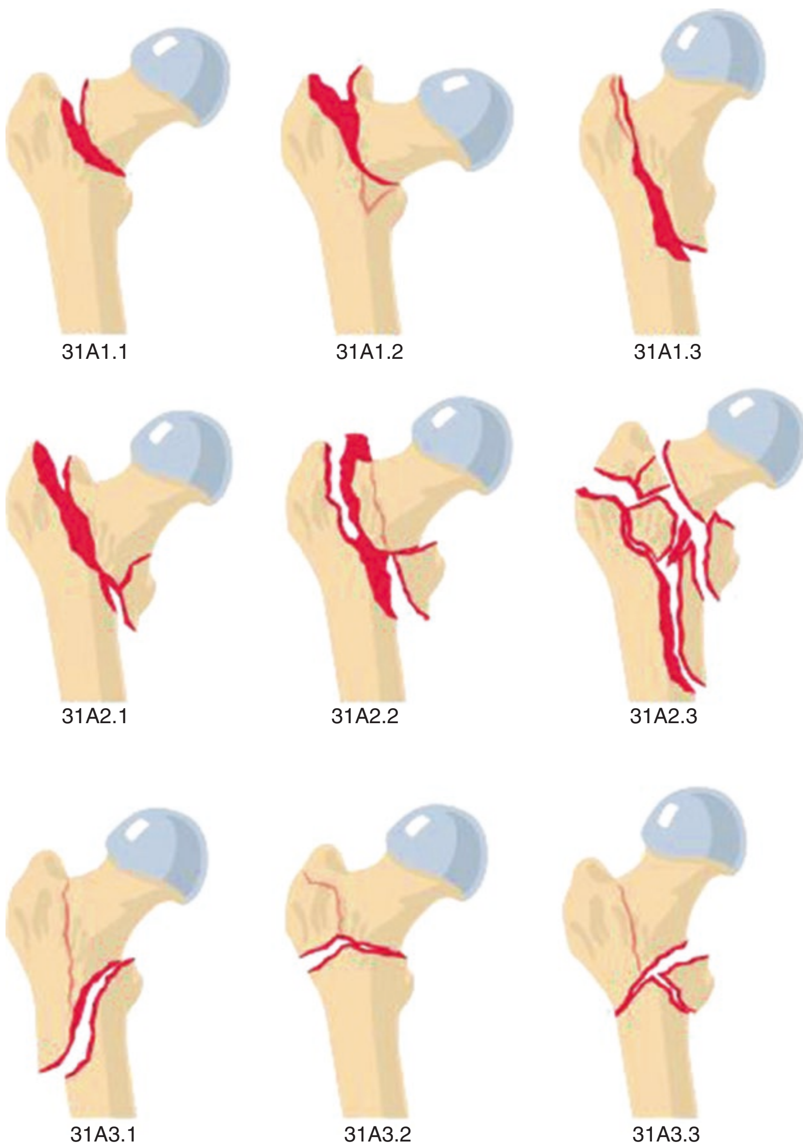


**Fig. 8.1** AO Classification system for intertrochanteric fractures. Adapted from "Tscherne Unfallchirurgie." N.P. Haas, C. Krettek; [Per- and sub-trochanteric fractures]; Copyright Springer: Berlin, Heidelberg 2012

distinguish between stable and unstable fractures. The AO classification system without sub-groups should be used in preference to all other systems.

## Relevant Anatomy and Biomechanics

The intertrochanteric femur region is one of the four distinct regions of the proximal femur (femoral head, neck, intertrochanteric, and subtrochanteric regions). The greater trochanter is an apophysis and insertion point for several important muscles: the piriformis muscle inserts on its tip, and the gluteus medius and minimus fan around the dorsolateral and ventrolateral side, while the intertrochanteric fossa is the insertion point for the short external rotators (Mm. gemelli, *obturatorius internus* and *obturatorius externus*). The lesser trochanter is the insertion point for the iliopsoas muscle and an important cortical stabilizer (Calcar). In intertrochanteric fractures requiring intramedullary nail fixation, four main fragments are commonly found: head-neck, greater trochanter, lesser trochanter, and shaft, corresponding to AO fracture types A2 and A3. As a mechanical axis runs medial to the lesser trochanter, the fracture typically displaces in a varus direction. In intertrochanteric fractures, the gluteal musculature and the iliotibial band cannot neutralize this force. After an intertrochanteric fracture, the resulting muscle forces lead to a typical displacement pattern. The gluteal muscles abduct the proximal main fragment. If the lesser trochanter is intact, the adherent main fragment is further flexed and externally rotated. The distal main fragment is commonly adducted through the adductor and hamstring muscles and externally rotated. Understanding the resulting muscle forces is a key prerequisite for assuring correct intra-operative reduction (Fig. 8.2). To counteract the displacement forces, the typical reduction maneuver thus requires traction, internal rotation, and abduction. To allow axial placement of the nail, however, adduction prior to nail insertion is necessary, depending on the entry point and patient body habitus. Intertrochanteric fractures are extracapsular fractures by definition and thus rarely compromise the femoral head perfusion [14]. However, if the piriformis fossa approach is used as an entry point for the intramedullary nail, injuries to the anterior branch of the medial femoral artery have been described [15].

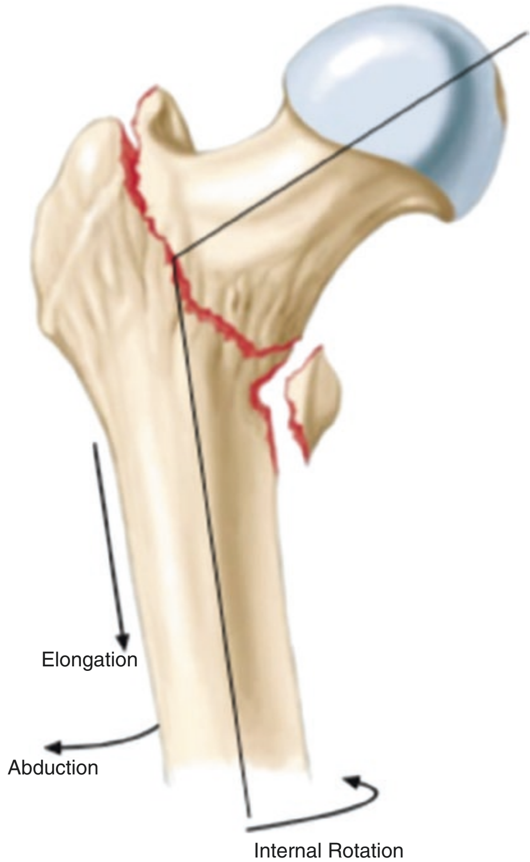


**Fig. 8.2** Typical reduction maneuver based on the common dislocation pattern encountered in intertrochanteric femur fractures requiring intramedullary nailing. Adapted from *Tscherne Unfallchirurgie*. N.P. Haas, C. Krettek; [Per- and sub-trochanteric fractures]; Copyright Springer: Berlin, Heidelberg 2012

## Initial Management

### Diagnostics

Standard anterior-posterior (ap) and lateral views of the fracture are usually enough to adequately diagnose and classify; however, due to severe pain, sometimes only one view can be achieved (Fig. 8.3). An additional ap pelvic view

**Fig. 8.3** Standard ap view of an intertrochanteric fracture with insufficient medial and calcar support, typically considered for intramedullary fixation

is advantageous for guiding intra-operative reduction based on the contralateral side, especially in severely displaced and comminuted fractures. To adequately assess whether intramedullary nailing is necessary, the medial calcar region of the proximal femur should be clearly visible on at least one plane. Traction-internal rotation radiographs may further delineate the calcar region and hint at ease of fracture reduction. Furthermore, the femur should be visualized distally to assess the inner diameter of the intramedullary canal and antecurvation of the femur. Computed tomography is rarely necessary, but should be considered if adequate classification and stability assessment of the fracture are not possible on plain radiographs, or in cases of suspected non-displaced fractures. In cases of occult fractures, magnetic resonance imaging (MRI) has superior diagnostic accuracy compared to both scintigraphy and thin layer radiography [16]. Overall careful pre-operative fracture visualization is the key to a reliable classification and implant choice [14].

## Timing of Surgery

Several large-scale studies and meta-analyses have investigated the effect of early definitive stabilization on treatment outcome. A recent meta-analysis that included more than 190,000 individuals showed significantly higher overall survival for patients operated within the first 48 h [14]. Surgery within 24 h has been shown to be associated also with a reduced risk for secondary complications, such as in-hospital pneumonia and pressure sores [17]. In general, any delay to operate significantly prolongs the hospital stay and thus increases the likelihood of hospital-related complications [18]. Preliminary studies from 2014 suggest that decreasing the time to surgery from 24 to 6 h further decreases the risk for major peri-operative complications and shortens the time to first mobilization [19].

From a clinical point of view, however, operating within the first 24 h remains a challenge. In the majority of institutions worldwide, femur fracture patients are operated with a delay of more than 24 h [20]. Statistics from the U.K. and France have shown that almost 50% of femur fracture patients are operated after more than 48 h [21]. One of the main reasons for this delay is the necessary management of comorbidities, which is especially complicated by older patients' intertrochanteric hip fractures that require intramedullary nailing, as they present with more and more severe comorbidities. However, in most of the cases, the delay is caused by organizational reasons, rather than medical [21]. Overall measures need to be established to enable surgery as quickly as possible without compromising patient safety by neglecting manageable medical comorbidities.

## Pre-operative Assessment, Managing Comorbidities

The outcome of femoral fractures requiring intramedullary nailing in elderly patients is directly influenced by the associated comorbidities. More than 75% of the intertrochanteric hip fracture patients are over 70 years old, and more than 95% of them present with at least one major comorbidity. A common rating scale to assess patient comorbidities that is directly associated with long-term mortality is the Cumulative Illness Rating Scale [22]. However, the need for medical optimization has to be weighed against a possible delay of surgery that could be required for further consultations. Medical reasons account for over 40% of surgical delays in femur fractures [21]. In many cases, there is no adequate alternative to surgery, and the risk of delaying surgery outweighs a specialist's consultation if the comorbidity cannot be correct in a timely fashion. Particularly in patients with coronary artery disease, additional investigations are not necessary, as long as a manifest acute coronary syndrome is not present. Likewise, chronic, stable congestive heart failure does not benefit from additional echocardiography [22]. A chest radiograph should be performed to recognize uncompensated heart failure in all patients over 65.

Despite the need for an expedited schedule to surgery, a reasonable preoperative delay to optimize a patient's electrolyte and volume status should be allowed. The intra-operative period, and also post-operative one (ICU vs. intermediate ICU), are periods in which the patient is closely monitored and, if necessary, urgent medical interventions can be provided immediately. To evaluate the necessity for further evaluation, the American College of Cardiology and American Heart Association have provided a flow-chart on peri-operative cardiovascular evaluation necessity (Fig. 8.4) [23]. As pulmonary

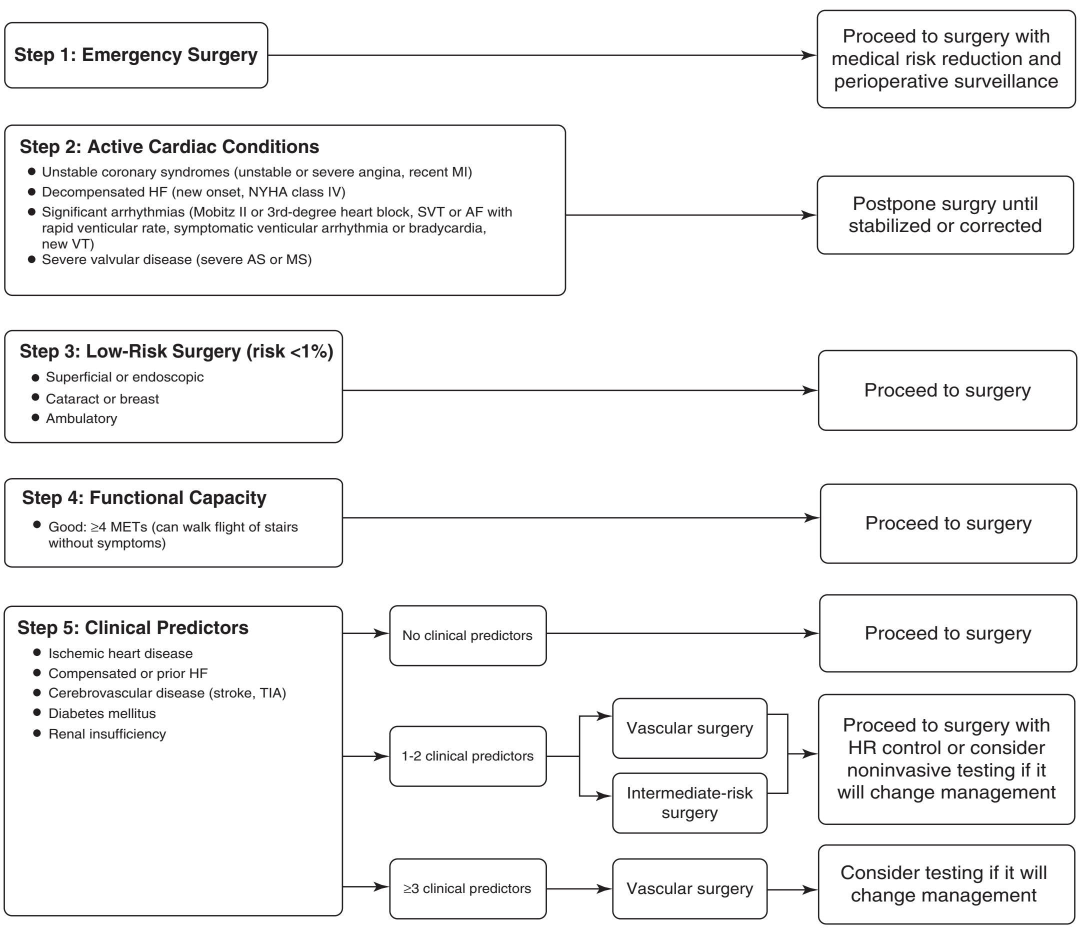


**Fig. 8.4** ACC/AHA flowchart to determine necessity for preoperative management of cardiovascular related comorbidities. Adapted from *Orthopedic Traumatology*, M.K. Sethi, A.A. Jahangir, W.T. Obremsky; Copyright Springer Science + Business Media: New York 2013

complications are as prevalent as cardiac complications, predictive risk factors need to be assessed. Especially important are chronic obstructive pulmonary disease, congestive heart failure, prolonged surgery, advanced age, and low serum albumin (<30 g/L) [24]. Chest radiographs and spirometry have limited evidence as risk stratification tools. Careful post-operative management is necessary if pulmonary complication risks are identified,and serum albumin levels can be corrected peri-operatively.

Another common problem is that many patients with intertrochanteric fractures require anticoagulants for either coronary artery disease-related interventions, or atrial fibrillation. Aspirin does not need to be put on hold, as the risk of peri-operative bleeding is clinically irrelevant [25]. Also, the commonly given clopidogrel has been shown to have no significant effect on bleeding, transfusions, length of surgery, or hospital stay [26]. Vitamin K antagonists, however, need to be interrupted and replaced by either unfractionated heparin, or low molecular weight heparin. In cases with an INR over 1.5, the administration of Vitamin K cannot timely correct the bleeding increase, but the administration of prothrombin complex concentrates allows an immediate correction without delaying surgery [27]. Newer oral anticoagulants, such as dabigatran, apixaban and rivaroxaban, might delay surgery for more than 48 h, as there is still no antidote available. Surgical intervention should be timed according to the respective antifactor Xa values for each drug, and in cooperation with the hematology department if available.

### Operative vs. Non-operative

Randomized studies comparing the difference between operative and non-operative treatment in intertrochanteric femur fractures are few. The goal to allow an early functional aftercare in patients with oftentimes severe comorbidities cannot be reached by non-operative treatment. Non-operative treatment is associated with significantly longer hospital stays and greater loss of independency [28]. Non-operative therapy of intertrochanteric femur fractures should thus only be considered in moribund patients or patients with severe comorbidities, placing them at an unacceptable risk for surgery and anesthesia [29]. Fracture union is rare, and even if it is achieved, severe rotational and longitudinal malalignment has to be expected [30]. The resulting muscle forces will cause the proximal main fragment to be in an abducted, flexed, and externally rotated position. Extension treatment will correct only longitudinal malalignment, so conservative treatment of femoral fractures is thus considered virtually obsolete [31].

## Techniques

### Intramedullary Nail vs. Sliding Hip Screw

The most recent Cochrane Review comparing intramedullary nails with the sliding hip screw design has reached the conclusion that there is no significant difference in the outcome between both devices for intertrochanteric femur fractures [32]. The reported outcome measures that do not differ between both fixation devices were cut-out, non-union, infections, mortality, length of surgery, pain, and return to previous residence. In light of the reported complication rates for intramedullary devices, namely intra-operative and late fractures around the intramedullary nail system, the review favors extramedullary fixation devices, especially in stable fracture situations. In contrast, other studies reported fewer complications, decreased intra-operative blood loss, earlier mobilization, and faster return home for intramedullary systems [33, 34]. Economic considerations warrant the use of extramedullary fixation devices in stable fracture AO type A1 situations. For potentially unstable fracture situations (AO types A2 and A3), in which the medial support of the calcar is missing, intramedullary fixation devices have an advantage

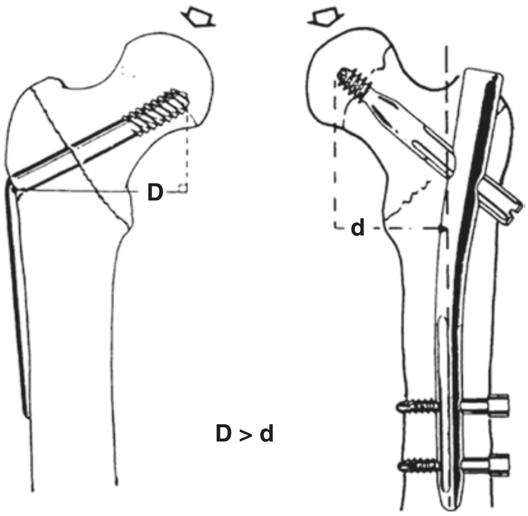


**Fig. 8.5** The concept of the shorter lever arm for intramedullary fixation compared to extramedullary plating is shown (D > d). Adapted from Leung 1992; Copyright The British Editorial Society of Bone and Joint Surgery, London 1992

over sliding hip screw systems. The developmental principle behind the intramedullary systems was in part to shorten the lever arm of force affecting the medial calcar region (Fig. 8.5). Biomechanical studies have shown that the load to failure resistance is almost doubled for intramedullary systems compared to extramedullary ones [35].

## Intramedullary Nail vs. Arthroplasty

There have been only a few studies on primary arthroplasty for unstable intertrochanteric proximal femur fractures. A Cochrane Review from 2006 concluded that there was no clear evidence for the advantage of one method over another. In the clinical practice, primary hip arthroplasty is not an appropriate treatment option for intertrochanteric fractures, as it is difficult to achieve sufficient primary stability of standard stems in the femur. One study, comparing cephalomedullary nailing in unstable fractures with long-stem, uncemented hemiarthroplasty, showed significantly higher surgical time, and more blood loss and mortality for the arthroplasty group [36]. Arthroplasty is thus mainly considered to be revision surgery for failed intramedullary treatment. One study comparing secondary arthroplasty after intramedullary nailing and extramedullary sliding hip screw surgery showed an increased complication rate for revision after intramedullary nailing [37]. No difference in functional results was seen.

## Differences between Intramedullary Nail Designs

There is a variety of intramedullary fixation devices, all of which have structural advantages and disadvantages (Fig. 8.6). The most common designs include either a femoral neck screw or blade. The blade offers the advantage of increased stability in lower-quality bone due to the impaction of the cancellous bone during implantation, and an increased load-carrying surface [38]. There are other design differences in the implementation of rotational stability, such as systems with additional anti-rotational screws placed in the femoral neck, as well as locking mechanisms for the femoral neck screw. Biomechanical studies and simulations have shown less cut-out risk for the locked one-screw designs [39], and the newest nail designs offer additional guidance systems for screw fixation of the lesser trochanter region. A recent Cochrane Review could not find any differences in the outcomes among the available nail systems [40]. Furthermore, in isolated intertrochanteric fractures, no difference was seen between failure rates of long and short cephalomedullary nails [41]. Biomechanical and limited clinical studies have shown increased cut-out resistance of cement-augmented intramedullary nails [42]. A careful operative technique is needed to avoid perforation of the femoral head with the guidewire, as this would lead to cement leakage into the hip joint. The risk of such leakage into the fracture, and thermal necrosis of the trabecular bone, can be avoided by applying only small amounts of cement.

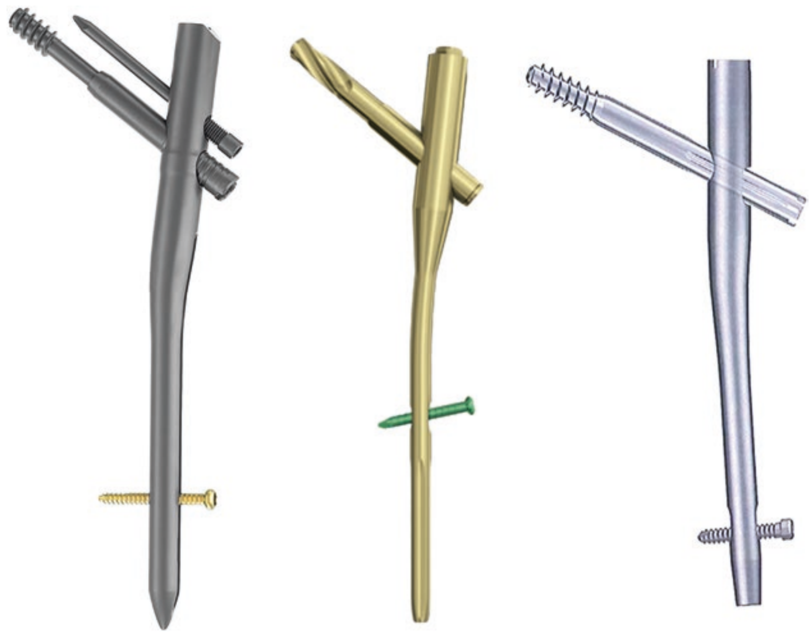

**Fig. 8.6** Different, current intramedullary nail designs are shown from left to right: a system with a femoral neck screw and additional anti-rotational femoral neck screw (Targon® PFT; B Braun AG Melsungen, Germany); a system with a femoral neck blade (PFNA; Synthes GmbH Umkirch, Germany); and a system with a femoral neck screw and anti-rotational locking inside the nail itself (Gamma3 Nail; Stryker GmbH & Co. KG: Duisburg, Germany)

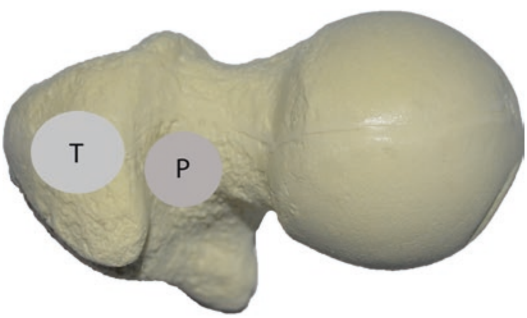


**Fig. 8.7** Superior view of the proximal femur. The trochanteric and piriformis entry points are marked by a T and P, respectively

## Piriformis vs. Trochanteric Entry Point

The piriformis fossa (Fig. 8.7) was introduced as an entry point that is in line with the longitudinal axis of the femur, to reduce the risk of varus malalignment at a time when rigid straight nails were used. Studies showed a high union and low infection rate [43]. A disadvantage of this entry point is its lower tolerance for incorrect portal placement. If the entry point deviates anterior to the piriformis fossa by as little as 6 mm, the resulting circumferential stresses can cause anterior cortical “blow-out” [44]. Establishing the entry point can be challenging in obese patients, due to the higher medialization needed, compared to the trochanteric entry point [45] especially in minimally invasive exposures. Cadaveric studies have shown that the piriformis entry point can damage the anterior branches of the medial femoral circumflex artery, compromising the femoral heads’ blood supply [15].

The trochanteric entry point was introduced by Kuentscher already in 1939. Almost all current nail designs accommodate for the trochanteric entry side by having a lateral, proximal bend between 4 and 6° to prevent varus malalignment. The entry point is easier to establish, more forgiving, and causes less soft tissue damage to the abductor complex and short external rotators [46]. Further studies have shown decreased operating and fluoroscopy time [47].

## Tip Apex Distance

To reduce the risk of screw migration or cutout, the distance between the tip of the femoral neck screw and the border of the femoral neck is a useful measure. This distance is measured in both the ap and lateral view and summated (Fig. 8.8). The resulting tip apex distance (TAD) is predictive of the risk of screw cutout. Studies have shown that TADs below 20–25 mm have significantly less migration and cutout complications [48, 49].

## Surgical Technique

The patient is placed in the supine position on a fracture table, and the non-injured leg is abducted, flexed, and placed in a stirrup. A perineal post with sufficient padding is placed between the legs, and the injured leg is placed in a traction device (Fig. 8.9). The reduction is performed prior to the skin preparation and draping under fluoroscopic control, alternatingly in ap and lateral views. The lateral view plane has to be adjusted to account for the femoral neck anteversion. Commonly, the fracture displacement is improved with traction and internal rotation of the leg. The preoperative radiographs should be available in the operating room to guide the reduction based on the contralateral anatomy. After correct reduction, the patient is prepped and draped in a sterile fashion according to standards (Fig. 8.10). A 4 cm skin incision is performed just proximal to the greater trochanter

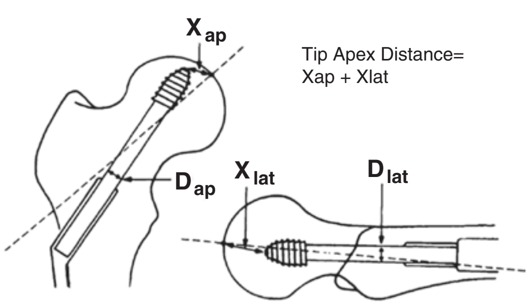


**Fig. 8.8** Calculation of the Tip Apex Distance. Adapted from "Tip-apex distance of intramedullary devices as a predictor of cut-out failure in the treatment of peritrochanteric elderly hip fractures" *International Orthopedics*, J.A. Geller; Copyright Springer: Berlin Heidelberg 2009

**Fig. 8.9** Preoperative patient positioning. The uninjured leg is abducted and flexed on a stirrup. A perineal post is placed to apply traction to the injured leg with a traction table setup. Adapted from *Operations atlas für die orthopädisch-unfallchirurgische Weiterbildung*. D. Kohn, T. Pohlemann; Copyright Springer, Berlin, Heidelberg 2010

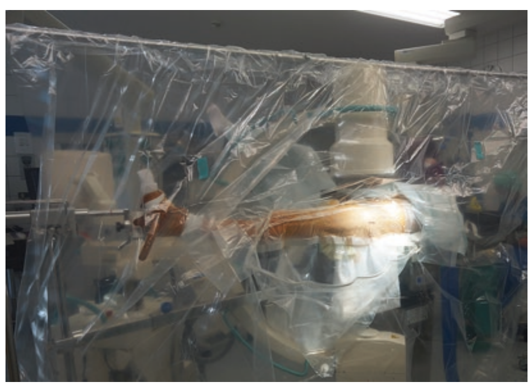

**Fig. 8.10** Prepped and draped patient for intramedullary nailing. The main skin incision is marked. Femoral neck and locking screw incisions are intra-operatively based on the aiming device. Fluoroscopy is placed for an ap view

with sharp dissection through the gluteal fascia. Soft tissue is spread on to the tip of the greater trochanter. By palpation and fluoroscopy, the entry point is visualized—either at the trochanter or the piriformis fossa, depending on the nail to be used.

An awl or guide pin is used to establish the entry point. If the more common trochanteric approach is chosen, the entry point should be placed just medial to the tip of the greater trochanter in the ap view and in the central portion of the femur in the lateral view. After correct reduction and positioning of the guide wire have been confirmed, an entry reamer is used to open the medullary cavity. In narrow medullary canals, reaming can be necessary, using a ball-tipped guidewire. The nail is then placed under fluoroscopic control. If the placement cannot be performed gently, further reduction or reaming might be required. Correct placement is fluoroscopically confirmed, and the guide pin for the femoral neck screw is placed through the nails' aiming device. To prevent malrotation during screw placement, another pin can be placed into the femoral head. Newer nail designs have incorporated aiming devices for this purpose. The guide is checked in both ap and lateral views. A cannulated step drill (with depth stop set to the previously measured screw length) is used to establish the path for the screw. In good quality bone, tapping prior to screw implantation is often necessary. The lag screw is then placed under fluoroscopic control to recognize and prevent medial guide perforation. After correct screw placement, traction can be released and the fracture compressed with the nail-specific instrumentation. Depending on the implant, a set screw, or an anti-rotational screw is placed. The nail is locked distally with an aiming guide or fluoroscopically controlled for long nails. The wounds are closed after copious irrigation in a layered fashion and a spica dressing might be applied.

## Intraoperative Medical Management

A recent study has shown that there is no difference in long-term mortality between general and regional anesthesia, and only the length of hospital stay is moderately decreased in regional anesthesia [50]. However, a commonly prescribed platelet anticoagulant (e.g., clopidogrel) is used as a contraindication for regional anesthesia. More importantly, intraoperative fluid optimization guided by left ventricular stroke volume can reduce hospital stay and accelerate post-operative recovery [51]. This effect was not seen for hemoglobin transfusions. Particularly in patients with severe comorbidities, no difference was shown between liberal (transfusion trigger at 10 g hemoglobin per deciliter) and restrictive (transfusion trigger at 8 g hemoglobin per deciliter) blood transfusion regimes. The studies conclude that it is safe to withhold blood transfusions, even below a threshold of 8 g/dL, as long as there are no other physiological symptoms of anemia [52]. Careful consideration of the accompanying risk factors (low cardiopulmonary reserve) is necessary.

## Aftercare

### Management on the Ward

Intertrochanteric fractures are associated with pain. To reduce the risk of the common post-operative delirium in older fracture patients, adequate analgesia has to be administered during all phases of treatment. Especially in the postsurgical phase, intravenous morphine is a safe and effective method to control post-operative pain without limiting the patients' cognitive potential [53, 54]. An important comorbidity is diabetes mellitus, as an independent risk factor for cardiac complications, heart failure, renal failure, infections, and overall mortality. To adequately reduce the peri- and post-operative complication risk, the American College of Endocrinologists recommends a glucose level below 110 mg/dL [55]. Various combined approaches of orthopedics and geriatrics, collectively known as orthogeriatrics, successfully manage the older patient clientele. Evidence in the literature for long-term clinical effects, however, is scant [56], and just one approach has shown reduced mortality and morbidity while improving walking ability: patients are postoperatively managed on a geriatric ward and orthopedic, anesthesiologic, and rehabilitation specialists determine the treatment for each patient individually [22].

## Weight-bearing

Post-operative weight-bearing, as tolerated in patients treated with intramedullary nailing, is technically possible and recommended. Intramedullary fixation devices provide sufficient working length to avoid increased stresses – even at comminuted fracture sites – and minimize shaft medialization [57]. Due to the advanced age of the patient, however, immediate patient-controlled full weight-bearing is not always feasible. Combined orthogeriatric and physical therapeutic supervision is needed to increase weight-bearing as early as possible. Early full weight-bearing decreases the risk for medical complications, improves functional recovery, accelerates hospital discharge, and reduces overall mortality [58, 59].

## Outcome

Studies have shown that the most predictive factors for the functional and overall outcome after intertrochanteric fractures are age, dementia, and preoperative function [60]. It has been shown that only about 55% of patients regain their previous walking ability, and about 34% of patients lose their previous level of daily living function. Unstable fracture patterns, typically treated with intramedullary fixation, have poorer functional outcomes in the first 3 months after surgery; however, this difference evens out over time. The number and severity of comorbidities, as well as gender, negatively affect the overall outcome – especially post-operative ambulation, quality of life, and activities of daily living [61]. The gender difference is particularly evident in mortality rates; the overall mortality rate after hip fracture is significantly higher in men, regardless of age. According to the literature, the overall mortality rate ranges between 12 and 35% in the first year [61], and intra-hospital mortality ranges between 2 and 8%.

## Complications

Several typical complications for the treatment of proximal femur fractures with intramedullary nails are known: The most common complication in the treatment of intertrochanteric hip fractures is inadequate fracture reduction and consecutive malpositioning of the femoral neck screw in the anterosuperior quadrant. Especially in osteoporotic bone, this can lead to screw cut-out (Fig. 8.11). Repeated drilling of the femoral neck screw has to be avoided, as almost 10% of the femoral head volume is lost with each drilling; even correctly placed screws can cut out in inferior quality bone through the screws' sliding mechanism [62]. To reduce the risk of screw cut-out, careful fluoroscopy-guided reduction, accurate screw placement, and a correct tip apex distance are mandatory [48]. During the placement of the femoral neck screw, perforation of either the screw, or the guiding wire into the small pelvis, have to be avoided by repeated, intraoperative fluoroscopy. During nail implantation, especially in unstable fracture situations, fragment dislocation through nail entry within the fracture line has been described [63]. This has to be avoided, as fragment displacement is associated with reduced stability and significantly poorer functional results. Careful preoperative planning and appropriate adjustment of the entry point can prevent this complication. Especially in cases where the femoral nail is damaged during the drilling of the neck screw, fatigue fractures of the nail at the nail-screw interface can occur [49]. Furthermore, there are several implant-related, cut-out complications: in implant systems with an additional anti-rotational screw, the so-called "Z-effect" is encountered when both screws run in opposite directions. Usually, the anti-rotational screw travels medially, due to its close proximity to the intrafemoral tensile trabeculae. This can lead to anti-rotational screw cutout, also known as the “knife-effect” (Fig. 8.12). Intertrochanteric nail systems that use a femoral neck blade (instead of a screw) are less prone to proximal cutout. Particularly in incompletely reduced fracture situations, however, they are prone to cut through the medial cortex of the femoral head. The gliding mechanism can lock, and if fragment alignment is not given, the blade might cut further into the femoral head (Fig. 8.13)

## Evidence-based Medicine

| Category | Summary | Author evidence | Level |
|---|---|---|---|
| Epidemiology | Up to 50% of hip fractures are intertrochanteric | [1] | III |
| | Advanced age increases likelihood for intetrochanteric fractures, with over 90% of patients older than 70; up to 75% are female patients | [8] | III |
| Classification | AO classification most prevalent; best inter-observer reliability if no sub-groups are used | [13] | III |
| Initial management | *Diagnostics* | | |
| | Good preoperative visualization needed by conventional X-ray; additional CT scan if no reliable classification possible | [14] | V |
| | *Timing* | | |
| | As early as possible (<48 h) for reduced mortality and secondary complications | [17, 65] | I |
| | *Pre-operative management* | | |
| | Medical management accounts for 40% of delays | [21] | III |
| | Aspirin and clopidogrel have no significant effect on bleeding | [26] | III |
| Operative vs. non-operative | Non-operative only if not manageable comorbidities; longer stay, more complications, lower healing rates, loss of independence | [28] | I |
| Technique screw | *Intramedullary nail vs. sliding hip* | | |
| | Overall sliding hip screw with fewer complications and more cost-efficient | [32] | I |
| | Biomechanical advantage in unstable fracture situations for intramedullary nails | [35] | III |
| | Decreased blood loss, earlier mobilization and return home for intramedullary fixation | [34] | III |
| | *Different nail designs* | | |
| | No difference between designs | [40] | I |
| | No difference between short and long nails | [41] | III |
| | *Technique* | | |
| | Trochanteric entry point with less soft tissue damage, shorter operating time | [47] | III |
| | Low tip apex distance decreases complication rate (<20 mm) | [48] | III |
| Aftercare | Pain-titrated analgesia with morphine has low complication rate and no cognitive effect (delirium) | [54] | III |
| | Increased infection and mortality rate with diabetes mellitus; recommended blood glucose level < 110 mg/dL | [55] | VI |
| | Restrictive transfusion regime (8 g/dL) is equally effective as non-restrictive regime (10 g/dL) if no physiological trigger exists | [52] | III |
| | Early full weight-bearing reduces mortality and complications, and improves functional recovery | [59] | III |
| Outcome | Predicted by age, gender, dementia, pre-operative function | [61] | V |
| | 55% regain previous walking level; 34% lose daily living function | [60] | III |

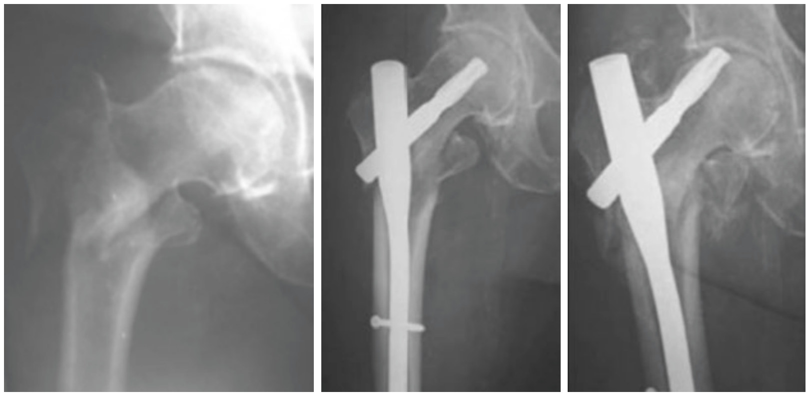

**Fig. 8.11** Femoral neck screw cutout after intramedullary nailing of an AO Type A3 fracture. Adapted from Fuchtmeier 2011; Copyright Springer: Berlin, Heidelberg 2011

**Fig. 8.12** Medialization of the anti-rotational screw (proximal), known as Z-effect and subsequent cutout. Adapted from Fuchtmeier 2011; Copyright Springer: Berlin, Heidelberg 2011

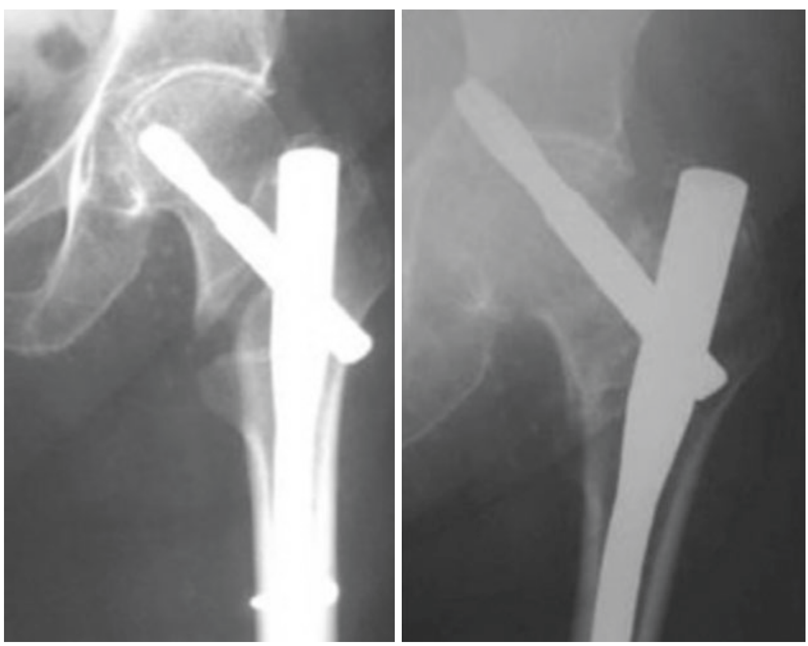

**Fig. 8.13** PFN—A screw cut-through in an incompletely reduced A 2.1 fracture situation. Adapted from Fuchtmeier 2011; Copyright Springer: Berlin, Heidelberg 2011

[64]. Femoral head necrosis has been described after intertrochanteric fractures, possibly due to injuries to the medial femoral circumflex artery during piriformis entry point approaches [15].

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# Subtrochanteric Femur Fractures

# 9

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## Introduction and Epidemiology

Subtrochanteric femur fractures are significant injuries that despite surgery can lead to relatively high rates of nonunion, malunion, and subsequent poor clinical outcomes.

Overall, subtrochanteric femur fractures comprise 10–34% of all hip fractures [1]. Several retrospective studies report a bimodal distribution among patients [2–5]. Velasco and Comfort reported that 63% of subtrochanteric fractures occurred in patients 51 years and older and 24% in patients between the ages of 17 and 50 years [4]. Younger patients sustain the fractures via high-energy mechanisms, while older individuals via lower-energy mechanisms as well as bisphosphonate-associated insufficiency fractures [2, 6–8]. A review of subtrochanteric fractures at a Level I trauma center, by Bergman et al., noted an average age of 40 years in the high-energy trauma group and 76 years in the low-energy trauma group [2].

An understanding of the relevant anatomy and biomechanics of the proximal femur has helped define operative management for subtrochanteric fractures. Advances in engineering and manufacturing of new implants [9–11] have provided hardware with greater strength and overall fatigue life. In addition to managing the deforming anatomical forces, the surgeon must chose an implant design that is able to withstand the large biomechanical forces subjected to the subtrochanteric region [12]. The use of cephalomedullary locked nails and open indirect reduction techniques that preserve the soft tissue envelope and vasculature has resulted in a reduction of postoperative nonunions [13–19]. With an understanding of each patient and their fracture patterns, the surgeon can strategically choose the appropriate treatment to improve their patient's clinical outcomes.

## Relevant Anatomy and Biomechanics

The subtrochanteric region of the femur is defined from the lesser trochanter to 5 cm distal to the lesser trochanter. These fractures can often extend into the intertrochanteric region and are called "pertrochanteric" fractures or intertrochanteric fractures with subtrochanteric extension. Proximal femoral anatomy causes powerful deforming forces that create characteristic, complex fracture pattern. The typical radiographic appearance consists of a proximal fragment that is in varus, abduction, and external rotation, while the distal fragment is adducted (Fig. 9.1).

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**Fig. 9.1** Anteroposterior (AP) radiograph exhibiting a comminuted subtrochanteric femur fracture with shaft extension. Note the proximal fragment in abduction, external rotation, and flexion, the typical appearance of this fracture pattern

The pull of specific muscle groups in the proximal femur results in this characteristic deformity. The gluteal muscles, the iliopsoas, and the short external rotators are responsible for the proximal segment external rotation, while the gracilis, adductor brevis, adductor longus, and adductor magnus adduct the distal femoral shaft.

Biomechanically, the forces about the proximal femur are some of the highest seen in the human body. The earliest studies by Koch first analyzed the mechanical stresses on the femur during weight bearing. He showed that up to 1200 lb/inch$^2$ of force could be generated in a 200-lb man. Compression stress exceeds 1200 lb/inch [2] in the medial subtrochanteric area 1–3 inches distal to the level of the lesser trochanter. Lateral tensile stresses are approximately 20% less [12]. While Koch's analysis was correct for the forces on the femur, he did not take into account the additional stress from the muscle forces [20]. Frankel and Burstein demonstrated a significant force on the hip and proximal part of the femur from flexion and extension of the hip while lying in bed, thus indicating continuous stress on a proximal femoral fixation device even with the patient at bedrest [21]. An analysis by Fielding et al. demonstrated that a medial cortical buttress was required to minimize local stress in the subtrochanteric region. They showed that nonunion results from fatigue failure of a fixation device and that nonunion is actually the cause of implant failure [22]. Higher bending forces are applied to an extramedullary device on the lateral femur than an intramedullary device, which is closer to the line of joint reaction force [23]. Froimson's description of muscle forces aids our understanding of subtrochanteric fracture displacement and also suggests how such fractures can be reduced [24]. These deforming forces create the obstacles to gaining appropriate reduction. Proper application of tools and implants has helped individuals gain successful reduction of these complex fractures.

## Classification

There are over 15 described classifications of subtrochanteric fractures in the literature [25]; however, the Russell and Taylor and the AO/OTA classifications have historically been the most widely reproducible [26, 27]. The Russell and Taylor classification was historically used to differentiate fractures that could be fixed with an intramedullary nail (Type I) or whether a lateral fixed angle device would be required (Type II). Type I fractures do not extend into the piriformis fossa (Type IA, no extension into the lesser trochanter; Type IB, extension to the lesser trochanter). Type II fractures extend into the piriformis fossa (Type IIA, no comminution of lesser trochanter; Type IIB, comminution of lesser trochanter) [26]. This classification has since lost favor due to the development of interlocking nails utilizing both trochanteric and piriformis starting points allowing (Table 9.1). These operative modifications have allowed Type II fractures to be treated with intramedullary devices.

**Table 9.1** Russell–Taylor classification

| | |
|---|---|
| Type IA | No extension into the lesser trochanter |
| Type IB | Extension into the lesser trochanter |
| Type IIA | No comminution of the lesser trochanter with extension into the piriformis fossa |
| Type IIB | Comminution of the lesser trochanter with extension into the piriformis fossa |

Historically used to determine between fixation with an intramedullary device (Type I) and an extramedullary device (Type II)
Current locked intramedullary implants with trochanteric and piriformis entry points allow fixation of Type II fractures

**Table 9.2** AO/OTA classification examples

| | |
|---|---|
| 32-A3.1 | Simple (A), transverse (3), subtrochanteric fracture (0.1) |
| 32-B3.1 | Wedge (B), fragmented (3), subtrochanteric fracture (0.1) |
| 32-C1.1 | Complex (C), spiral (1), subtrochanteric fracture (0.1) |

Fracture location: femur (3), diaphysis (2), subtrochanteric region (0.1)
Fracture pattern: simple (A), wedge (B), complex (C)

The AO/OTA classification, typically the most widely used, takes into account the bone, the location, the energy of the trauma, and the mechanism [27]. Conventionally subtrochanteric fractures are categorized along with other diaphyseal femur fractures (Table 9.2). The AO/OTA classification is the most widely used in the literature for research; however, in practice, subtrochanteric fractures are typically described by its location and any fracture extension and/or severity of comminution.

## Initial Evaluation, Work-Up, and Management

Subtrochanteric fractures, especially in the young patient, typically involve high-energy mechanisms and must be evaluated for other associated injuries. A primary survey under the ATLS guidelines is essential [28, 29]. Life-threatening injuries must be identified and resuscitative measures initiated. The secondary survey should be performed later as part of a more detailed head to toe examination. Critically ill, multiply injured patients should be evaluated and temporarily stabilized and resuscitated.

In the older individual with a lower mechanism of injury, a detailed history of how the accident occurred should be performed to uncover any possible comorbidities leading to injury. If the patient had a syncopal episode resulting in a fall, then an appropriate work-up must be conducted before the patient can be cleared for any surgical intervention. The patient's medication history must be evaluated for the use of bisphosphonates. Recent studies have shown that chronic bisphosphonate therapy for more than 3–5 years may increase the risk of atypical femoral fractures [6–8]. In regard to bisphosphonates, prodromal thigh pain as well as contralateral imaging should be performed. Concern for insufficiency fracture can be diagnosed further with advanced imaging such as magnetic resonance imaging, CT, or bone scan [30–34].

On physical examination when the fracture is displaced, the injured extremity is most often shortened and externally rotated. The thigh may be swollen and can at times have a bony prominence from the deforming forces acting on the proximal fragment. Patients are unable to actively flex their hip or tolerate any range of hip motion. The patient is usually neurologically intact without vascular deficit. Penetrating injuries, on the other hand, can cause neurovascular injury to the surrounding structures and must be carefully evaluated. Initial diagnostic studies should include plain radiographs consisting of anteroposterior (AP) and cross-table views of the hip along with full-length femur views. An AP pelvis view (typically obtained during the trauma work-up) can be helpful in assessing femoral neck/shaft morphology of the uninjured side.

The characteristics of an atypical fracture due to long-term bisphosphonate use on radiographic evaluation include lateral cortical thickening, transverse fracture orientation, lack of comminution, and medial cortical spike [7]. Diagnostic studies on the contralateral side are indicated if the patient has any history of thigh pain on the contralateral side of the injury. A recent retrospective study by Saleh et al. suggested that if a symptomatic patient taking long-term bisphosphonate therapy presents with lateral cortical thickening and no radiolucent line, then discontinuation of bisphosphonate treatment and conservative treatment with teriparatide can resolve the fracture [35]. When a radiolucent line is visible along with lateral cortical thickening, then surgical prophylaxis is recommended to prevent propagation to a complete fracture [7, 8, 35]. Identification of an occult fracture will change the clinical course of the patient providing a definitive medical management and a shorter hospital stay [36].

Initial management includes proper evaluation and hemodynamic resuscitation, if needed. Skeletal traction via a distal femoral or proximal tibial traction pin not only restores length but also can provide considerable pain relief. Skin traction (i.e., Buck's traction) is also an alternative [37] but will not restore femoral length. Medical optimization prior to operative intervention is of paramount importance.

## Nonoperative Management

Due to the high morbidity and mortality, nonoperative management is truly reserved for those in severe extremis that will likely succumb to other organ injuries [38]. Alternatively, those patients in end-of-life care that choose not to undergo operative fixation may opt for nonoperative management but should only do so after a long discussion with the patient and the family. Even in those patient populations (and even in those non-ambulatory), operative stabilization of the femur can offer benefits not only in regard to pain relief but also to their caregivers, as it will facilitate easier hygiene care and the ability to transfer.

## Operative Management

### Intramedullary Locked Nail

The intramedullary locked nail is the gold standard for fixation of acute subtrochanteric femur fractures. Biomechanically, there are several advantages when using the intramedullary nail compared to plate and screws. The nail provides increased rigidity, shorter moment arm, and bending stiffness [39]. The intramedullary nail provides more efficient shared load transfer while resisting deforming forces of medialization from the adductor muscles [11, 40, 41].

There are several IM nail types available for treatment of subtrochanteric fractures. The cephalomedullary hip nail (Fig. 9.2a, b) is most often used in older patients or those with poor bone stock; it utilizes a large threaded screw for stability and protection of the femoral neck. In the younger patient, with healthy bone, a smaller diameter (reconstruction) intramedullary nail (Fig. 9.2c, d) with two smaller screws into the femoral neck can be used to avoid a large screw tract while providing rotational stability of the proximal fragment. Some reconstruction nails incorporate a proximal crossing screw configuration, which has one screw up through the femoral neck and one screw from the greater trochanter to the lesser trochanter. A biomechanical study by Grisell et al. comparing the cross-screw configuration to the parallel screw configuration showed greater axial failure loads and significantly higher stiffness in the cross-screw technique [10].

There are several options for positioning of the patient for IM nailing. Placing the patient supine on or off a fracture table allows for easier imaging and intraoperative traction of extremities for polytrauma mechanisms. The patient can also be placed lateral on a fracture table or a radiolucent flat table. Placing a patient lateral will allow the distal fragment to flex matching the proximal fragment. This position allows for easier access to the starting point in heavier people with adduction allowing for access.

An important step in ensuring proper fracture reduction is achieving the ideal starting point in either the piriformis fossa or trochanteric tip [14, 42]. Historically, the piriformis starting point was used with straight intramedullary nails. However, an improper piriformis start point can lead to fracture malalignment and increased fracture comminution, and if too anterior, increased hoop stresses can lead to femoral bursting of the proximal femoral fragment [40].

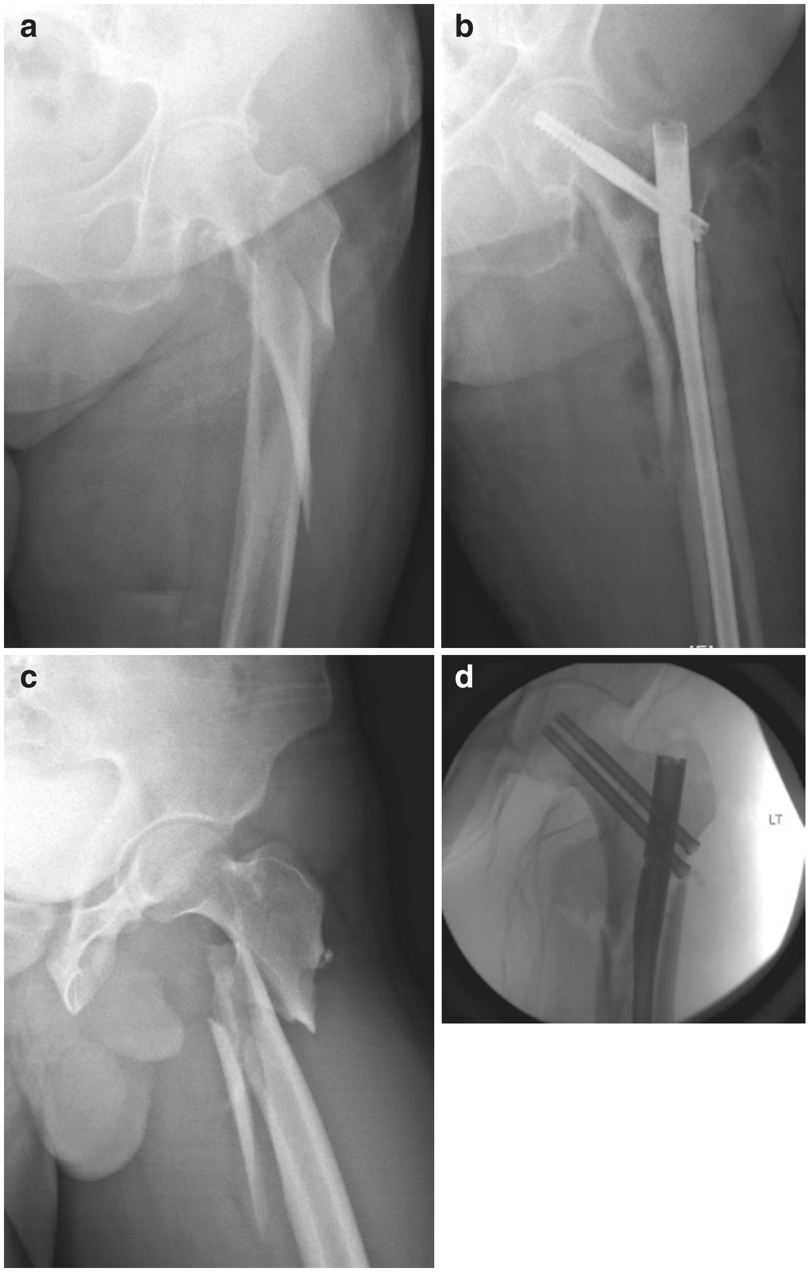


**Fig. 9.2** (**a**, **b**) In the elderly, cephalomedullary IMN utilizing a single lag screw can be sufficiently utilized, while in the younger patient, (**c**, **d**) smaller bore reconstruction-type screws can offer less bone loss and more rotational control with two points of fixation

More recently manufactured intramedullary nails were designed for use through a trochanteric starting point. These intramedullary nails have a built-in proximal bend of 4–6° to help prevent varus malreduction. Although the starting point allows for a more subcutaneous landmark, a perfect starting point is still vital for a successful outcome [43, 44]. The starting point needs to be slightly more medial in order to avoid varus malreduction, which can still occur despite the proximal bend [43]. A cadaveric study analyzing the greater trochanters in 100 specimens found that only 63% had an unobstructed ideal entry point, whereas the remaining 37% all had some degree of obscuring of the entry portal [9].

After the ideal starting point is obtained, there are a number of strategies that can be used to further help achieve proper alignment of the fracture (Fig. 9.3a–c). While traction can restore femoral length, the powerful deforming forces of the proximal femoral segment can result in varus and flexion malalignment. In two-part subtrochanteric fractures, the "finger" or cannulated reduction tool can be passed down the canal to provide stabilization and allow passage of the guide wire down an ideal path [45]. Blocking screws can be placed in the concavity of the fracture in comminuted fractures that span longer distances in the subtrochanteric region [45]. A small open incision can be made for any fracture pattern to allow room for clamps to provide efficient fixation while reaming and placement of the intramedullary nail [46–48]. Despite using an open technique for fracture reduction, union rates have remained high with intramedullary locked nails [46, 47].

The most common pitfalls in operative management of subtrochanteric femur fractures include varus malreduction, rotational malreduction, leg length discrepancy, and missed ipsilateral injury. Obtaining anatomical reduction is required prior to placement of any IMN. The standard construct is an anterograde, long, reamed, statically locked cephalomedullary nail [10, 19, 49]. While there lacks high-level

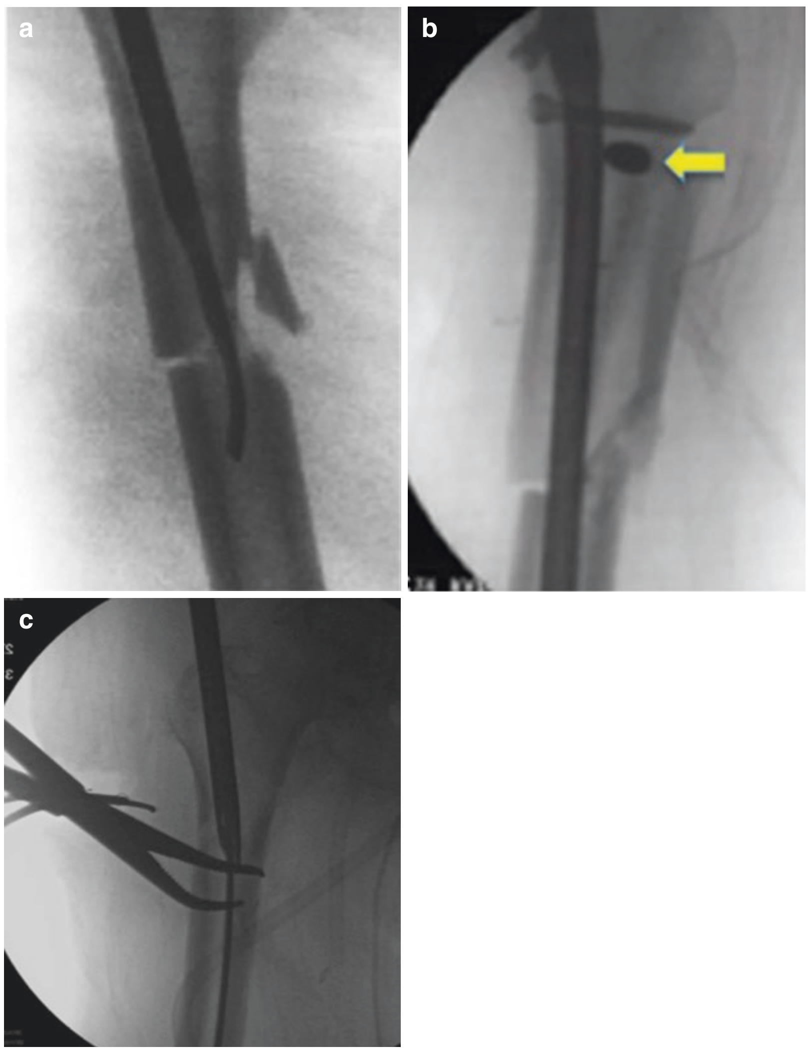


**Fig. 9.3** Reduction aids include the use of the (**a**) "finger," which is a stiff reduction aid that can help temporarily align the fracture to help pass the guide wire; (**b**) blocking screws (or a blocking drill bit or Schanz pin) can aid in maintaining nail position as well as reduction; (**c**) a small, open incision (often the same used for the cephalomedullary screws) can be utilized to place a clamp which can reduce the fracture and facilitate facile IMN placement

evidence, this construct is widely accepted as the standard due to its inherent biomechanical strength aided by a locked, long working length which allows for reliable, immediate weight bearing. Biomechanically, dual cephalomedullary screws (crossing or parallel) are stronger than a single screw, and two distal locking screws are stronger than one; there is no clinical evidence to support one or the other [10, 19, 49]. When postoperative radiographs demonstrated malreduction greater than or equal to 10° in any plane, there was a statistically significant higher rate of delayed or nonunion [50]. In comminuted fractures, preoperative imaging of the contralateral leg can help avoid leg length mismatch and rotational malreduction. The femoral neck should be heavily scrutinized with fluoroscopy at the beginning and end of the case to prevent missed ipsilateral injuries. A proper knee exam before leaving the operating room is necessary to avoid missing ipsilateral knee injuries.

Overall the use of intramedullary locking nails for these fractures have a high rate of union and low rate of reoperation. The outcomes can be further divided in the high-energy mechanism group primarily involving younger individuals. An early series by Wiss showed 99% fracture union with the use of a piriformis start IM nail [13]. A more recent study by Starr et al. showed 100% union rate without the need for bone graft or a secondary procedure when using a cephalomedullary nail for young patients in high-energy mechanism accidents [14]. The second group of outcomes can be categorized by low-energy mechanisms most commonly seen in the elderly. The current approach is using a trochanteric entry point with a cephalomedullary hip nail. The elderly have an increased level of social dependence and far more comorbidities that predispose them to higher rates of reoperation, and an increase in mortality is seen at the 1-year mark postoperatively [51].

## Fixed Angle Blade Plates

Fixed angle blade plates (Fig. 9.4a, b) have historically been successful in treating severely comminuted subtrochanteric fractures [52–54]. Kinast showed that using indirect reduction techniques significantly reduced nonunion rates to 0% when compared to direct reduction group [55].

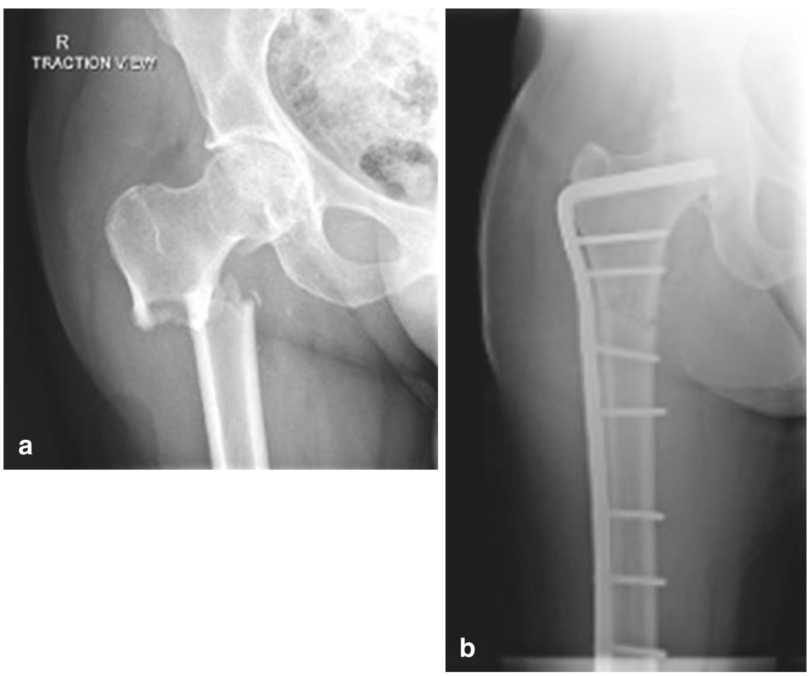


**Fig. 9.4** Traditionally, blade plates have been excellent options for treating subtrochanteric femur fractures in the acute period. (**a**) An AP hip radiograph exhibiting a subtrochanteric femur fracture, restoring length alignment and rotation with a (**b**) blade plate. With the advent of IMN, however, acute treatment with blade plates has fallen out of favor, avoiding the necessary excessive exposure (Images courtesy of Kenneth A. Egol, MD)

Unfortunately, these results have not been reproducible as Brien et al. showed a nonunion rate of 32% when comparing the blade plate to interlocked IM nails [15]. Plate and screw techniques rely on obtaining compression and thus primary bone healing at the fracture site. The indirect reduction technique is predicated on accurate proximal fixation to ensure a proper neck shaft angle and adequate compression at the fracture site. Compared to IMN, blade plates are more technically difficult to use, and trainees are not exposed to the technique during training and thus have fallen out of favor for use as an initial treatment.

In most cases, the 95° blade plate fixation is reserved for fracture malunion or nonunion. Varus malalignment in subtrochanteric fractures can cause leg length discrepancies and decreases abductor working length. The corrective procedure is an osteotomy at the apex of the deformity with the use of a blade plate. Multiple studies have demonstrated that successful union can be obtained as long as there is stable proximal fragment fixation [52, 53].

## Proximal Femoral Locking Compression Plates

The newest plate technology that is available for subtrochanteric femur fractures is the proximal femoral locking compression plate (PFL). This is another type of fixed angle plate. Biomechanical studies have shown that the PFL plate has more axial stiffness, less torsional stiffness, and equivalent irreversible deformation to cyclic axial loading when compared with the blade plate [56].

Comparison of PFL plate to intramedullary nail fixation showed no difference in the number of complications, onset of complications incidence, and time of full-weight bearing. Although the Harris Hip Score among patients improved in both methods of treatment, there was no difference between the two groups [57]. However, subsequent studies have not been able to reproduce similar results when comparing the PFL plate and locked intramedullary nails.

El-Desouky et al. showed PFL plate provided a strong construct for fixation of comminuted subtrochanteric fractures either by open or biological techniques. Unfortunately, low patient compliance was an influential factor for implant failure in both types [58]. While locked proximal femoral plates were created to address the technical difficulty associated with other fixed angle blade plates and provide a more rigid construct, the results following their use have demonstrated high rates of failure (Fig. 9.5) [59]. Fractures with posteromedial comminution [60] and atypical femoral fractures

**Fig. 9.5** While early results and biomechanical studies were promising in regard to PFL plates, recent reports of hardware failure have increased concern for stricter indications and use (Images courtesy of Nirmal C. Tejwani, MD)

[61] treated with these implants have also had poor outcomes and high failure rates.

Only one study has demonstrated favorable outcomes with established nonunions of subtrochanteric femur fractures using the PFL plate [62]. However, due to the more recent evidence regarding high failure rates, surgeons' use of the PFL plate is waning; higher-level studies or, perhaps, more specific criterion and/or technique must be set forth prior to more widespread use. More reliably, subtrochanteric nonunions without malalignment have shown high rates of fracture union and functional improvement with exchange nailing (with reduction) with or without bone grafting [53].

## Special Consideration: Atypical Femoral Fractures

The operative management of patients with atypical femoral fractures introduces a few more issues that cannot be overlooked. Review of the radiographs for a lateral cortical thickening, transverse fracture orientation, lack of comminution, and medial cortical spike is essential [7]. These atypical fracture patterns have a higher rate of intraoperative femoral shaft comminution during nail insertion and a higher rate of iatrogenic fracture during nail placement [61]. There is also a higher rate of delayed union leading to higher rates of revision surgery [63]. Care must be taken to evaluate the patient for contralateral thigh as there is a high association with bilateral insufficiency fractures [64]. Comparing nonoperative versus operative management with prophylactic fixation of femoral stress fractures showed a decreased average hospital stay for those undergoing fixation [7]. Many of the femoral fractures in the nonoperative group eventually went on to completion and required operative fixation leading to a longer hospital stay [36].

## Complications

Complications include nonunion, malunion, and infection. In regard to nonunion and malunion, typical causes are related to failure to obtain an anatomic reduction. These can occur for a myriad of reasons, which include utilizing an incorrect starting point and accepting too much flexion and/or varus, which occurs from a lack of reduction aid utilization [65]. Postoperative malunion can be problematic as any degree of external rotation causes a posterior shift of the weight-bearing axis in the sagittal plane and may lead to a change in gait mechanics [66]. One cannot emphasize the importance of obtaining an acceptable reduction prior to implant placement; placing the IMN in a malreduced fracture is the most common cause of malunion and nonunion. The IMN will not reduce the fracture and increases risk for nonunion and subsequent implant failure with loss of fixation. Nonunions and malunions can typically be treated via exchange nail (with re-reduction) or via corrective osteotomy and blade plate placement (Fig. 9.6a–d).

As with any surgery, infection is also a potential complication. Increased risk for infection can arise from host factors (i.e., diabetic, smoker, immunocompromised, etc.) and can occur in the acute postoperative period. Superficial infection and deep infection can occur, with increased risk associated with excessive soft tissue stripping, which can typically occur with large open exposures while attempting to obtain anatomic reduction. Treatment of deep infection depends on the amount of fracture healing. Although rare, a completely healed fracture with evidence of deep infection likely requires IMN removal. In the setting of a nonhealed fracture, initial irrigation and debridement with an intravenous antibiotic course can be tried until the fracture heals. In the event of a deep infection and persistent nonunion, complete infection eradication is required for healing. Temporizing fixation can be obtained by utilizing an antibiotic-coated IMN. Laboratory markers are used after the completion of the antibiotic therapy to check for normalization of inflammatory levels. Once the infection has been eradicated, definitive fixation is then performed. Debridement of the bone can be supplemented with bone grafting to further enhance healing potential [67, 68].

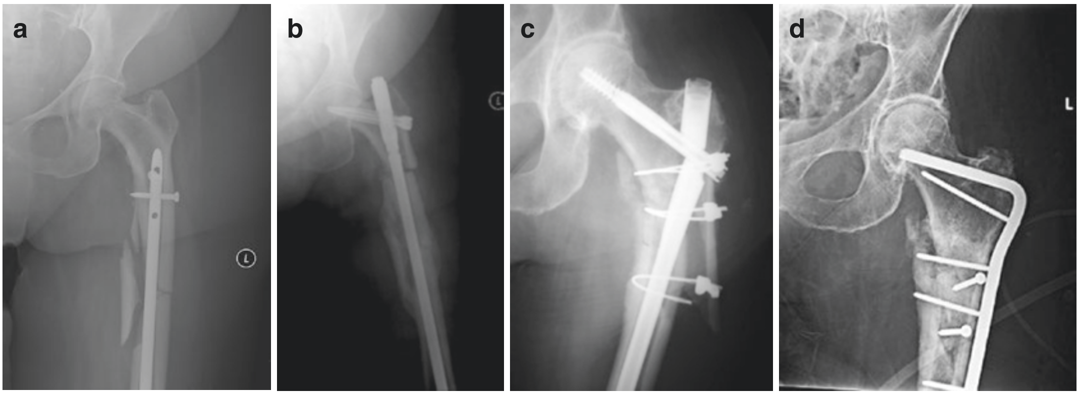


**Fig. 9.6** Subtrochanteric femur fracture nonunions (**a**, **b**) can be treated via exchange nail or via blade plate. (**a**) Here, a subtrochanteric femur fracture treated with a retrograde IMN went onto nonunion. (**b**) Exchange with an antegrade cephalomedullary nail and distal fixation provided the necessary environment for healing. Similarly, a failed cephalomedullary nail (**c**) construct left in varus was successfully treated via ORIF and (**d**) blade plate fixation (Images courtesy of Kenneth A. Egol, MD)

## Summary

Subtrochanteric fractures are generally treated with operative management. Occurring in a bimodal distribution, both high-energy mechanisms in the young and low-energy, possible bisphosphonate-related etiologies in the elderly must be evaluated and treated. Powerful deforming forces in the proximal femur that historically caused high rates of malreduction, shortening and nonunion, can be overcome via several reduction tools and techniques, including clamps, cerclage cables, blocking screws, and fragment controlling pins. Today, the standard treatment for subtrochanteric femur fractures is anterograde, reamed, statically locked, long, cephalomedullary nails. Biomechanically, two cephalomedullary screws along with two distal locking screws are the strongest. Blade plates and exchange nails are reliable treatments for nonunions/malunions, while recent reports exhibiting high failure rates have limited the use of PFL plate. Future research, involving higher-level evidence, is required to truly determine even more specific, ideal constructs and treatment algorithms for these difficult to treat fractures.

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# Nonunions of the Proximal Femur

# 10

Kenneth A. Egol and Jordan Gales

## Introduction

Although elderly patients may do well functionally with nonunions of long bones in the upper extremity (clavicle, Humerus and ulna), nonunited fractures of the proximal femur are not well tolerated in active individuals [1, 2]. Femoral nonunions, however, are more frequently painful and may preclude weightbearing on the affected extremity. If, however, pain is minimal or nonexistent and occurring within a nonambulatory individual, nonoperative management is the treatment of choice.

## Anatomic Considerations

The hip is a ball-and-socket joint formed by the femoral head and the acetabulum. The *femoral head*, an imperfect sphere of cancellous bone sheathed in articular cartilage, is characterized by a relatively dense meshwork of trabecular bone that facilitates the absorption and distribution of weightbearing stresses to the dense cortical bone of the femoral neck and proximal femur. The size of the femoral head varies, more or less, in proportion to body mass, ranging from roughly 40 to 60 mm in diameter [3]. The thickness of the articular cartilage covering the femoral head averages 4 mm superiorly and tapers to 3 mm at the periphery [4].

The *femoral neck* comprises the region between the base of the femoral head and the intertrochanteric line anteriorly and the intertrochanteric crest posteriorly. The femoral neck forms an angle with the femoral shaft ranging from 125 to 140° in the coronal plane and 10–15° (anteversion) in the transverse plane [5]. The cancellous bone of the femoral neck is characterized by trabeculae organized into medial and lateral systems [6]. The medial trabecular system forms in response to the joint reaction force on the femoral head; the epiphyseal plates are perpendicular to the medial trabecular system. The lateral trabecular system resists the compressive force on the femoral head resulting from contraction of the abductor muscles.

The *intertrochanteric region* of the hip, consisting of the greater and lesser trochanters, represents a zone of transition from the femoral neck to the femoral shaft. This area is characterized primarily by dense trabecular bone that serves to transmit and distribute stress, similar to the cancellous bone of the femoral neck. The greater and lesser trochanters are the sites of insertion of the major muscles of the gluteal region: the gluteus

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medius and minimus, the iliopsoas, and the short external rotators. The calcar femorale, a vertical wall of dense bone extending from the posteromedial aspect of the femoral shaft to the posterior portion of the femoral neck, forms an internal trabecular strut within the inferior portion of the femoral neck and intertrochanteric region and acts as a strong conduit for stress transfer [7, 8].

The *subtrochanteric region*, which extends from the lesser trochanter to an area 5 cm distal, consists primarily of thick, dense cortical bone. This is an area of high stress concentration, with large compressive forces medially and tensile forces laterally. The dense cortical bone permits efficient transmission of both axial and torsional loads.

The *hip capsule* is attached to the labrum and transverse acetabular ligament of the acetabulum, the medial side of the greater trochanter, the intertrochanteric line anteriorly, a site immediately superior and medial to the lesser trochanter, and the femoral neck posteriorly [9]. The entire anterior aspect of the femoral neck and the proximal half of its posterior portion lie within the capsule of the hip joint. Fractures within this area are thus termed *intracapsular*.

The musculature of the hip region can be grouped according to function and location [9]. The abductors of the gluteal region, the *gluteus medius* and *gluteus minimus* that originate from the outer table of the ilium and insert onto the greater trochanter, function to control pelvic tilt in the frontal plane. The *gluteus medius* and *gluteus minimus*, along with the *tensor fascia lata*, are also external rotators of the hip. The hip flexors are located within the anterior aspect of the thigh and include the sartorius, iliopsoas, and rectus femoris. The pectineus is a hip flexor located within the medial thigh but shares its function and innervation with the anterior compartment hip flexor group. The *iliopsoas*, *comprised of the iliacus and psoas major*, inserts upon the lesser trochanter. The *gracilis* and the *adductor* muscles (longus, brevis, and magnus) are located in the medial aspect of the thigh. The short external rotators, the *piriformis*, *obturator internus*, *obturator externus*, *superior* and *inferior gemelli,* and *quadratus femoris*, all insert onto the posterior aspect of the greater trochanter. The *gluteus maximus*, originating from the ilium, sacrum, and coccyx, inserts onto the gluteal tuberosity along the linea aspera in the subtrochanteric region of the femur and the iliotibial tract. The gluteus maximus serves as an extensor and external rotator of the hip. The *semitendinosus*, *semimembranosus*, and *biceps femoris*, which originate from the ischium to form the hamstring muscles of the thigh, are responsible for knee flexion as well as hip extension.

The two largest tributaries of the profunda femoral artery are the *medial* and *lateral femoral circumflex arteries*. The latter originates from the anterolateral aspect of the profunda femoral artery. It then proceeds laterally across the iliopsoas muscle, passes horizontally between the divisions of the femoral nerve, and then runs deep to the sartorius and rectus femoris, where it divides into ascending, descending, and transverse branches. The *medial femoral circumflex artery*, which originates from the medial or posteromedial side of the profunda femoral artery, runs posteriorly between the iliopsoas and pectineus muscles. A key structure responsible for ensuring blood flow to the distal extremity when a blockage occurs between the proximal femoral and external arteries is the cruciate anastomosis. It is located within the upper thigh at the inferior margin of the quadratus femoris muscle. This circulatory anastomosis is comprised of a descending branch of the inferior gluteal artery, the first perforating branch of the profunda femoral artery, the medial and lateral circumflex arteries, and often a posterior branch of the obturator artery. The *superficial femoral artery* continues in the thigh within the adductor canal, separated from the profunda femoral vessel by the adductor longus muscle. The femoral artery then passes from medial to posterior in the thigh through a tendinous hiatus in the adductor magnus (*Hunter's canal*), becoming the *popliteal artery*.

The blood supply to the femoral head and neck is complex and has important orthopedic implications [10–12]. The medial and lateral circumflex arteries send branches that anastomose to form an extracapsular arterial ring at the base of the femoral neck. Coming off this arterial ring are the ascending cervical arteries, also known as the *capsular* or *retinacular arteries*, which pierce the joint capsule and traverse the neck of the femur deep to the synovial membrane. There are four major retinacular arteries—*anterior*, *medial*, *posterior*, and *lateral*—named for their position relative to the femoral neck. The lateral retinacular artery is the most important blood supply to the femoral head and neck. The retinacular vessels anastomose at the base of the femoral head to form the subsynovial intra-articular ring. Small epiphyseal arterial branches then pierce and supply blood to the femoral head. The artery of the ligamentum teres is either a branch of the posterior division of the obturator artery or a branch from the medial circumflex artery.

This artery, which supplies blood to small, variable area of bone adjacent to the fovea of the femoral head, appears to be of limited clinical importance following physeal closure.

## Definitions

Fractures heal at different rates depending on various factors (i.e., comminution, anatomical site, blood supply, etc.). Most fractures, however, will unite by 4–6 months or at a minimum show progressive healing on serial radiographs. If a fracture fails to heal in that time frame or in the average or usual time for similar fractures, it is defined as a delayed union. A nonunion is an arrest of the fracture repair process; there is no further potential for fracture union (REF).

## Etiology

In general, fracture nonunion results from a combination of host, injury-specific, initial treatment, and complicating factors. The most commonly observed contributors include excessive fracture motion, continued fracture gap, avascularity, and ongoing infection. Fracture gap can result from soft tissue interposition, fracture distraction, fracture malposition, or bone loss. Avascularity results from damaged nutrient vessels, excessive soft tissue stripping, or severe fracture comminution. General patient factors which predispose to nonunion include nicotine, older age, poor nutritional status, corticosteroid use, anticoagulation medication, radiation therapy, and burns.

## General Principles

Nonunion of the proximal femur must be divided into three separate regions with specific anatomical consideration: the femoral neck, the intertrochanteric region, and the subtrochanteric region. Although femoral neck and intertrochanteric fractures occur with a similar incidence, fractures of the femoral neck are more likely to progress to nonunion due to their intracapsular nature. The lower incidence of subtrochanteric femur fractures and their extracapsular location make them less commonly observed.

In most cases treatment of proximal femoral nonunion requires operative intervention if a patient is to regain functional use of their lower extremity. Surgical options vary based upon factors including preinjury functional status, age, and the condition of the articular cartilage.

When treating the patient with proximal femoral nonunion, correction of any regional deformity must be addressed in addition to obtaining union. The goal of joint mobilization should be met to return function to the extremity. When present, resolution of infection may require staged surgical intervention. When the history of infection is remote, union may be achieved. Suppressive antibiotics are required in the occurrence of infectious recrudescence following fracture union.

Furthermore, there is potential for autogenous or allogenic graft requirement if significant bone loss is present or previous infection has resulted in significant bone resorption. Active, draining infection suggests the presence of necrotic material at the nonunion site. These cases will require extensive debridement with concomitant bacterial culture for appropriate antibiotic selection [13–15].

## Diagnosis

The diagnosis of proximal femoral nonunion can be difficult to make, especially within the femoral neck. The diagnosis should always be considered in the patient who has undergone fixation and complains of hip or groin pain 4–6 months after surgery [16]. In many cases, failure of fixation will herald the presence of fracture nonunion [17].

If an ununited fracture is suspected clinically, a standard radiographic series of the hip including anteroposterior and lateral views may elucidate a persistent fracture line or a subtle change in the neck-shaft angle. An internal rotation view of the hip that brings the femoral neck into profile can assist the treating physician if there is any question. Computed tomography has virtually replaced plain tomography for the diagnosis of fracture nonunion. CT reconstruction views are good for detailing fracture margin sclerosis, and multiplanar reformatted images can evaluate fracture fixation for breakage or loosening by reducing metallic artifact [18] (Fig. 10.1).

In the case of femoral neck nonunions, it is important to clearly establish the presence of osteonecrosis within the femoral head prior to surgery, as greater than 50% involvement of the head may herald eventual collapse and therefore preclude repair of the nonunion [19]. Diagnosis of AVN may be difficult with implants in place. If titanium implants are within the femoral neck and head, an MRI can be utilized to evaluate the hip for AVN. Otherwise a Tc99 bone scan or intraoperative laser Doppler flowmetry can be obtained [20, 21].

The presence of infection should be ruled out in any patient with a nonunion and history of previous surgery. Laboratory values including an erythrocyte sedimentation rate and C-reactive protein should be obtained preoperatively. Gallium scanning has been shown to be of limited value in these cases [22].

Lifestyle factors such as tobacco use have a risk of nonunion associated with it [23]. Patients should be counseled as to this risk, and all attempts to cease smoking should be made in the pretreatment phase.

## Preoperative Planning

Preoperative planning should include the use of templates of the hardware to be used, superimposed on preoperative radiographs (Fig. 10.2). The normal side may be used as a template for the prospective end result of the surgery. Special implants or prostheses that may be used should be ordered well in advance of the planned surgery. Special tests such as a bone scan, arteriogram, or

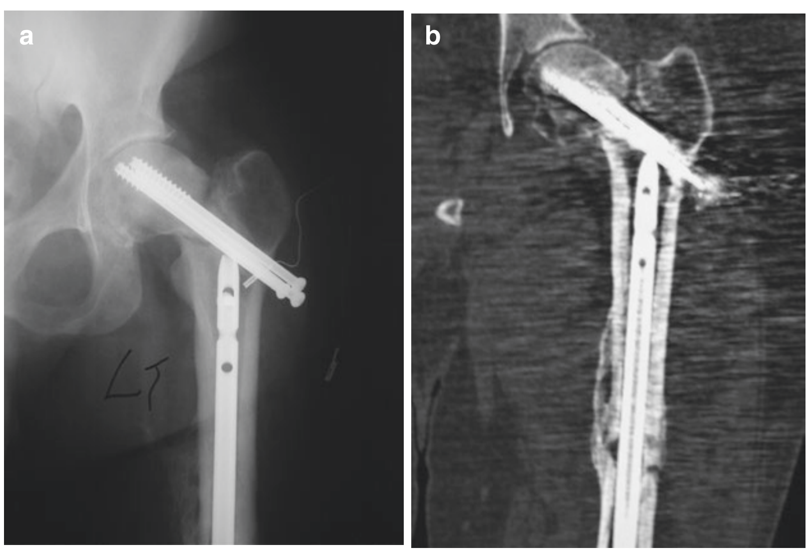


**Fig. 10.1** A 38-year-old male who sustained an ipsilateral femoral neck and shaft fracture. (**a**) Anteroposterior (AP) radiograph at 4 months suggests nonunion. (**b**) A reconstructed CT image demonstrating a clear femoral neck nonunion

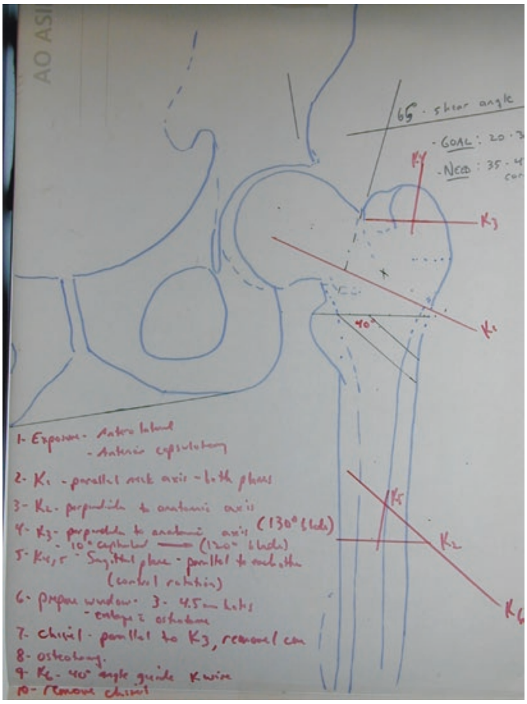


**Fig. 10.2** The preoperative template for the patient in Fig. 10.1. All aspects of the surgical tact are accounted for

Doppler ultrasound for vascularity should be performed as part of the preoperative plan.

Consultations with anesthesia, vascular surgery, plastic surgery, internal medicine, cardiology, neurology, urology, psychiatry, and any other services necessary for diagnosis or treatment should be obtained well in advance of surgery.

Overall, preoperative planning should be thorough, thoughtful, and complete. It should include social services with consideration of financial and family concerns, in addition to the medical and surgical consultations listed previously. Only with proper preoperative planning can a successful result be obtained in a high percentage of elderly patients who have a nonunion.

## Incidence

The reported incidence of nonunion following fracture of the femoral neck varies from less than 5% to greater than one third of observed cases within the literature [24]. Its clinical significance is highlighted by the high rates of reoperation for cases of nonunion. In two randomized controlled trials, the rates of nonunion were 34.5% and 36%, with avascular necrosis occurring in 4.9% and 6%, respectively [25, 26]. In these trials, the reoperation rate after internal fixation was 40% and 42%, respectively, with 75% of those progressing to nonunion requiring surgery [25, 26].

In comparison, avascular necrosis of the femoral head following femoral neck fracture requires reoperation in one third of patients [24]. Certain factors have been repeatedly shown to be associated with nonunion of a femoral neck fracture. To date, these factors have yet to reliably demonstrate robust predictive capacity. The association between osteonecrosis of the femoral head and femoral neck fracture nonunion is important to discuss.

Development of osteonecrosis does not preclude the ability to heal a femoral neck nonunion. Prior studies have shown union in the face of established osteonecrosis of the femoral head as well as osteonecrosis that develops following surgical treatment of the nonunion [27, 28].

Certainly, the amount of initial fracture displacement has some bearing on the development of nonunion. There is a clear relationship with fracture nonunion and displaced femoral neck fractures compared to non-displaced fractures [29]. Fracture comminution, particularly of the posterior cortex, has been linked to decrease fixation stability and increased incidence of nonunion [30]. Timing of surgery and adequacy of the reduction may be more important for the development of osteonecrosis but may also contribute to the development of nonunion [27]. Furthermore, the type of implant utilized may have some bearing on the incidence of nonunion [31, 32].

The orthopedic literature is replete with studies that look at treatment of femoral neck fractures. In a systematic review of the literature and a meta-analysis of 106 studies, the incidence of femoral neck nonunion in displaced femoral neck fractures was reported to be as high as 33% [33]. Factors felt to be associated with development of fracture nonunion included inadequate reduction, poor internal fixation, premature weightbearing, and infection [34]. Individual studies of femoral neck fractures observed varied results. Banks reported on the 20-year experience in Boston. He reported on 301 femoral neck fractures, of which 296 were displaced. There were 34 nonunions in this series [35]. In their study of over 1500 femoral neck fractures, Barnes et al. found no correlation with length of time to reduction and the development of nonunion, but the adequacy of reduction was an important factor with regard to development of nonunion [36]. In a prospective, randomized study comparing sliding hip screw and divergent cannulated pins for the treatment of displaced femoral neck fractures, the authors reported an overall incidence of nonunion of 28%, with the sliding hip screw group significantly higher. Interestingly, no correlation between adequacy of reduction and development of nonunion could be made [31].

Yang, Lin, and Chao et al. reported a series of 202 femoral neck fractures treated with three cannulated screws. Their nonunion rate was 21.7% with significant differences in nonunion rate among fracture type, reduction quality, and screw tip subchondral purchase [24]. Their study also reported a significant difference in rate of fracture nonunion based upon cannulated screw configuration. In a similar series reported by Cobb and Gibson, comprised of 65 femoral neck fractures with adequate reduction and technically sound fracture repair, the nonunion incidence was only 4.7% [37]. Garden reported the incidence of nonunion to be 16.6% in his series of 500 patients with subcapital femoral neck fractures [38]. Another report on 76 patients out of an initial 179 showed an incidence of nonunion with and without osteonecrosis of 21% [39].

In a prospective, randomized study looking at internal fixation of femoral neck fractures, 128 patients were treated with a sliding compression screw and 127 with a nail plate. Eleven percent of Garden 3 and 4 fractures went on to nonunion with the compression screw and 25% with the nail plate device [40]. These authors confirmed results of previous studies in which the presence of a varus malunion was associated with development of nonunion. Stromqvist et al. had 22 healing complications in 68 displaced femoral neck fractures. The rate was higher in the flanged nail group [41]. In a second report, Stromqvist et al. reported on 300 femoral neck fractures treated with “Hook Pins.” Of these 215 fractures were displaced, Garden 3 or 4. The incidence of nonunion was 25% overall and 35% in surviving patients [41]. Finally, Skinner and Pauwels reported that in a series of 107 displaced femoral neck fractures, 15 developed a nonunion by 1 year in fractures treated with a sliding hip screw [42].

The incidence of nonunion following surgical repair of an intertrochanteric hip fracture is rare, given the excellent blood supply and cancellous bone stock within the segment. Literature regarding intertrochanteric fracture nonunion and its treatment is limited. Limited case series regarding revision internal fixation and bone grafting following fixation failure have shown encouraging results [35, 43]. Most intertrochanteric fractures treated by conservative methods or internal fixation heal. In a large prospective study performed on over 500 intertrochanteric hip fractures, Kyle et al. reported a 2% incidence of nonunion. All of these occurred in the unstable type 4 fracture patterns treated with a variety of implants [44]. However, nonunion rates may approach 10% when excessive stripping of comminuted fractures disturbs bone nutrition [45]. Mariani and Rand reported on the treatment of ununited intertrochanteric hip fractures. Upon reviewing the initial postoperative radiographs, the authors noted an association with failed ORIF and poor reduction as well as medial displacement osteotomy [46]. Bogoch et al. reported a 6.5% incidence of nonunion following intertrochanteric hip fracture in patients with rheumatoid arthritis [47]. The authors felt the condition of rheumatoid bone was a contributing factor in healing complications.

Subtrochanteric nonunion is more common than intertrochanteric nonunion, most likely owing to its high-stress region in the femur. The incidence of nonunion reported in the literature range from 0.5 to 5% [48–50]. Nonunion of subtrochanteric fractures may be related to poor fracture reduction, unfavorable fracture pattern, poor bone quality, loss of medial column support, and early weightbearing [51–53].

Seinsheimer reported the results of 56 patients treated for subtrochanteric fracture treated with a variety of methods and implants. There were eight failures of fixation and three persistent nonunions reported [49]. The authors associated failures and nonunions with fractures that had extensive comminution in the posteromedial cortex; thus, the lateral plate is subjected to excessive medial bending forces as well as a fracture length greater than 8 cm.

Zickel reported on 84 subtrochanteric femur fractures treated by one surgeon with a cephalomedullary device. He had only one nonunion in his series [54]. Wiss et al. reported on 95 subtrochanteric femur fractures. There was only one nonunion in his series (1%) of fractures all treated with an interlocking intramedullary nail [50]. The authors performed their surgery without exposing the fracture site, and thus there was no stripping of medial soft tissues.

In their series of 50 patients with subtrochanteric femur fractures, Velasco and Comfort reported a complication rate of 21%. However, only one patient (2%) developed nonunion of their fracture [55].

## Treatment Options

### Femoral Neck Nonunions

In most cases, a femoral neck nonunion requires operative treatment if a patient is to regain functional use of their lower extremity. However, if the patient experiences minimal discomfort and has a sedentary lifestyle, one should treat the patient nonoperatively with mobilization out of bed and ambulation using assistive devices as needed. Surgical options vary based on several factors, including preinjury functional status, patient age, condition of the articular cartilage, and the presence or absence of osteonecrosis.

### Pauwels Osteotomy

The concept behind the intertrochanteric osteotomy in the treatment of femoral neck nonunion is the conversion of principally shear forces acting on the fractured femoral neck to compressive forces. At no time is the nonunion site exposed. Healing of the nonunion is purely due to alteration in the biomechanical forces at the femoral neck. The technique relies on careful preoperative planning and meticulous attention to surgical detail. Good-quality biplanar radiographs are essential. Classically, the amount of the wedge resection is based on the angle the fracture line makes with the femoral shaft. The operation is performed at the intertrochanteric level. A 30–60° wedge is removed from the lateral cortex, and the osteotomy site fixed with a 95–120° blade plate for fixation depending on the size of the wedge is removed. The blade should enter the proximal fragment 2 cm proximal to the osteotomy site, and its tip should lie in the inferior quadrant of the femoral head [56] (Fig. 10.3). Patients should be kept partial weightbearing for 6–12 weeks until fracture and osteotomy site union has occurred.

Raaymakers and Marti reported on their experience with 66 patients treated with intertrochanteric abduction osteotomy of Pauwels performed in the setting of femoral neck nonunion [32]. Union of the femoral neck was achieved in 58 (88%) of the cohort and union of the osteotomy achieved in 65 (99%). Overall, a good or excellent result was achieved in 62% of patients. Of 30 cases requiring further intervention, 21 underwent subsequent total hip replacement for osteonecrosis. Healing occurred in the setting of femoral head osteonecrosis without the need for further treatment in 13 cases. Eight persistent nonunions following osteotomy required additional intervention, with only one final treatment failure.

Marti et al. reported on 50 patients treated with intertrochanteric abduction osteotomy of Pauwels [28]. The authors treated all patients less than age 70 with this operation regardless of the presence of femoral head necrosis. Eighty-six percent of their patients healed their femoral neck

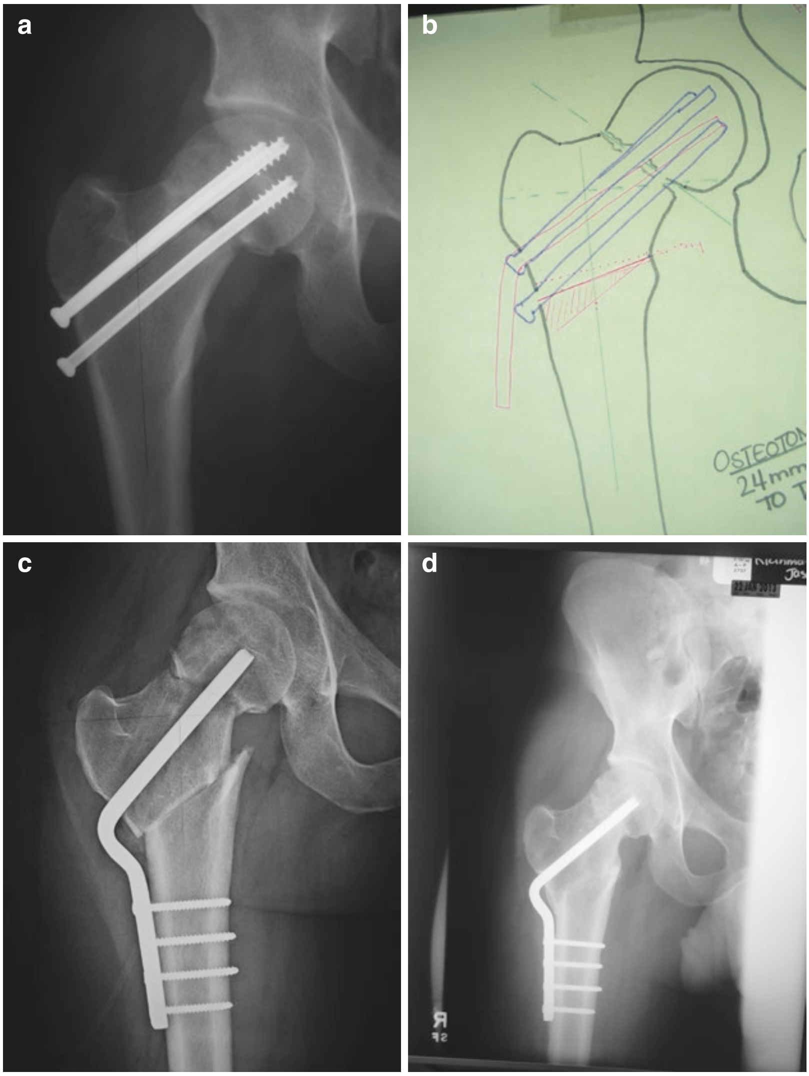


**Fig. 10.3** A 21-year-old male is 6 months following ORIF of a displaced femoral neck fracture. He has developed a nonunion. (**a**) AP radiograph at 6 months. (**b**) Preoperative plan. (**c**) Immediate postoperative following osteotomy. D0 AP radiograph at 1 year following surgery, the osteotomy site and femoral neck have healed with no signs of AVN of the femoral head

fractures. Seven patients went on to hip arthroplasty, but only three of these were for persistent nonunion.

## Open Reduction and Internal Fixation

The concern with open/closed reduction of the femoral neck following femoral neck nonunion is the creation of osteonecrosis, secondary to disruption of the blood supply during the surgical exposure and nonunion reduction. These procedures have been reported in small series mostly for neglected femoral neck fractures that have gone on to nonunion but also following failed internal fixation. Although neglected femoral neck fractures are rarely observed in Western society, the phenomenon persists in nations with limited medical resources. The technique involves an anterior approach to the hip (Watson-Jones) with removal of fibrous tissue from the nonunion site and placement cancellous bone graft. This is followed by screw fixation of the femoral neck under fluoroscopic control.

Elgafy, Nabil, and Gregory reported their experience with 17 cases of aseptic symptomatic femoral neck nonunions following open reduction and internal fixation [57]. These patients underwent revision internal fixation with nonvascularized fibular bone graft. Fibular autograft had a 69.2% success rate with a mean time to union of 4.8 months. Those receiving allograft had a 33.3% success rate with mean time to union of 13.3 months.

A meta-analysis by Jain, Mukunth, and Srivastava identified seven studies with a total of 406 patients undergoing internal fixation and nonvascularized fibular grafting for neglected femoral neck fracture [58]. The average time to union was 22.5 weeks ($n$ = 170). There were 33 persistent nonunions and 11 incidences of avascular necrosis reported among 374 patients for an 11.3% complication rate.

Nagi et al. reported on 40 cases of neglected femoral neck fractures treated by open reduction and internal fixation and free fibular grafting to act as a biological implant [59]. They had 38/40 patients healed. Seven of the eight patients who had preoperative evidence of AVN revascularized without collapse. Seven patients had radiologic evidence of AVN following surgery, four of which went on to complete collapse.

## Vascularized Pedicle Grafts

The theory behind vascularized pedicle grafting is that the graft will bring blood supply to the region and promote nonunion healing. Sheng-Mou et al. described this approach with the utilization of a vascularized iliac crest bone graft based on the deep circumflex iliac vessels rotated into the nonunion site. All of their five cases healed and were without aseptic necrosis of the femoral head at 2 years. This technique achieves good final functional results, but requires greater operative expertise.

Leung et al. also reported on the use of a vascularized pedicle graft in 15 patients, 6 with established nonunion of the femoral neck and 9 acute fractures with delays in treatment [60]. Their patients mean age was 38 years. Technique involved laying the vascularized iliac crest pedicle graft in a trough perpendicular to the fracture site. The tightening of the screws locks the graft into place. All nonunion sites eventually united.

Another approach involves a pedicled graft of part of the greater trochanter and quadratus muscle. This technique is utilized via a posterolateral approach to the hip and involves meticulous dissection of the quadratus femoris from the hip capsule and transection from the greater trochanter with attached bone. The capsule is incised and the graft is fashioned to fit in a trough along the posterior femoral neck. Meyers et al. reported on 32 patients who were treated with internal fixation and quadratus muscle pedicle grafting for neglected hip fracture (more than 30 but less than 90 days following their injuries) and failed ORIF [61]. Eighteen patients had supplemental autogenous cancellous grafting to the posterior femoral neck. Seventy-two percent of cases achieved union. This procedure has received good results when a true synovial pseudarthrosis exists [13]. Nair, Patro, and Babu reported similar outcomes with their experience of 17 similar patients [62]. They encountered two cases of persistent nonunion and no cases of osteonecrosis. Their series supported the utility of quadratus femoris muscle pedicle bone grafting as adjunctive therapy, demonstrating good functional results comparable to other methods.

Bhuyan retrospectively reported on 48 patients treated for neglected femoral neck fracture by internal fixation and tensor fasciae latae-based muscle pedicle bone grafting [63]. Union was achieved in 41 (85.4%) patients who were followed postoperatively for an average period of 4.4 years. Three nonunions persisted and two patients experienced avascular necrosis.

## Arthroplasty

Most authors agree that in young active patients, all attempts should be made to save the hip joint. In elderly, more debilitated individuals, the option of arthroplasty is a viable one. The decision to perform hemiarthroplasty vs. total hip arthroplasty is based on several factors, including the presence of preexisting acetabular arthrosis and patient life expectancy (Fig. 10.4).

In one study of 84 total hip replacements performed for failed osteosynthesis of a femoral neck fracture, the authors reported early failure

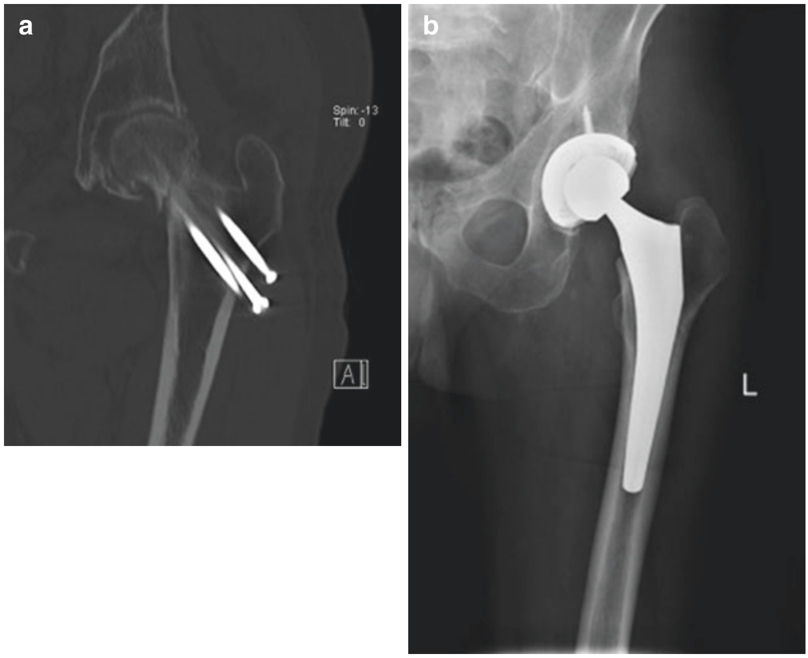


**Fig. 10.4** A 68-year-old active male presents 6 months following in situ pinning of a valgus impacted femoral neck fracture. (**a**) A CT scan demonstrates nonunion. (**b**) Following non-cemented total hip arthroplasty

of 9 hips. At latest follow-up 35 hips were available for follow-up. The age and sex adjusted complication rate for total hip arthroplasty for failed femoral neck fracture was 2.5 times higher compared to arthroplasty for osteoarthritis [64]. Mabry, Prpa, and Berry et al. investigated long-term outcomes for total hip arthroplasty for femoral neck fracture nonunion [65]. Ten-year rate of component survival free of revision or removal for any reason was 93%. Ninety-six patients were pain-free or reported only mild pain at final follow-up.

If an arthroplasty is to follow a failed internal fixation, planning must include removal of all implants. In addition, the use of a stem at least two cortical diameters past the most distal screw hole should be considered.

## Hip Arthrodesis

The advent of arthroplasty techniques over the past 25 years has made this operation virtually obsolete. It should be reserved for very limited indications such as failed revision osteosynthesis who are not candidates for arthroplasty, such as in the case of severe infection.

## Intertrochanteric Nonunions

Patients with an intertrochanteric nonunion are more likely to be symptomatic than those who have developed a nonunion after femoral neck fracture. Therefore, most intertrochanteric nonunions require operative treatment. Osteonecrosis is not present given the lack of interruption to the intracapsular blood supply, and one is more likely to try to preserve the femoral head than with femoral neck nonunion.

## Repeat ORIF with Bone Grafting

The richly vascularized, large bony surfaces associated with the intertrochanteric region lead to the low incidence of nonunion with intertrochanteric hip fractures. Implant choices for these nonunions include a sliding hip screw, intramedullary hip screw, variable angle screw, and multiaxial sliding plate (Fig. 10.5). While autogenous iliac crest bone graft remains the gold standard, newer biologics such as demineralized bone matrix, calcium phosphate, and a variety of synthetic bone morphogenic proteins are being used in concert with allograft cancellous chips.

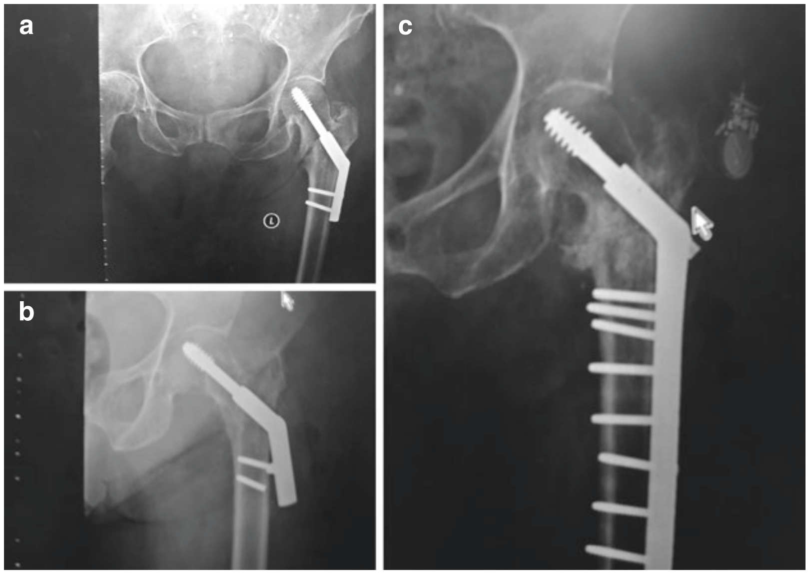


**Fig. 10.5** A 73-year-old female sustained a left stable intertrochanteric hip fracture. (**a**) Immediate postoperative films. (**b**) At 4 months the fracture is ununited and the hardware has failed. (**c**) Three months following revision ORIF with a longer side plate, autogenous bone graft, and an implanted electric bone stimulator. The fracture has healed

Because there is a high association between a varus neck-shaft angle and nonunion, an attempt to alter the neck-shaft angle into a more valgus position should be made. In their series of 20 intertrochanteric nonunions treated over a 20-year period, 11 patients underwent repeat ORIF with a variety of implants and 6 receiving a bone graft. Nine of the 11 (82%) achieved union at an average of 6 months. The mean neck-shaft angle preoperatively in this series was 1120; postoperatively it increased to only 1160 [46]. Haidukewych and Berry reported similar findings in a series of 20 patients undergoing revision internal reduction and bone grafting with 19 (95%) fractures healing [66]. One persistent nonunion treated with an angled blade plate and autograft failed to heal and required revision hemiarthroplasty at 12 months postoperation. At follow-up 16 of 19 healed nonunions reported freedom from pain.

If the nonunion site is mobile, a more valgus position can be achieved by utilizing a fixed-angle device and inserting the proximal fixation point (blade or lag screw) into an inferior neck position and utilize the side plate to add valgus when brought into contact with the shaft. Implants that can be utilized include a 95–120° blade plate, 95° dynamic condylar screw or a sliding hip screw.

## Osteotomy

Medial displacement osteotomy similar to that of Demon and Hughson has been described for the treatment of intertrochanteric nonunions [48]. The concept behind the operation is to medialize the shaft and achieve a valgus position of the proximal fragment which should reduce shear at the site of the nonunion. The procedure is performed via an anterolateral approach, direct visualization of the nonunion site occurs, and the wedge removed from the intertrochanteric region is a good source of bone graft. The osteotomy is fixed with a 130° blade plate. The trochanteric fracture is wired back to the plate and shaft.

Sarathy et al. reported on six patients with intertrochanteric nonunions treated with this procedure [48]. The authors reported healing in all cases. Potential complications associated with this treatment method include AVN of the femoral head, risk of future lateral compartment knee arthritis, difficult conversion to total hip if needed, and failure of trochanteric union.

## Arthroplasty

There are few series of arthroplasty, either hemi or total, reported for intertrochanteric hip fracture nonunions. While treatment to preserve the femoral head is usually preferred for young patients, salvage treatment with hip arthroplasty may be considered for older patients with poor bone quality, bone loss, or articular cartilage damage. Haidukewych and Berry reported 60 patients with hip arthroplasty for failed treatment of intertrochanteric hip fractures [67]. Thirty-two patients underwent total arthroplasty, while 28 were treated with hemiarthroplasty. All patients reported improvement in pain and functioning with 87.5% of patients free from any implant revision at 10-year follow-up. Salvage arthroplasty presents increased operative challenges and risk of medical complication within the older patient but can provide good pain relief and functional improvement.

Patients with systemic diseases such as rheumatoid arthritis, Parkinson's disease, or AVN should undergo total hip arthroplasty [47, 68]. Elderly less functional patients with good acetabular cartilage can be considered for endoprosthetic replacement.

Implant choice is dependent on the amount of bone loss following resection of the proximal fragment. A significant amount of proximal femoral bone loss may require the use of a calcar replacing stem. Newer stem designs and improved metallurgy with superior alloys may obviate the need for such implants.

The biggest pitfall in the use of prosthetic replacement for these fractures is unsecured greater trochanteric fixation if a separate fragment. With failure of trochanteric union following arthroplasty, the patient is at higher risk for postoperative dislocation.

## Subtrochanteric Nonunions

Nonunion following subtrochanteric fracture is more common than either femoral neck or intertrochanteric fracture. To date there have been no large clinical series to guide the clinician treating a subtrochanteric nonunion. Deformity, bone loss from prior hardware, and the high stresses of the subtrochanteric region of the femur pose challenges to achieving union. Similar to intertrochanteric nonunions, osteonecrosis is rarely present. Furthermore, the large size of the femoral head and neck segment makes repeat internal fixation a better treatment option and prosthetic replacement. Haidukewych and Berry described their institution's experience with 21 patients with subtrochanteric nonunion [51]. Implants used for revision internal fixation included cephalomedullary nail, standard anterograde femoral nail, fixed-angle blade, sliding hip screw, dynamic condylar screw, and dual large fragment plates. Eighteen of twenty-one patients had bone grafting. Twenty of twenty-one nonunions healed. Overall the series demonstrated high rate of union and functional improvement with multiple fixation techniques.

### Intramedullary Nailing

The treatment of subtrochanteric nonunions depends in part on what initial treatment was utilized. Prior to the 1990s, implant options for the treatment of these nonunions was limited. In cases where a fixed-angle device and side plate were used to fix the fracture, conversion to a reamed, locked intramedullary nail is a very good option.

If this device is selected, a cephalomedullary-type nail should be used. The operation is performed on a radiolucent flat table. All hardware is removed utilizing previous incision. An anterolateral approach to the hip is performed if needed to correct any malpositioning. Antegrade intramedullary nailing is then performed either through the greater trochanter or a starting point just anterior to the piriformis fossa. If the nonunion site is not violated, autogenous bone grafting need not be performed.

Classically, intramedullary nailing is performed utilizing a fracture table. The table achieves fracture reduction through sustained longitudinal traction. A perineal post provides a fulcrum against which traction is applied. The design of most fracture tables allows circumferential access to the extremity for manipulation, surgical exposure, and imaging. Nailing can be performed with the patient in the lateral decubitus or supine position. The advantages of a lateral decubitus position include improved access to the piriformis fossa, especially in obese patients or those with ipsilateral hip disease with decreased hip range of motion. Disadvantages of the lateral position include respiratory compromise for patients with pulmonary injuries, valgus angulation of the fracture, difficulty in determining proper rotation, and greater difficulty inserting distal locking screws. There are several advantages to the supine position, including ease of setup, less respiratory compromise, better fracture alignment, and easier distal screw insertion. A proper entry point is critical to insure proper nail placement and fracture reduction. A 2 cm longitudinal incision is made one handsbreadth proximal to the great trochanter in line with the femoral shaft. The fascia of the maximus is incised, and the muscle bluntly splits in line with its fibers down to the piriformis fossa. A clamp is placed in the piriformis fossa, its position confirmed with fluoroscopy and spread open upon withdrawal. A guide pin is then placed into the piriformis fossa and checked on the AP and lateral views. Next, the guide pin is overreamed to gain entry to the proximal fragment. Medial portal placement should be avoided, as this may cause a femoral neck fracture. Portal placement laterally may lead to comminution and varus alignment in proximal fractures. Alternatively, an awl may be placed in the piriformis fossa and the proximal femur opened by creating a pilot hole. If this technique is chosen, a larger skin incision will be required.

If a subtrochanteric nonunion is treated with an intramedullary nail, it should be reamed and statically locked. Supplemental bone grafting may be performed. If a subtrochanteric fracture treated with an IM nail goes on to nonunion, it can be treated with an exchange nail or converted to internal fixation (Fig. 10.4).

## Revision Open Reduction and Internal Fixation

In these cases, repair of the nonunion follows more traditional approach of direct exposure of the nonunion with revision fixation and autogenous cancellous bone grafting.

The operation may be performed on or off the fracture table. Initially, all hardware is removed via the previous incision. If the nonunion is of the hypertrophic type, revision fixation with a fixed-angle device of the surgeon's choice may be sufficient to treat the nonunion. If the nonunion is of the oligo- or atrophic type (most commonly), autogenous bone grafting is required. Most agree that eight cortices of screw fixation distal to the nonunion site are required in the proximal femoral shaft for secure fixation [63] (Fig. 10.6).

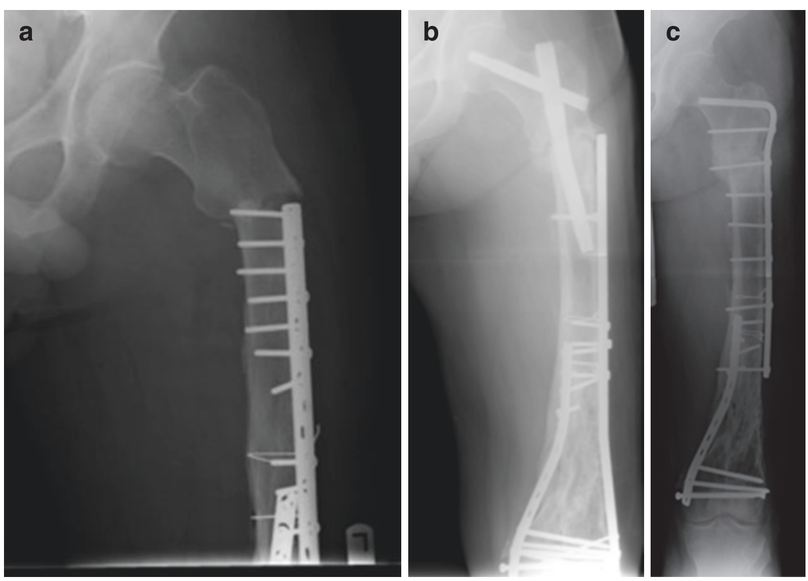


**Fig. 10.6** A 52-year-old male who is 20 years s/p repair of a previous femur fracture after MVA. (**a**) Initial X-rays demonstrate a subtrochanteric fracture above the previous hardware. (**b**) At 4 months the patient has an established nonunion following IM nailing. (**c**) Six months following nonunion repair with plate and screw compression and autogenous bone graft the fracture is healed

## Summary

For most nonunions encountered by orthopedists, treatment includes reversing the causative factors involved in the development of the nonunion. Thus, in cases of gap, fracture ends are compressed; in cases of avascularity, autogenous bone grafting is utilized; and in cases of excessive motion, stabile internal fixation is required to properly treat the nonunion. While all of these conditions apply to the proximal femur, the additional biomechanical factors related to the hip must be taken into account to properly treat the established nonunion of the hip.

The techniques available for the treatment of these ununited fractures are somewhat technically demanding. However, with newer implants and synthetic bone grafting at its infancy, the already relatively high success rate seen with these injuries can be expected to increase, while morbidity associated with their performance decrease.

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# Ipsilateral Femoral Neck and Shaft Fractures

11

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## Incidence

Fractures of the femoral neck and femoral shaft are relatively common but are rare in combination. The reported incidence of a femoral neck fracture in the setting of a femoral shaft fracture is 1–9%, with the largest retrospective review to date reporting a 3% incidence [1–12]. These injuries commonly occur in young patients (average age, 34 years) [8, 13–18] and are a result of a high-energy mechanism such as a motor vehicle accident or fall from a height [2, 3, 5, 6, 9, 11, 12, 19, 20]. The incidence of ipsilateral fractures of the femoral neck and shaft is increasing due to the rising number of high-energy motor vehicle accidents, improved survivorship after high-energy accidents, and enhanced recognition of this injury pattern [9, 12, 13, 21]. Importantly, multi-system injuries have been reported to occur in between 73% and 100% of patients presenting with this injury [8, 9, 13–15, 22].

Ipsilateral femoral neck and shaft fractures frequently exhibit a characteristic fracture pattern. The shaft fracture is more likely to be highly comminuted compared to isolated femoral shaft fractures [5, 6, 8]. Associated femoral neck fractures have a higher likelihood of being nondisplaced compared to isolated femoral neck fractures [6, 9, 12]. One explanation for this injury pattern is that during axial loading, the knee and femoral shaft absorb most of the energy of impact, thereby reducing the energy transferred to the femoral neck [11, 13, 16]. This is further supported by the high incidence of ipsilateral knee injuries in this population, reported in 14–40% of cases [8, 9, 13, 15–17]. Femoral neck fractures in young patients, both isolated and those with an associated femoral shaft fracture, tend to be intracapsular and vertical in orientation [6, 9, 20, 23]. While a number of femoral neck fracture patterns have been described in association with a femoral shaft fracture, a recurrent finding is a caudal exit point near the junction of the caudal neck and calcar as opposed to more medial exit points in valgus patterns [24].

## Diagnosis

While the diagnosis of a femoral neck fracture is rarely challenging, they can be easily missed in the setting of an ipsilateral femoral shaft fracture. Previous studies have reported that up to 20–50% of femoral neck fractures are initially missed during the presentation of a patient with an ipsilateral

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femoral shaft fracture [2, 3, 5, 7, 8, 25, 26]. There are a number of reasons why these fractures are commonly missed. As stated above, the fracture pattern is often non-displaced and therefore difficult to visualize. Poor-quality radiographs are commonly accepted, as the patient is in severe discomfort secondary to the shaft fracture. Because the femoral neck is anteverted, internal rotation of the hip is necessary to bring the long axis of the femoral neck perpendicular with the radiographic beam. In patients with femoral shaft fractures, internal rotation of the leg will not internally rotate the proximal segment. The proximal femur will therefore be externally rotated on an AP radiograph, which may make identification of the femoral neck fracture difficult. Lastly, distracting injuries are common and may both mask the patient's pain and focus the direction of the physician elsewhere.

Due to the high incidence of missed femoral neck fractures in patients with femoral shaft fractures, a comprehensive imaging protocol is recommended. The initial radiologic evaluation should consist of dedicated hip radiographs. If oblique views of the pelvis are obtained for a suspected acetabular fracture, they should be used to evaluate the femoral neck. Oftentimes, the obturator oblique view will be of benefit in this pursuit, as the femoral neck may be seen along its long axis. In high-risk patients (young age, high-energy mechanism), a dedicated 2-mm fine-cut CT scan through the femoral neck can be obtained. If a CT scan is obtained for the evaluation of abdominal or pelvic trauma, the axial images should be scrutinized for the presence of a femoral neck fracture. When a femoral neck fracture is not identified in the setting of a femoral shaft fracture, intraoperative fluoroscopic images of the neck should be obtained prior to antegrade nailing. After antegrade nailing is complete, fluoroscopic images of the hip can again be obtained with the hip in 15 degrees of internal rotation. Lastly, dedicated hip radiographs can be taken before leaving the operating room to confirm the integrity of the femoral neck. Using a protocol of a dedicated internal rotation radiograph of the hip, a 2-mm fine-cut CT scan through the femoral neck, a lateral fluoroscopic image of the hip prior to internal fixation, and orthogonal hip radiographs in the operating room at the conclusion of the procedure, Tornetta et al. reduced their delay in the diagnosis of femoral neck fracture by 91% compared to the year prior [10]. It is important to remember that femoral neck fractures can still be missed on CT scan with O'Toole et al. finding that both plain radiography and CT have a similar and significant rate of missed femoral neck fractures, with a sensitivity ranging from 56% to 64% [27]. Furthermore, fractures can also occur or displace during surgery, so the absence of a fracture preoperatively does not obviate the need to evaluate the femoral neck during and after surgery. Despite improved physician awareness, these fractures may still be missed in up to 11% of patients [8, 14, 16, 18, 28, 29]. For this reason, patients should be questioned regarding the presence of hip pain at all follow-up appointments and if positive should undergo additional evaluation.

The importance of prompt recognition of femoral neck fractures in the setting of femoral shaft fractures cannot be understated. Early identification allows for timely stabilization, which may decrease the risk of nonunion and avascular necrosis. Failure to recognize an associated femoral neck fracture can lead to fracture displacement at the time of surgery, limiting the number of fixation options for the femoral neck [8, 26]. With a significant delay in diagnosis, complications such as malunion, nonunion, or avascular necrosis may require extensive reconstructive procedures.

## Initial Management

Initial assessment of the severely injured patient should follow the guidelines of the Advanced Trauma Life Support (ATLS) protocol. In the conscious patient, the presence of a femoral shaft fracture is usually obvious, with local pain, bruising, swelling, deformity, or instability. This injury should not distract the physician from a careful history and physical examination. The history may be obtained from the patient, family members, and emergency personnel. The history should include the mechanism of injury, time from injury to presentation, location of the accident, and any known associated injuries. After the ATLS protocol is complete, the initial physical examination should include a visual inspection and palpation of all extremities, pelvis, and spine for associated injuries. The ipsilateral hip and knee should be examined thoroughly. It is difficult to examine the hip in a patient with an ipsilateral femoral shaft fracture, emphasizing the importance of femoral neck-specific imaging. Meniscal and ligamentous knee injuries are commonly associated with femoral shaft fractures, and therefore the knee should be examined for laxity and instability [30, 31]. While this can be attempted in the emergency room, it is frequently more accurate in the anesthetized patient at the conclusion of surgical stabilization of the femur fracture. In general, these findings should be documented and followed but do not require immediate surgical repair or reconstruction.

The vascular and neurologic status of the injured extremity must be documented at the initial assessment. The presence of a vascular injury with major hemorrhage or distal limb ischemia may threaten the survival of the patient or limb. Palpation or Doppler examination of distal pulses should be performed to determine the vascular status of the injured extremity. If there is a discrepancy with the contralateral extremity, further evaluation is necessary. The presence of normal pulses does not exclude the possibility of vascular injury, which emphasizes the need for repeated evaluation in these patients [32].

Physical examination of the thigh should include a circumferential visual inspection to identify any open wounds, degloving injuries, bruising, or abrasions. Open wounds should be gently irrigated with any foreign material or gross debris removed. Extruded bone ends should be reduced if possible to minimize pressure necrosis of the underlying skin and muscle. Sterile dressings should be applied, and antibiotics administered accordingly. For both closed and open fractures, prophylactic anticoagulation should be administered. Recent evidence has suggested that foot pumps are an important adjunct to medical anticoagulation in the prevention of deep venous thrombosis [33]. If significant shortening at the femoral shaft fracture site is identified, skeletal traction may be applied for patient comfort prior to operative intervention.

## Treatment

The optimal treatment for ipsilateral femoral neck and shaft fractures remains controversial. Although the level of available evidence is generally weak, most contemporary studies support initial open or closed femoral neck fracture reduction and fixation with either cannulated screws or a sliding hip screw device followed by reamed, locked, retrograde medullary nailing. Other, less commonly utilized strategies involve using a reconstruction-type nail to stabilize both fractures with a single implant or independent screw fixation of the femoral neck with antegrade nail or plate fixation of the femoral shaft. The advantages, disadvantages, and surgical aspects of each technique will be discussed in detail.

### Femoral Neck Fracture Reduction and Fixation Followed by Retrograde Femoral Nailing

#### Rationale

Initial reduction and fixation of the femoral neck with either cannulated screws or a sliding hip screw device followed by reamed interlocked retrograde medullary nailing is the most commonly described technique for management of combined femoral neck and shaft fractures (Fig. 11.1) [8, 34, 35]. This technique allows the surgeon to first prioritize anatomic reduction and fixation of the femoral neck. Clinical experience has shown that the femoral neck component of this injury pattern is the more challenging part of the procedure in terms of achieving anatomic reduction and stable fixation [16, 19, 35]. In addition, complications typically arise from the femoral neck fracture component. Open/closed reduction and sliding hip screw fixation of the femoral neck fracture and retrograde nail fixation have yielded the highest reported rates of appropriate reduction and


**Fig. 11.1** Ipsilateral femoral neck and shaft fracture treated with a sliding hip screw with antirotation screw, followed by retrograde nail fixation of the shaft component

uneventful healing [8, 34, 35]. The primary drawback of the technique is that it necessitates a retrograde nail, which some surgeons prefer to avoid over concern for iatrogenic knee injury and decreased union rates [25, 36, 37]. The merits and demerits of antegrade versus retrograde nailing for any femoral shaft fracture remain controversial [34, 36].

### Surgical Technique

When employing this strategy, the patient is positioned supine on a radiolucent flat-top table with a bump under the ipsilateral sacrum and torso. This position will allow an unobstructed lateral view of the femoral neck, which is essential for placement of the sliding hip screw. As with any femoral shaft fracture, radiographic evaluation of the contralateral femur can be performed for comparison of length, alignment, and rotation. The entire limb is prepped and draped from above the iliac crest to the toes. Alternatively, the contralateral side can be prepped into the field for intraoperative clinical comparison.

It is reasonable to attempt an initial closed reduction of the femoral neck. This is best achieved by inserting a 5-mm Schanz pin into the proximal femoral shaft for manipulation. In select cases, a second Schanz pin can be inserted and connected with an external fixator bar in an attempt to optimize control of the proximal segment. If the femoral neck fracture is not displaced or an anatomic reduction of a displaced fracture can be obtained with closed manipulation, percutaneous screws, a sliding hip screw, or a combination of the two can be utilized based on fracture pattern and surgeon preference. All of the treatment principles that apply to reduction and fixation of isolated femoral neck fractures apply in this situation as well. If an anatomic reduction cannot be achieved, an open reduction via a Smith-Peterson or Watson-Jones approach should be performed according to surgeon preference. If a sliding hip screw device is used, the side plate should be overlapping the tip of the retrograde nail. It is recommended to choose at least a three-hole side plate to ensure overlap and allow for at least two or three screws with good purchase anterior or posterior to the nail. Initially, the more distal screw or screws should be inserted as unicortical screws so as not to interfere with femoral nailing. A sliding hip screw combined with a nail has the theoretical advantage of protecting the entire bone as compared to cannulated screws and a retrograde nail, but periprosthetic fractures between these two implants do not seem to be a major clinical problem [8, 34].

Once satisfactory femoral neck fracture reduction and fixation has been achieved, the surgeon can move on to retrograde nailing of the femoral shaft. The surgical technique is the same as for retrograde nailing of an isolated femoral shaft fracture with a few exceptions. The surgeon must be careful not to compromise the femoral neck fracture fixation with aggressive mallet blows to the retrograde nail. To make nail insertion as gentle as possible, the medullary canal can be over reamed by 2 mm. Nail length should also be carefully planned to overlap the side plate of the sliding hip screw without being prominent in the knee. Once the nail has been inserted and interlocked, any unicortical screws in a femoral neck slide plate can be placed bicortically around the nail.

## Reconstruction-Type Nailing of Femoral Neck and Shaft Fracture

### Rationale

Simultaneous reconstruction nailing of both fractures is attractive for its elegance and efficiency (Fig. 11.2). Theoretically, the surgeon can simultaneously stabilize both injuries with a single device while avoiding trauma to the knee, and some authors have described good results with this technique [6, 11, 38–40]. However, others have reported an increased incidence of problems with femoral neck reduction and healing as compared to the aforementioned two-implant technique [14, 19, 28, 35, 41]. Some surgeons feel that an antegrade reconstruction nail is best reserved for a minimally or non-displaced femoral neck fracture, particularly one identified intraoperatively [35, 42].

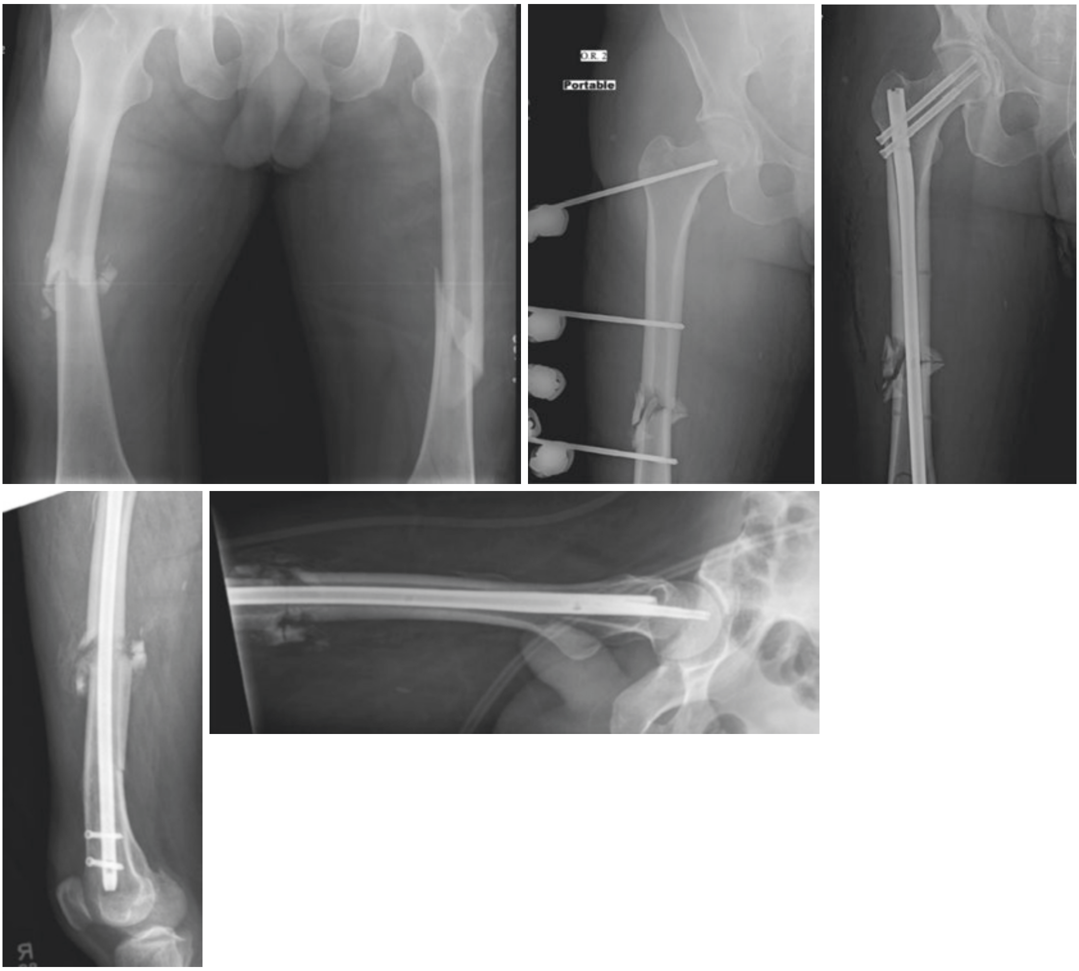


**Fig. 11.2** Non-displaced femoral neck fracture with ipsilateral femoral shaft fracture treated initially with external fixator as part of a damage control orthopedic approach, followed by reconstruction nail fixation after stabilization of the patient

## Surgical Technique

The patient may be positioned either on a radiolucent flat-top table or an orthopedic fracture table. If a radiolucent flat-top table is selected, a small trochanteric bump can facilitate access. Prep and drape techniques for contralateral comparison are the same as mentioned above.

Again, an initial attempt at closed reduction can be performed. This can either be done by utilizing the fracture table or by employing a Schanz pin(s) with or without an external fixator bar. If anatomic reduction cannot be obtained closed, an open approach is undertaken to facilitate reduction under direct vision. Once an appropriate reduction has been obtained, it can be stabilized with Kirschner wires strategically placed outside the path of the nail. These wires can even be supplemented with a cannulated screw.

Once the femoral neck has been reduced and provisionally stabilized, attention is turned to the femoral shaft. In the setting of an open femur fracture with a relatively simple pattern, provisional unicortical locked plate fixation of the shaft can be performed at the time of debridement. This can greatly simplify passage of the guidewire and nail with minimal biologic cost if the site has already been exposed for debridement. In the setting of a closed fracture, the usual closed or minimally invasive reduction techniques can be employed.

A trochanteric start reconstruction nail is typically selected for this application, optimizing screw trajectory into the head/neck segment. A starting point is established using conventional techniques and the medullary canal opened. The guidewire must be placed across the femoral shaft fracture site without disrupting the provisional fixation of the neck. Again, the femur should be over-reamed by 2 mm, so the nail can be inserted as gently as possible. As with any cephalomedullary device, the version of the nail must match the version of the femoral neck so that the reconstruction screws can be placed centrally into the femoral head. Partially threaded screws should be used to allow for ongoing compression at the femoral neck [39, 40]. Routine distal interlocking can then be performed.

## Alternative Techniques

### Rationale

Less commonly employed alternatives to the aforementioned strategies have also been described. One of these is independent screw fixation of the femoral neck after antegrade femoral nailing of the femoral shaft (Fig. 11.3). This technique is most relevant when a femoral neck fracture is identified after medullary nailing has been completed. Under these circumstances, provided the fracture is not displaced or an appropriate reduction can be obtained, cannulated screws can be deployed around the nail to stabilize the femoral neck. This can be challenging as the nail can compromise precise screw placement, and the surgeon must remain sensitive to the importance of screw position in femoral neck fracture fixation [41, 42]. If appropriate reduction and stabilization of the femoral neck cannot be achieved with the nail in place, it should be removed and an alternative strategy employed. Finally, plate fixation of the femoral shaft can be performed after surgical treatment of the femoral neck. Plate fixation avoids the forceful insertion of a nail into the femoral canal below a femoral neck fracture and obviates the need for reaming which is a known source of systemic inflammation and potential pulmonary compromise [43, 44]. It may also be more attractive in very distal fractures where intramedullary nailing may be more technically difficult or biomechanically less appealing. That being said, reamed, locked intramedullary nailing is the treatment of choice for the vast majority of femoral shaft fractures, with plate fixation serving a limited role given its more invasive nature and inferior biomechanics.

### Surgical Technique

Independent screw fixation of the femoral neck with separate antegrade femoral nailing is most frequently performed when a femoral neck fracture has been identified with the nail already in situ. Under these circumstances, whatever position, prep and drape has been selected for the femoral nailing can also be utilized for the femoral neck fixation. The most important step remains obtaining an anatomic reduction using conventional closed or open reduction techniques. The challenge comes in placing screws that avoid the nail and are appropriately positioned to stabilize the femoral neck fracture femoral neck. If appropriate reduction cannot be achieved or if the nail prevents appropriate femoral neck fracture fixation, all implants should be removed and an alternative strategy employed.

Plate fixation of the femoral shaft following femoral neck fixation can be performed supine on a conventional radiolucent table or a fracture table. Although many surgeons prefer the lateral position when performing plate fixation of isolated femoral shaft fractures, this position is suboptimal for femoral neck fracture reduction and fixation. Depending on the clinical circumstances and femoral shaft fracture pattern, the plate can be deployed in bridge, neutralization, or compression mode. Although there are reports of utilizing a single device such as a compression screw with a long side plate in these circumstances, we believe that separate implants optimally placed for either femoral neck or femoral shaft fracture fixation are preferred.

**Fig. 11.3** Antegrade fixation of a comminuted femoral shaft fracture in a 28-year-old patient. Postoperative X-rays revealed a displaced femoral neck fracture, which was reduced and stabilized with two cannulated screws, placed around the nail

## Complications

The rates of femoral neck-related complications following ipsilateral femoral neck and shaft fractures are less than those observed after isolated femoral neck fractures. Rates of femoral neck nonunion after neck-shaft fracture have been reported between 0% and 6.7%, while malunion has been reported in 3.7–5% [2, 3, 6, 8, 25, 34, 38]. While rates of AVN have been reported to be 0–22%, the average among studies is approximately 5% [3, 6, 8, 25, 34, 38]. There are several potential explanations for this discrepancy. The natural history of a femoral neck fracture above a femoral shaft fracture may be different because the elements of the femoral neck fracture itself are different. Much of the energy of the injury may be absorbed by the femoral shaft, leading to a lower-energy fractures at the femoral neck and lesser degrees of displacement [11, 13, 16]. Similarly, the location of the fracture seems to be different, with many being extracapsular. Finally, the treatment may be different. It is likely that more of these fractures are treated at designated trauma centers by surgeons with subspecialty training in orthopedic trauma leading to a decrease in complications [45, 46]. Alternatively, there may be differences in fixation strategy and postoperative rehabilitation.

The rates of femoral shaft-related complications following ipsilateral femoral neck and shaft fractures are greater than those observed after isolated femoral shaft fracture. Rates of femoral shaft nonunion after neck-shaft fracture are reported between 0% and 23%, and rates of malunion are anywhere from 3.7% to 40% [2, 3, 6, 8, 11, 25, 34]. In contrast, isolated femoral shaft fractures go on to successful healing at a rate of approximately 98% with modern techniques [47, 48]. As mentioned above, this may be due to a number of reasons. The femoral shaft fracture in associated neck-shaft fractures typically has a more comminuted pattern. With an associated neck fracture, the surgeon may be forced to change their preferred implant choice. The rehabilitation protocol may also change, as weight-bearing may be protected after surgery to protect the femoral neck.

## Evidence-Based Medicine

The rare nature of this injury pattern makes it difficult to study, and most studies are retrospective in nature with small sample sizes and nonuniform outcome measures. Overall, outcomes tend to be good in approximately 70–94% of these cases when the injury is recognized immediately and treated appropriately [5, 8, 11, 16, 34, 38]. Unfortunately, these studies are underpowered to be able to determine differences in outcomes between various treatment strategies. A meta-analysis of 722 cases from 65 studies found no superior implant choice or treatment option [2]. Bhandari performed a more recent meta-analysis of all studies evaluating outcomes after treatment of ipsilateral femoral neck and shaft fractures from 1969 to 2002 [49]. The evidence to support a single implant over separate femoral neck and shaft implants was determined to be weak, with the author reporting that only small case series have found a lower rate of reoperation for separate implant procedures. The author also reported moderate grade evidence to support the use of antegrade nailing over retrograde nailing, which was associated with a 47% reduction in malunion. However, given the wide confidence intervals in the included studies, future studies are needed to further support this [49].

While the use of a cephalomedullary nail offers the advantage of lower implant costs, there may be an increased risk of femoral neck malunion or nonunion when the neck is displaced [35, 39] Theoretically, this could lead to a higher rate of secondary procedures that would offset any potential cost savings of using a single implant during the initial procedure. There has been no cost-effectiveness analysis comparing a single implant with a combination of implants for ipsilateral femoral neck and shaft fractures. Single implant constructs such as a reconstruction nail should only be used when the surgeon feels confident that they can obtain an anatomic reduction of the femoral neck.

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# Medical Management

# 12

Vikramjit Mukherjee and Ezra Dweck

## Introduction

Proximal femur fractures, and their associated morbidity and mortality, raise a significant public health concern in the United States. The annual incidence of such fractures ranges from approximately 400/100,000 for men to almost 1,000/100,000 for women [1]. While the incidence of hip fractures has steadily declined over the last decade in parallel with increased bisphosphonate use, the 1-year mortality from this disease has not decreased and remains approximately 30% [2]. Additionally, there is a significant reduction in the patient's quality of life due to loss of independence, financial burden, and associated morbidity. The role for medical management of hip fractures includes optimizing patients preoperatively, attending to immediate postoperative complications, and coordinating long-term follow-up for evaluation and treatment of associated comorbidities.

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Medical management of hip fractures involves the following aspects of care:

(a) Pain control
(b) Optimizing medical comorbidities prior to surgery
(c) Postoperative complications:
    1. Infections
    2. Venous thromboembolism
    3. Delirium
    4. Pressure ulcers
    5. Anemia
(d) Early mobilization, rehabilitation, and falls prevention
(e) Nutritional support
(f) Secondary prevention with osteoporosis treatment
(g) Long-term cognitive outcomes

## Pain Control

While provision of patient comfort is a fundamental obligation of healthcare providers, recent data shows that pain is inadequately treated in the perioperative period [3]. Barriers include cognitive impairment leading to inability to report pain reliably, reliance on primitive pain scoring tools, and lack of evidence-based recommendations. Inadequate pain control not only leads to suffering, but also contributes to delirium and suboptimal rehabilitation which may lead to slower



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recovery, pressure sores [4], and longer hospital lengths of stay.

Nonverbal clues such as restlessness, agitation, and facial expressions as well as physiologic signs such as tachycardia, tachypnea, or hypertension should be carefully evaluated in the elderly patient and especially in those with cognitive impairment—a population in whom hip fracture is exceedingly common.

Both opiod medications and regional nerve blocks are therapeutic options to control pain in patients with hip fracture. The sensory innervation of the proximal femur and a portion of the intracapsular femoral neck arise from the femoral nerve; hence femoral nerve block (FNB) is a therapeutic option in such patients. Additionally, FNB plays a unique role in the elderly patient with multiple comorbidities who may be unable to tolerate the cardiorespiratory side effects of systemic opiods. FNB results in a reduction of the quantity of systemic analgesia required [5]. Ultrasound-guided FNB has been shown to be superior to the traditional nerve stimulation-guided method and provides faster, longer pain relief with a smaller volume of anesthetic use [6].

Systemic opiods play a complementary role to FNB but should be used with caution until cardiorespiratory and metabolic parameters have been reviewed. Early fracture fixation provides the most effective pain control [7]. Most importantly, a standard pain control protocol should be adopted. Initiation of a pain control program using preoperative FNB as well as utilization of a systematic approach to nutrition, fluid, and oxygen therapy; and avoidance of urinary retention led to reduction in postoperative complications (including delirium, confusion, urinary tract infection) as well as a reduction in mortality in certain patients [8].

## Optimizing Medical Comorbidities Prior to Surgery

Studies show that early surgery—within 24–48 h of hospitalization—leads to lower incidences of delirium, fatal pulmonary embolism, and pressure sores and is associated with a lower 1-year mortality [9]. There are, however, certain scenarios where the benefits of early surgery are outweighed by the risks of delaying surgery while medical comorbidities are optimized.

Advanced age is not an independent risk factor for complications after surgery, but the geriatric population is predisposed to having concurrent medical conditions. Patients with active high-risk cardiac conditions such as acute coronary syndromes, severe valvulopathy, or decompensated heart failure [10] should undergo medical optimization prior to surgery. Cardiopulmonary status and metabolic parameters should be carefully assessed. Major abnormalities such as significant hypotension, active infection, decompensated heart failure, acute coronary syndrome, coagulopathy, severe respiratory failure, and significant metabolic abnormalities have all been shown to be independent risk factors for the development of postoperative complications [11]. Hence, these risk factors should be addressed prior to surgery.

ASA classification can also be used to risk stratify patients undergoing surgery. ASA III and IV (moderate to severe systemic disease that impacts the patient's function and severe systemic life-threatening disease, respectively) have nine times higher 1-year mortality rates compared to ASA I and II (normal, healthy patients and mild systemic disease with no functional limitations) [12].

The elderly population is often exposed to polypharmacy which increases the likelihood of adverse drug reactions. Meticulous attention should be paid to the patient's medication list in the perioperative period in order to minimize pharmacokinetic and pharmacodynamic interactions.

Preoperative testing should routinely include a full blood count, a basic chemistry panel, and an electrocardiogram. Other studies are indicated based on the patient's underlying comorbidities. Operative blood loss is expected; hence preoperative transfusion should be considered if the Hb is <9–10 g/dL. Dyselectrolytemias predispose to cardiac arrhythmias and should be corrected preoperatively. Special attention should be paid to the patient's underlying cardiac rhythm, since the incidence of atrial fibrillation is very common in the elderly. For patients who are chronically anticoagulated prior to admission, a recent trial showed that forgoing bridging anticoagulation in patients with atrial fibrillation who were on warfarin was noninferior to perioperative bridging with low-molecular-weight heparin, with lower risk of major bleeding [13]. Cardiac consultation should be considered in patients with indwelling cardiac stents, implantable cardiac defibrillators, and pacemakers.

## Managing Postoperative Complications

Postoperative complications are common, add to the morbidity and mortality of hip fracture surgery, and require a high degree of vigilance in elderly patients to detect. Common postoperative complications are listed in Table 12.1. Studies have shown that most of the common postoperative complications are independently associated with increased 30-day and 1-year mortality [14].

Between 14 and 20% of patients will have postoperative complications after hip surgery [14], the most common being respiratory infection (9%), heart failure (5%), and urosepsis (4%). Patients with preexisting comorbidities are, predictably, more likely to develop complications and require even closer attention in the postoperative periods.

### Infections

Surgical site infections (SSI), chest infections, and urinary tract infections make up the majority of infectious complications. The typical onset of an SSI is between day 3 and day 8 postsurgery

**Table 12.1** Frequent postoperative complications

| Complication | Incidence (%) | Prevention |
|---|---|---|
| Surgical site infections | 1.6–22.7 | Preoperative medical optimization |
| | | Prophylactic antibiotics |
| | | Intraoperative sterility |
| | | Glycemic control |
| Chest infections | Unknown | Handwashing |
| | | Early extubation and remobilization |
| | | Avoidance of PPI |
| | | Avoidance of sedation |
| Urinary tract infections | 38 | Early catheter removal |
| | | Antibiotics in patients with positive urinary culture, regardless of symptoms |
| Delirium | 10–65 | Daily screening for hyperactive and hypoactive delirium |
| | | Pain control |
| | | Avoidance of polypharmacy |
| Venous thromboembolism | 1.0–4.3 | Anticoagulant therapy |
| | | Early mobilization |
| Delirium | 61 | Pain control |
| | | Oxygen, fluids, nutrition |
| | | Environmental stimulation |
| Constipation | | |
| Pressure ulcers | 10–40 | Foam mattress |
| | | Mobilization |
| | | Nutritional support |
| Anemia | 80 | Avoid unnecessary phlebotomy |
| | | Transfuse to goal Hb > 8 g/dL |
| Secondary fractures | Unknown | Falls prevention |
| | | Vitamin D |

and is reduced by active surveillance, hand hygiene, attention to nutritional status, glycemic control, and perioperative antibiotic prophylaxis [15].

Chest infections are common and are associated with increased length of stay, worsening morbidity, and increased mortality. Age-related immunosenescence, age-related changes to the lung epithelium, silent aspiration of oropharyngeal secretions, reduced alertness and gag reflex, and immobility all contribute to the development of chest infections in the elderly postoperative patient [16]. Vigilance is key because the elderly patient often will not mount the classical signs of infection such as fever or leukocytosis.

Chest infections are sometimes grouped under the broader category of postoperative pulmonary complications (PPCs), which include atelectasis, pneumonia, respiratory failure, and venous thromboembolism (VTE). VTE will be discussed in more detail separately; however, atelectasis and respiratory failure deserve special mention here.

Atelectasis is common, and postoperative orthopedic patients are prone to this because of immobility, inadequate pain control, body habitus, and preexisting cardiopulmonary disease. Regular pulmonary toilet, incentive spirometry, early extubation, and ambulation must be stressed upon in the postoperative period. Hypercapnic respiratory failure is common as well, most commonly from excessive administration or reduced excretion of centrally acting medications or from undiagnosed sleep apnea. Hypoxic respiratory failure is often multifactorial and can occur from fluid overload, aspiration, atelectasis, venous thromboembolism, and pneumonia.

## Venous Thromboembolism (VTE)

VTE is a serious and common complication following hip fracture surgery [11] which significantly contributes to worse outcomes in terms of morbidity and mortality. Without prophylaxis, the incidence of VTE is as high as 46–75% [17] with a fatal pulmonary embolism (PE) rate of 4% [18]. Delay in presentation to the hospital or delay in time to surgery increases the risk for developing VTE by almost ten times. Patients are at risk for VTE soon after the time of injury and not after surgical repair; therefore prophylactic anticoagulation should be initiated immediately.

The incidence of VTE can be substantially reduced by the use of appropriate and timely VTE prophylaxis. Mechanical VTE prophylaxis such as intermittent pneumatic compression devices (IPCD) has been shown to reduce deep venous thromboses rates [19]. The American College of Chest Physicians, in its 2012 guidelines, recommends the use of only portable, battery-powered devices that are capable of recording and reporting wear time; additionally, it advises at least 18 h/day of daily compliance [20].

Chemical prophylaxis is key in preventing VTE in patients following hip fractures. Options include heparinoids (unfractionated heparin, low-molecular-weight heparin (LMWH)), fondaparinux, direct oral anticoagulants (DOAC, apixaban, rivaroxaban, dabigatran), vitamin K antagonists (warfarin), and aspirin. Using an agent such as LMWH reduces symptomatic VTE rates to <2% in the first 5 weeks postsurgery. LMWH should be used in preference to other agents, irrespective of the use of IPCD, unless there is a contraindication to doing so. Thromboprophylaxis should be extended to 35 days postoperatively since the risk of VTE is highest during these first 5 weeks. There is no established role for routine prophylactic inferior vena caval filter insertion or Doppler screening for DVT in asymptomatic patients [20].

Because of the high incidence of VTE, a high index of suspicion for PE must be maintained in the perioperative course. Traditional Wells' criteria for diagnosing PE does not perform well in this population [21], and coexisting pulmonary pathologies such as atelectasis, aspiration, and opiod-induced hypercapnia makes hypoxia an extremely nonspecific finding. [Bedside ultrasonography and the use of end-tidal $CO_2$ monitoring are exciting tools to use in differentiating the etiology of cardiorespiratory failure in this setting. Lower extremity Doppler examination, biomarkers for right ventricular strain such as troponins and beta-natriuretic peptide, echocardiogram, and imaging such as a CT angiogram or a ventilation/perfusion scan are modalities in the workup for possible PE.]

Treatment largely depends on the cardiopulmonary effects of PE. Non-massive PE and low-risk sub-massive PE are usually treated with anticoagulation alone (either heparinoids or vitamin K antagonists or direct oral anticoagulants), while patients with high-risk sub-massive PE may be candidates for thrombectomy or catheter-directed thrombolysis. IVC filters are reserved for patients in whom anticoagulation is contraindicated or has failed, while systemic thrombolysis is usually a salvage measure for massive PE.

## Delirium

Delirium is common in elderly patients, and its incidence is significantly increased in patients who are hospitalized. There is a large overlap among patients with delirium and those with hip fractures. Common risk factors include age, polypharmacy, gait instability and coexisting dementia, and other medical comorbidities. The incidence of perioperative delirium after hip fracture is high as 60% [22]. At 6 months, patients with delirium were found to have increased hospital length of stay, increased postoperative complications such as urinary incontinence and decubitus ulcers, and an increased chance of dying or being placed in a nursing home.

Factors predisposing patients to delirium include the use of centrally acting medications, especially benzodiazepines and opiods, poor nutritional status, hypoxia, sepsis, and preexisting dementia [23].

A high level of suspicion for delirium should be maintained in the perioperative setting. Hypoactive delirium may be as common as hyperactive delirium but is more difficult to diagnose. Risk factors for developing delirium should be minimized. Delirium can be prevented in one-third of at-risk patients and can be minimized in the others. If the underlying cause of delirium cannot be corrected and the patient's behavioral symptoms cannot otherwise safely be controlled, antipsychotics can be considered. Their toxicity, especially cardiac arrhythmias and extrapyramidal side effects, however, should be carefully monitored. Efforts should be taken to institute a multidisciplinary stepwise approach to assess and treat patients who are at high risk for developing delirium.

## Pressure Ulcers

Pressure sores are common after hip fractures with reported incidence rates of 10–40% [24] and have significant effects such as an increase in pain scores, length of stay, costs of care, medical complications, and mortality [25]. Of note, hospital-acquired pressure ulcers are considered a "never event," and the Centers for Medicare and Medicaid Services does not reimburse hospitals for the cost of their treatment.

Older patients with hip fractures are at high risk for developing pressure ulcers. Predisposing factors include immobility, poor nutritional status, incontinence, and the presence of coexisting diseases such as diabetes and anemia [24, 25]. Pressure sore prevention is crucial and involves minimizing surgical delay, pressure-relieving mattresses, good skin care, rehabilitation, and regular assessment of the patient's nutritional status [26].

Pressure ulcers are particularly difficult to heal. Treatment principles include careful assessment of severity, releif of pressure and friction, moist wound healing, removal of debris, and management of bacterial contamination [26]. Severe complications of pressure sores can include osteomyelitis and bacteremia.

The mere presence of a pressure ulcer is a prognostic sign. Only about 10% of ulcers heal by the time of hospital discharge, and as many as two-thirds of patients with pressure ulcers die during acute hospitalization. Patients whose pressure sores heal do significantly better than those in whom the sores persist. Though pressure sores themselves are not causally related to poor outcomes, their existence marks a patient who may have significant risk factors for developing perioperative complications leading to increased mortality and morbidity [27].

## Anemia

The incidence of preoperative and postoperative anemia following hip fracture is high and is associated with increased length of hospitalization and increased 6-month and 12-month mortality [28]. While approximately 40% of patients are anemic on admission, intraoperative blood loss leads to postoperative anemia in almost all patients with hip fractures [29].

A large, well-designed, randomized controlled trial has helped determine optimal transfusion thresholds in patients following hip surgery [30]. In this trial, more than 2000 high-risk patients (as defined by history of or risk factors for cardiovascular disease) were randomized to a liberal transfusion strategy (hemoglobin threshold of 10 g/dL) or a restrictive transfusion strategy (symptomatic anemia or a hemoglobin threshold of 8 g/dL). There was no difference among the two groups in terms of mortality or functional capacity at 60 days; neither were there any differences in in-hospital myocardial infarction or unstable angina.

## Early Mobilization and Rehabilitation

While early mobilization of the elderly patient with a recent hip fracture can be challenging, there is robust evidence to support aggressive early mobilization following hip fracture surgery. Increased immobility leads to worsening morbidity and mortality [31] and predisposes to postoperative complications such as pressure ulcers, urinary retention, ileus, and VTE. Studies show that early ambulation (first walk on postoperative day 1 or 2) accelerates functional recovery and reduces the need for high-level care compared to delayed ambulation [32]. Processes should be in place to facilitate early mobilization. These include aggressive and timely pain control, removal of indwelling catheters, minimizing sedative medications, and an early assessment by the rehabilitation team.

## Nutritional Support

More than half of hip fracture patients are malnourished [33]. Nutritional deficiency is strongly implicated in the pathogenesis of hip fractures [34], as they accelerate bone loss, predispose to gait instability, and are associated with higher comorbid indices [35]. Therefore it is imperative to pay close attention to the nutritional status of elderly patients to (a) prevent hip fractures, (b) enhance recovery, and (c) prevent recurrence.

Calcium and vitamin D supplementation in elderly patients has been shown to increase bone density and reduce the incidence of hip fractures and is a cost-effective way of managing high-risk patients [36]. Among patients who have developed a hip fracture, macronutrients and micronutrients must be replenished. Macronutrient deficiencies such as low protein intake play a detrimental role in recovery, and replacement aids in reducing complication rates and hospital length of stay. In general, hyperproteic nutritional supplements are recommended in the inpatient care of elderly patients with hip fractures. Micronutrients that play a pathogenic role in the disease process include vitamin D, vitamin K, and calcium, and efforts should be made to replete their deficiencies.

## Secondary Prevention and Management of Osteoporosis

The occurrence of a second hip fracture is approximately 10%, and care should be taken to avoid such recurrence. Risk factors include age, female gender, obesity, coexisting illnesses such as diabetes, hypertension, as well as the prolonged use of analgesics and anti-inflammatory medications [37]. Guidelines clearly state that osteoporosis treatment is necessary to prevent recurrence of hip fractures [38]. Vitamin D supplementation suppresses parathyroid hormone and increased bone mineral density. It also helps to prevent falls after hip fracture [39].

Bisphosphonates are key in preventing the loss of bone mass and help reduce vertebral and non-vertebral fractures [40]. Of all the bisphosphonates available, special attention should be given to zoledronic acid. A large randomized controlled trial showed that an annual infusion of zoledronic acid within 90 days after repair of a low-trauma hip fracture reduced the rate of clinical fractures and improved survival [41]. Hip protectors may reduce the risk of hip fractures, although compliance is low secondary to discomfort and practicality [42].

## Long-Term Cognitive Outcomes

Cognitive impairment is common in all older hospitalized patients and is multiplicated in patients suffering hip fractures, with incidence rates approaching 60% in this group [43]. Hip fracture patients who suffer from cognitive problems have increased hospital lengths of stay, higher risk of death, and poorer functional recovery. Risk factors for such cognitive impairment include preexisting dementia, coexisting comorbidities, inadequate pain control, effects of anesthesia, as well as sleep and sensory deprivation in the hospital. In elderly hip surgery patients without a preoperative diagnosis of cognitive impairment, patients who develop postoperative delirium have nearly double the risk of being subsequently diagnosed with dementia compared to at-risk patients who do not develop delirium.

Efforts should be made to prevent and treat delirium, especially since the risk of dementia in patients developing delirium is extremely high [44]. Screening for underlying delirium and cognitive impairment is vital, and well-validated tools such as CAM-ICU should be routinely used.

### Conclusions

Hip fractures are a common condition in the elderly and significantly contribute to increased mortality and morbidity in this population. Evidence-based medical care improves clinical outcomes, and systems should be in place to address the common perioperative complications, as well as facilitate early rehabilitation and nutritional support in these patients. Long-term consequences of hip fracture include cognitive impairment, fracture recurrence, and functional disability. A coordinated multidisciplinary team approach involving orthopedic surgeons, internists, geriatricians, nurses, physical and occupational therapists, nutritionists, dieticians, and social workers has been shown to decrease complications and improve outcomes in this population [43].

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# Quality and Safety

# 13

Nathan Kaplan and Stephen L. Kates

## Introduction

Fractures of the proximal femur in elderly patients represent a significant burden on society for a number of reasons. The worldwide population is aging at an increasing rate, and with age, the rate of fragility fractures, including fractures about the hip, increases in prevalence. The morbidity and mortality associated with hip fractures is derived from a number of different factors that affect the diagnosis, treatment, and overall care of patients who sustain these injuries. In order to optimize patient outcomes, minimize health-care costs, and decrease the burden of disease associated with these injuries, it is important to understand all of the various factors that play a role in shaping the natural history, pathophysiology, and treatment strategies. This chapter will summarize the recent literature and evidence-based recommendations pertaining to the overall care of patients who present to the hospital with a hip fracture or are at risk of sustaining a hip fracture, to assist any health-care provider involved in the management of these patients in providing the best care possible.

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## The Need to Improve Quality and Safety: Estimating the Burden of Disease

Hip fractures represent an increasingly prevalent problem in an aging population. These injuries carry a significant morbidity, high mortality rate, and high associated treatment cost [1, 2]. As the population continues to age, and as people live healthier lives into later decades, functional expectations will continue to increase.

The National Inpatient Sample comparison reports over the past 20 years have yielded consistent projections demonstrating that hip fracture prevalence (and thus treatment for hip fracture) is expected to continue to increase in the coming years [3]. Several projection models indicate that osteoporosis-related fractures (including hip fractures) are on the rise and are expected to continue to increase, almost doubling in some age groups around the world [4]. Historical estimates predict that the number of hip fractures in the United States may exceed 500,000 annually by 2040 [5]. While there is great variation in hip fracture incidence based on regional data from worldwide sampling of inpatient data, and hip


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fracture incidence in the United States appears to be decreasing, certain populations remain at risk [6]. These at-risk groups are most notably ages 60 and older, where fracture incidence exponentially increases [6]. Risk factors such as osteoporosis, frequent falls secondary to medical comorbidities, functional decompensation, and polypharmacy increase as people age. With a significant proportion of the population entering their sixth and seventh decades of life, it is important to recognize that as more and more fractures occur, orthopedic treatment is going to be in high demand unless risk factors can be minimized.

These injuries carry high associated rates of morbidity and mortality. Analysis of the NSQIP database indicates that surgical intervention for hip fracture carries a high risk of adverse events and that the type of procedure performed affects the complication profile that these patients are susceptible to [7]. Many patients lose functional independence after sustaining a hip fracture. As high as 50% of hip fracture patients have walking disability, and patients have more disability with transferring and grooming [8]. This can lead to an increased need for professional and costly long-term care. Medical comorbidities including chronic cardiac and pulmonary conditions can acutely worsen as a consequence of physiologic changes associated with a long bone fracture and prolonged bedrest. One-year mortality rates have been 22–29%. Even though in-hospital mortality rates have been decreasing since the late 1980s, increasing age and multiple comorbidities have been associated with higher mortality rates [9]. Mortality rates remain elevated above baseline for 5 years following the fracture event [10].

The prolonged inpatient hospital stays and increased medical and functional needs necessarily lead to high costs to the health-care system and society. The estimated lifetime attributable cost of a hip fracture is $81,300. The average hospital cost for discharges with primary hip replacement as treatment for a hip fracture has steadily increased from 2003 to 2010 and is projected to continue to increase in similar fashion as the Healthcare Cost and Utilization Project (HCUP). Fortunately, with better recognition and care models being implemented across the country, the average length of stay for discharges with primary hip replacement for hip fracture has remained stable at around 6.6 days and is projected to decrease [3]. Evidence has shown that there are ways to minimize these costs by changing the way we evaluate and treat patients with hip fractures through the use of efficient care models in large centers [11].

## Quality of Care: Reviewing the Historical Management of Patients with a Hip Fracture

In order to minimize the barriers to effective care for patients with hip fractures in current hospital systems and models, we must first evaluate the quality and standards of care in the recent past and present. In light of the increasing burden of disease, there is an increasing amount of data and evidence-based literature reviewing historical care of these patients and the need for newer, more comprehensive, and more streamlined care models. Before addressing the future of care models, it is important to understand areas for improvement in our current systems.

The traditional history of a patient who sustains a hip fracture consists of the following simplistic overview:

- The patient falls or has an episode of acute trauma that leads to inability to ambulate and pain.
- The patient is seen in the emergency department and diagnosed with a hip fracture.
- Admission to the hospital, either to an orthopedic or medical service, where the patient is optimized and "cleared" for surgery.
- The fracture is treated surgically.
- The patient is optimized for discharge on the hospital ward.
- Discharge is arranged, either home or to a subacute rehabilitation facility depending on functional limitations imposed by the treatment method, the injury itself, or medical comorbidities that limit the patient's ability to care for themselves.

Each step of this traditional care model carries its' own limitations and inefficiencies that can contribute to the overall morbidity of the patient.

## Emergency Department Evaluation

Oftentimes, there is a delay between the injury itself and presentation to the ED. A patient who lives alone can fall at home and may not be found for hours to days. This leads to the exacerbations of chronic medical conditions and development of new medical complications that can cause further harm, delay care once the patient reaches the hospital, and thus affect outcomes. They can develop rhabdomyolysis with subsequent kidney injury, decubitus ulcerations from lying in the same position for a prolonged period of time, dehydration, and fasting [2]. Medical comorbidities can acutely worsen secondary to bleeding, dehydration, and not taking critical medications. Mental status changes can develop that further limit compliance with necessary care.

Once the patient does gain access to emergency medical services, they often complain of groin or thigh pain, and due to the traumatic nature of the injury, they are transported to the ED using a backboard or stretcher in an ambulance. Upon arrival to the ED, the patient then enters the process of being triaged and, depending on medical comorbidities or the presence of concomitant injuries, can often spend a significant amount of time in the ED, where management can be insufficient and further delays to eventual definitive treatment occur.

ED overcrowding has become an issue across the country in this health-care system. In a busy hospital setting, the amount of time spent in the emergency department for a patient with a hip fracture can range from 4 1/2 h of working time or more, which is, on average, longer than that for other patients admitted through the ED [12]. Oftentimes, the busy ED environment can promote further confusion and delay in medical and surgical treatment as these patients are generally triaged into lower level of care categories in the absence of other injury and can be neglected in understaffed emergency settings. Furthermore, conflicts arising between potential admitting services, once the diagnosis of hip fracture is established, can further delay access to appropriate treatment.

To rectify this situation, patients with hip fracture must be seen and evaluated by a physician who can appropriately make the diagnosis with a problem-focused history and physical examination. A full medical and surgical history using patient medical records, information from family, and the patient's own recall must be performed in an effort to optimize any medical comorbidities. There is some evidence to support a comprehensive geriatric assessment when indicated, if it does not delay surgical treatment [13]. Any acute medical conditions that may have led to the injury or have developed as a result of the injury must be appropriately diagnosed and a treatment plan formulated. A social history is helpful in identifying and clarifying benefits to surgical intervention, postoperative functional expectations, and anticipating eventual discharge planning. Advance directives and goals of care must be identified and established early in this care process. Again, in the busy ED setting in most major medical centers throughout the United States, these steps are typically not addressed by ED physicians, and newer models of care have been developed to help facilitate this process.

## Admission to the Hospital and Preoperative Medical Assessment

Once the patient has been diagnosed with a fracture, the type of admission must be determined. All too frequently, this is a time when conflicts arise as to which service will be the admitting service, the medical or the orthopedic team. An established care model with well-defined admission criteria can help facilitate this step in the patient's care and can help minimize the amount of time the patient spends in the crowded ED.

Regardless of admission status, the patient must be "cleared" for surgery. In general, this refers to the preoperative medical assessment to optimize any unstable medical comorbidities to minimize the risk of intraoperative and postoperative complications. The challenge here becomes performing this task in a timely fashion. Again, this is a step where a preexisting care model may be beneficial in coordinating care among the necessary teams to safely prepare the patient for surgery. Interdisciplinary care models have been shown to achieve the best outcomes [14]. These care teams often consist of the orthopedic surgeon, the primary care physician, the geriatric or internal medicine team, and the anesthesiologists [14]. This approach has been shown to not only minimize the delay before surgery, but also to minimize cost with the use of fewer unnecessary tests preoperatively (Friedman quality management and protocol driven care) [11, 15, 16].

Preoperative medical concerns that must be addressed include mental status, standard laboratory tests and any abnormalities (including anemia or any coagulopathy), a preoperative cardiac evaluation, a pulmonary evaluation, and any chronic medications that must be held in the perioperative period. These issues will be discussed in more detail later in this chapter. Early involvement of the patient's family, guardians, or other health-care decisionmakers as well as the social work team not only helps coordinate a surgical plan but also helps by preparing effectively for the expected postoperative course.

Once the patient has been optimized for surgery, and the anesthesia team is comfortable with proceeding, the surgical team must be ready to operate. This is another stage where delay can occur, especially in the operating room where other emergent cases can take precedence over these patients, who are often categorized as less urgent cases. The current literature indicates that short-, mid-, and long-term outcomes are associated with timing of fracture repair [17]. Surgery within 24 h has been shown to affect postoperative pain scores, length of stay, mobility, and in-hospital mortality, though longer-term effects on mortality are unclear and reports are conflicted [5, 18–22]. Surgery should be performed expeditiously, and the best option for fixation should be chosen to allow the patient to bear weight postoperatively. Once surgery is performed, the patient should be transferred to the ward.

### Postoperative Care

After surgery, the focus of care shifts from timing to prevention. The goal of the postoperative period is to prevent complications and any long-term disability caused by the injury and need for surgical intervention. The main concerns to be addressed are postoperative pain control, infection prevention and wound care, thromboprophylaxis, nutrition, rehabilitation, and stabilization of any acute medical problems and maintenance of chronic medical comorbidities.

Patients typically stay in the hospital for a period of a few days to determine an analgesic regimen that can maximize the patient's ability to mobilize and participate in rehabilitation. It is during this period that a safe disposition plan is determined by the multidisciplinary care team, and the patient is discharged to a facility appropriate for the patient's level of care once they are medically safe to do so. The physical therapists and social work team collaborate to determine this level of care, and options for post-acute care often include discharge home (either alone or with a family member or guardian), acute rehabilitation, or a skilled nursing facility for subacute rehabilitation. It is during this period that with an effective care model and multidisciplinary team, the best outcomes for the patient can be achieved.

## Alternatives to the Traditional System: Other Care Models

The traditional model, with one service acting as a primary service and one as a consultant, is an efficient system only when all of the aforementioned processes function together. Without appropriate planning at large medical centers, this can be difficult to coordinate. New models of care have been developed by bringing together the multiple care teams involved in the hospitalization and treatment of geriatric fractures and planning how to most efficiently utilize resources and manpower to streamline the diagnosis, admission, and treatment course for patients who sustain these injuries [23].

### Closed Panel HMO

This care model was created in the early 1970s as a technique to reduce the cost of providing benefits and improving quality of care by contracting with a variety of health-care providers and organizations who have agreed to provide care in a cost-effective and more standardized form. Care is often coordinated by the patient's primary care provider (PCP) or a primary care team with involvement of specialists at the request, or consult, from the primary care team.

In this model, a patient with a hip fracture is admitted to the hospitalist service at a designated facility approved by the patient's HMO. After being diagnosed with a fracture, the hospitalist team would consult the orthopedic surgeon and would then focus on medical optimization prior to operative fixation. The patient would undergo surgery, and postoperative care would be primarily guided by the hospitalist. Transfer to an HMO-approved rehabilitation facility once medically safe is the typical discharge plan. Follow-up care is then dictated by the HMO.

Few studies have evaluated this model with specific regard to geriatric fracture care. One small study reported 1-year outcome improvements in functional recovery and improved ambulation comparing HMO patients and fee for service patients with hip fractures [24]. This care model is one example of a system that has been developed to standardize care not only for patients with geriatric fractures but for any patient admitted to the hospital within the organization, in an effort to minimize adverse events, minimize costs, and maximize outcomes.

### Comanaged Care

This model of care also uses a multidisciplinary approach to expedite care through standardization. Its focus is on rapid admission through the ED and quickly, but safely, optimizing the patient for surgery.

The patient is "fast tracked" through the ED with evaluation of medical stability. The patient is seen and admitted to the orthopedic surgery service with consultation by the geriatric, internal medicine, or hospitalist service for medical optimization. The aim is to obtain a complete preoperative medical evaluation and to stabilize the patient's active medical problems all while preparing for early surgical intervention (within 24 h). This allows for effective medical risk stratification to assist the anesthesiologist in providing safe anesthesia while minimizing unnecessary and time-consuming preoperative evaluation. Postoperatively, the patient's care is comanaged by the medical and surgical teams. This allows for efficient monitoring and management of any postoperative complications that may arise on the ward. Without complications, early discharge planning by the social work and physical therapy teams allows for an abbreviated postoperative hospital stay and early transfer to the appropriate facility that provides the level of care necessary for the patient to begin rehabilitation.

In general, it has been demonstrated that ortho-geriatric collaboration has been effective in improving mortality [25]. More recent evidence has demonstrated that the comanagement approach is effective in the improvement of some outcome measures, with improvements in length of stay, 30-day readmission, reoperation, and costs of care [16, 26, 27]. Other studies demonstrate that this model can decrease time to surgery and in-hospital mortality rates [15]. Improved management of medical comorbidities has been demonstrated, with lower rates of cardiac complications, thromboembolism, delirium, and infection [11]. While current evidence suggests that the comanaged care model is effective in improving quality of care of geriatric patients with hip fractures, more quality studies are needed to compare this model to other traditional systems.

Despite evidence supporting the use of an interdisciplinary, comanaged care model, there is resistance toward implementation [28]. It will require cooperation among various services involved in care, collegiality among the treating physicians, and efforts from administrators to restructure the inpatient units, change reimbursement models, and coordinate with physicians to further respond to changes and improve care of these patients [28].

## Implementing Change: The Roles Involved and Need for Cooperation

In implementing a new care model system, several roles, influences, and providers need to work together to change the traditional model. Every person involved in the care of the patient from the top of the chain of command to the bottom must work cohesively in their own positions to improve care. Some barriers to implementation include lack of leadership, costs associated with implementation, and competing interests [28]. Understanding the players involved and the roles they play can help facilitate a team approach to implementation and hopefully overcome some of these barriers.

### The Role of the Administrator

One of the most important roles when it comes to implementing change is that of the hospital administration [2]. This role is the key in balancing the two driving, and often opposing, forces in health care: costs and quality of care. This entails a knowledge of not only the economic factors involved in determining health-care costs, but the administrator must have an understanding of the basics of health-care quality including how to provide care to a growing number of patients with more complex medical needs in a comprehensive manner [2].

The influencing forces from an economic standpoint are changing in the United States. The Affordable Care Act is placing more pressure on hospitals to decrease costs. Payers responsible for reimbursement are also pushing to cut costs and will "shop" for the providers and hospitals that provide the highest value of care. The administrator must work to identify the factors that play into this value system and push for quality improvement measures that can assist in decreasing costs while minimizing impact on patient care.

The administrator works in his or her role in an important collaboration with the physicians, who deliver patient care. Through the physicians, who provide care and are constantly observing and coordinating the rest of the care team (nursing, therapists, etc.), the administrator works together to create and carry out a vision of practice, or a blueprint. The physician formulates the vision, and the administrator assists in the development of a business model that can implement and sustain any changes in the most cost-efficient way possible [2].

Lean principles, originally derived from the Toyota Production System, have been utilized more recently to implement improvements in health care and have been shown to be effective in both joint replacement and in the development of a hip fracture service [16, 29]. The administration can use these principles in collaboration with the physician to develop a plan that can be presented to hospital boards and more senior administration in order to provide a coherent and comprehensive plan that maximizes values important to all involved parties in a manner that everyone can understand.

### The Role of the Physician

The physician provides patient care while working to minimize adverse events and improve patient satisfaction. The physician interacts with nurses, therapists, social workers, nutritionists, and techs, to deliver high-quality patient care. The physician also understands the medical necessities that are crucial to providing adequate and complete care to the patient. Most importantly, by providing care every day, the physician is acutely aware of the practice inefficiencies that can be improved to provide this comprehensive care in the most cost-effective way. Lean business principles can help to identify the causes of medical errors, discharge delays, office wait times, waste in the operating room, and other care inefficiencies that lead to patient harm.

Once wasteful practices are identified, the care team then must problem solve the current practice and create the vision of practice that would ideally minimize waste [29]. The physician then presents the vision to the administration, who must work with the physician to present the plan to the hospital board in order to gain access to the resources necessary to implement the plan. Depending on the scope of practice being addressed, this often requires presentations to multiple levels of administration for approval.

Again, collaboration between the physician and an administrator is essential, as these presentations must be constructed in manner that an administrator can understand and agree with. This involves the use of a simple business plan, minimizing medical language and focusing on the problem-solving nature of the proposed restructuring [2].

Using evidence-based practice principles discussed later in this chapter, the physician must be able to provide the best care possible to the patient and maximize not only patient satisfaction but also patient clinical outcomes. In the setting of geriatric fractures, the physician must coordinate care to enable functional recovery all while avoiding adverse events in this at-risk population.

### The Role of the Nurse

Nurses provide much of the care to patients and serve as the direct line of communication between the patient and the physician. They provide direct patient care, carry out the orders, and address patient needs and facilitate these through communication with physicians. Older methods of communication, such as paging systems, are augmented through the use of the electronic medical record. Nurses coordinate interdisciplinary rounds that include physical therapists, social workers, mid-level practitioners, and occasionally physicians to identify needs of patients and ensure that they are being addressed appropriately. If not, then they take on the responsibility of communicating these needs to the mid-level provider or physician. Frequently, nurses are the primary communication point person involved in the care of the geriatric patient such as family, guardians, friends, health-care proxies, and other medical decisionmakers.

Nurses must be able to recognize the medical, social, and psychological needs of orthopedic geriatric patients. Oftentimes, providing comprehensive care for these older adult patients can be difficult; thus, it has been proposed that special nursing units be arranged where nurses are specifically trained to work with this patient population. They should be trained in specific competencies such as fall prevention, postoperative weight bearing, transfers, bed mobility, special equipment, as well as nutrition, bowel, bladder, pain management, skin care, and monitoring for mental status changes in addition to standard nursing care.

The American Nurses Association has created an online resource in the National Database of Nursing Quality Indicators (NDNQI), which serves as an online quality of service measurement by comparing quality data at a specific hospital against national, regional, and state [30]. NDNQI is a means of standardizing and optimizing nursing quality of care. There are also nursing educational resources found online, including the Nurses Improving Care for Healthsystem Elders (NICHE) program created by the New York University School of Nursing to provide avenues of learning online to further focus skills toward care of geriatric patients. In forming and remodeling the hospital care models and systems for geriatric fracture care, it is important to recognize these online resources as tools that can be used by nursing staff to improve care.

### The Role of the Therapist

Physical and occupational therapists are essential team members who work with the patient to maintain functional independence from the immediate postoperative period until completion of the process of rehabilitation. Communication between therapists and physicians through the use of the electronic record, interdisciplinary team, and direct interaction is of utmost importance. Special instructions such as weight-bearing status, timing of mobilization, and any precautions must be established in order to plan for discharge planning, outpatient rehabilitation, and expectations for future recovery and independence.

Therapy must be individualized to the patient, and geriatric patients are no exception to this rule. Each geriatric patient may respond differently to various cues and prompts based on medical comorbidities, mental status and cognition, and overall physical well-being and capacity. Therefore, a therapy team focused on the care of this patient population may better be able to understand the unique needs and the best approach to overcoming barriers to recovery for each patient. Therapists should include family in training and education as caregivers are integral in care for the geriatric fracture patient after discharge from the hospital. It is helpful to schedule therapy sessions at a time of day when caregivers may be available.

Just as the surgeon chooses the correct operation to provide stability for early mobility, the therapy team must be focused on getting patients out of bed immediately postoperatively. Physical and occupational therapists should evaluate patients as early as postoperative day 1. In the absence of the therapist, the patient can be transferred and mobilized early and frequently by their nurse and patient care technicians.

Once the functional needs of the individual patient have been established, the therapist plays the crucial role of supporting the discharge plan. Any special equipment such as assistive ambulatory devices, lifts, beds, commodes, or access ramps that the patient may require as an outpatient should be communicated to the nursing staff and social workers so that proper arrangements can be made to have these items available to the patient immediately upon discharge. If the therapist feels that the level of independence of the patient is not sufficient for a safe home discharge, then the social work team must be notified early in the hospital stay to seek an alternative discharge plan.

### The Role of the Mid-level Provider

Mid-level providers include physician assistants and nurse practitioners who provide care either directly with a physician or under the supervision of that physician (depending on the regulations set by the state in which care is provided). The mid-level acts to assist the physician by sharing the clinical duties including daily rounds, medical assessment, coordination of care, discharge planning, follow-up of tests, and the initial evaluation of patients when they present to the hospital.

In the setting of geriatric fracture care, the mid-level provider performs time-intensive tasks such as the history and physical exam, admission order entry, medical reconciliation, and communicating with family members and caregivers. This is a crucial role in the care of geriatric fracture patients as these patients are frequently admitted to orthopedic surgery teams with complex medical backgrounds. In many centers, the mid-level provider oversees the routine care for the patient and coordinates care between various services throughout the hospital stay. By training specifically in geriatric fracture care, the mid-level provider attends to the special needs of these patients.

## Care Factors: How to Medically Optimize the Patient for the Best Surgical Outcome

Fundamental to the overall care of the patient with a hip fracture is the management of medical comorbidities, risk factors, medications, and prevention of adverse events. There is a great deal of literature available to assist the surgeon and the medical practitioner in optimizing older adults for the best outcome.

## Preoperative Considerations

### Management of Anticoagulation and Coagulopathies

Preoperative medication reconciliation and comprehensive assessment must include an evaluation of patients using anticoagulants, as these must be appropriately managed perioperatively to minimize blood loss from the fracture itself, or from surgery, while also preventing exacerbation of comorbidities. This patient population carries a number of medical pathologies that carry a high correlation between age and prevalence. Medical diagnoses including atrial fibrillation, cerebrovascular events, coronary artery disease that has required intervention, and other chronic medical conditions often require management with one of many newer and older pharmacotherapeutic agents. In general, most surgeons and geriatricians feel as though the risk of bleeding and anemia outweigh the risks of continuing these agents as medical prophylaxis. Therefore, any treating physician must be aware of reversal characteristics and protocols for frequently used agents.

Management of patients on chronic warfarin therapy is unclear. Warfarin is a vitamin K antagonist that interferes with the synthesis of protein factors responsible for the clotting cascade, which can be reversed by synthetic vitamin K compounds or by replacing the clotting factors themselves by giving fresh-frozen plasma. A prothrombin time/INR level should be checked as a part of the standard admission laboratory profile for hip fracture patients, and most surgeons agree upon an INR of 1.5 as the threshold under which surgery may proceed. Warfarin reversal with both vitamin K and fresh-frozen plasma has been shown to be both safe and efficacious, with a reduction in time to surgical intervention over watchful waiting [31–33]. Thus, most physicians agree that reversal of warfarin should occur for patients with an elevated INR to minimize time to surgery [34].

The PROSPECT trial, a prospective cohort that evaluated using enoxaparin perioperatively instead of oral anticoagulants, demonstrated low bleeding risk and safety with use surrounding minor and major surgery [35]. Any patients at high risk of perioperative thrombotic event, such as patients with mechanical heart valves, atrial fibrillation with an elevated CHADS2 score, or patients with a recent thromboembolic event, who are on preoperative chronic anticoagulation, should be bridged with daily enoxaparin therapy perioperatively [36].

Newer agents including factor Xa inhibitors and direct thrombin inhibitors are not well studied in the specific setting of hip fracture patients; however, consensus seems to be in favor of stopping any anticoagulation therapy prior to major surgery including hip fracture surgery. There are general principles to consider when managing patients on these agents; they have a shorter half-life than warfarin, and the onset is within 2 h. Currently, for direct thrombin inhibitors such as argatroban and dabigatran, cessation for 48 h should be sufficient enough based on a half-life estimate of 14–17 h in patients with normal renal function. The same approach is recommended for factor Xa inhibitors rivaroxaban and apixaban [37]. For patients with impaired renal function, this holding period may need to be prolonged. There are no known current reversal therapies available for these agents.

## Cardiopulmonary Evaluation

Patients are at an inherent risk for cardiopulmonary events when undergoing orthopedic surgery. Preoperative cardiac evaluation is paramount to evaluate for any preventable or modifiable risk factures that can be controlled with medical intervention prior to surgery. However, evaluation must proceed with the understanding that preoperative medical testing must be minimized to prevent unnecessary delays. The American College of Cardiology (ACC) and American Heart Association (AHA) have created a task force to develop practice guidelines on evaluating and treating patients at risk for perioperative cardiac events [38].

Evaluation should begin with the comprehensive history and physical examination. Cardiac-specific history including any chronic conditions or recent testing should be explored. Unstable coronary disease, decompensated heart failure, or severe arrhythmia/valvular disease generally requires further evaluation and management prior to undergoing anesthesia or any operative procedures. Without recent outpatient cardiac evaluation, functional status (based on metabolic equivalents or METs) can be assessed (ACC/AHA guidelines) [38]. Patients who have poor functional capacity or are symptomatic should undergo a more detailed evaluation. In general, orthopedic procedures are typically considered moderate to high risk [38].

An ECG should be obtained and reviewed on all geriatric fracture patients. Any concerning features for unstable cardiac disease should be further evaluated with a cardiology consultation and testing such as an echocardiogram or a stress test. These tests should not be obtained routinely as they can lead to delays in surgical treatment for patients who may not require further evaluation [38].

Preoperative pulmonary evaluation consists of a chest X-ray to evaluate for acute cardiopulmonary processes which may lead to complications. Intervention for pulmonary conditions may be limited preoperatively, however. Any concern for infection should be addressed with appropriate antibiotic or antimicrobial therapy. Bronchodilators or steroids can be used in the setting of reactive airways, but adrenergic agents should be used with caution due to the effect on cardiac function.

Early involvement of medical and geriatric specialists will help expedite this evaluation and care and any further evaluation that may be warranted.

## Anemia and Transfusions

The preoperative laboratory profile obtained upon admission should also include a hemoglobin and hematocrit level, as hemoglobin level less than 12 has been demonstrated to be a risk factor for perioperative cardiac event. The Transfusion Trigger Trial for Functional Outcome in Cardiovascular Patients Undergoing Surgical Hip Fracture Repair (FOCUS) trial evaluated the optimal perioperative transfusion threshold for hip fracture patients who had preexisting cardiovascular disease or risk factors [39]. Comparing liberal and restrictive thresholds, this study revealed similar rates of in-hospital coronary syndrome and mortality, as well as composite endpoint of symptoms of anemia. The restrictive threshold in the study was a hemoglobin level below 8 g/dL or development of symptoms of chest pain, orthostatic hypotension, unresponsive tachycardia, or congestive heart failure [39]. A recent Cochrane review of similar studies demonstrated agreement of these results [40].

Clinicians must keep in mind that the hemoglobin level is variable preoperatively based on the patient's hydration status. Most patients with hip fracture present to the ED in a state of dehydration, and the hemoglobin level can be deceptively elevated in a state of hemoconcentration due to dehydration. Kumar et al. recommend rechecking a hemoglobin level in patients with an admission hemoglobin less than 12.0 g/dL immediately prior to surgery to evaluate the effect of fluid resuscitation on hemoglobin level and to minimize risk of cardiac events [41].

The hemoglobin level should then be monitored closely alongside clinical indicators of anemia such as physical exam and vital signs to minimize morbidity. The above recommendations apply to management of postoperative anemia.

## Beta-Blockers

The use of beta-blockers before surgery has been a controversial topic with varying outcomes and results reported in the literature. A systematic review to assess the role of perioperative beta-blockade was undertaken for the recent ACC/AHA guideline updates [38]. The conclusion of the review suggested that beta-blockade started within 1 day or less for noncardiac surgery helped prevent nonfatal MI but increased risk of cerebrovascular event, hypotension, and bradycardia [42]. The guidelines recommend that beta-blockers be continued in patients who have been on chronic beta-blockers and that the use of chronic beta-blockers should be guided by clinical circumstances regardless of when the agent was started. It is suggested that patients with intermediate- or high-risk myocardial ischemia or with three or more RCRI risk factors beginning a beta-blocker before surgery may be reasonable. Guidelines recommend against starting a beta-blocker on the day of surgery (ACC/AHA guidelines) [38]. The executive summary does note that the evidence is quite conflicting after systematic review and that better studies are needed to provide more confidence in the recommendations.

## Perioperative Hydration

Most patients who sustain a hip fracture present to the ED in some state of dehydration. Dehydration can be the underlying medical cause of the fall, or it can present as a secondary medical complication of a fall event leading to a prolonged time down on the ground before being found by family or EMS staff. Fluid resuscitation should begin immediately upon presentation and basic metabolic chemistry profile assessing serum electrolyte concentrations, serum creatinine, and blood urea nitrogen levels to quantify the hydration status. Fluids must be administered using clinical judgment as situations of under- and over resuscitation can lead to development of organ dysfunction. Current literature review demonstrates no benefit to colloid versus crystalloid administration [43]. Any abnormalities in fluid balance must be diagnosed during the initial preoperative evaluation and appropriate resuscitative efforts initiated to minimize development of complications in the postoperative period.

## Surgical Considerations

### Anesthesia

There are several options in providing anesthesia for hip fracture repair. Regional, spinal, epidural, and general anesthesias are all possible anesthetic plans. In general, the literature currently supports regional over general anesthesia with respect to outcomes in patients who have hip fractures [22]. Studies have demonstrated that spinal, epidural, and regional analgesia have led to decreased pulmonary complications, decreased incidence of deep vein thrombosis, and decreased intraoperative blood loss, postoperative delirium, and overall inpatient and early mortality in orthopedic procedures [44–46]. In addition to reducing these complications in geriatric hip fracture surgery, one review also reported a tendency toward fewer myocardial infarctions [47].

Despite outcomes suggesting that neuraxial anesthesia is safe, at least with respect to short-term outcomes, it is not without risks. Of particular concern in this patient population is the risk of bleeding and hematoma formation when undergoing spinal or epidural anesthesia. Geriatric patients are commonly on chronic anticoagulation therapy for various medical comorbidities, placing them at risk for this complication. Hematoma can be a devastating complication, often requiring urgent surgical decompression. Rarely, cases of cardiac arrest and other neurologic complications ranging from cauda equina syndrome to peripheral neuropathies have also been reported in the literature. Hypotension, bradycardia, and CNS events including stroke have been associated with spinal anesthesia [48, 49].

Regional anesthesia with peripheral nerve blockade can be considered for both preoperative and postoperative pain management. Regardless of surgical anesthetic choice, the use of single injection, continuous peripheral nerve blockade, or compartment block can help minimize opioid use and, thus, opioid-related side effects in the perioperative period [46, 50]. Studies evaluating the optimal type of peripheral blockade are generally of poor quality, but review of the literature demonstrated that a combination of obturator and lateral femoral cutaneous nerve blockade seemed to be the most effective in improving acute postoperative pain, and fascia iliaca blockade was the least associated with postoperative delirium [51]. Regional anesthesia can be beneficial in minimizing perioperative complications and should be considered in patients with hip fracture.

Given the lack of clear benefit with respect to one mode of anesthesia, each case must be approached individually and the anesthesia team must decide the most appropriate approach based on patient circumstances and comorbidities [52, 53].

## Blood and Fluid Management

Just as preoperative fluid status should be optimized prior to surgical intervention, appropriate intake and output must be balanced in the immediate postoperative period. The geriatrics/medicine consultant can help in maintaining adequate hydration surrounding surgery, but it is important for all members of the care team to be able to interpret general parameters that can indicate over or under hydration. In addition to daily lab work and a chemistry profile, intake/output should be monitored on the floor. A rate of 30–35 mL/h or 250 mL in 8 h should be the minimum goal, in the absence of diuretic use while patients recover and rehabilitate on the surgical ward [2]. Fluid maintenance and balance are crucial in maximizing functional recovery.

Preoperative and postoperative hemoglobin levels are associated with shorter lengths of stay, lower mortality, and lower readmission rates [41, 54]. As discussed earlier in the chapter, more restrictive and conservative transfusion indications have been favored in the literature [39, 40]. Maintaining perioperative hemoglobin levels above 8 g/dL is the current recommended cutoff for transfusion. The use of this threshold can minimize the risks of transfusion and overutilization of increasingly scarce blood product resources.

## Postoperative Considerations

### Pain Management

Pain management in this population can be very challenging, yet at the same time, it is crucial to adequately manage discomfort in the elderly as there has been a clear association between mismanagement of postoperative pain and outcomes. Longer lengths of stay, diminished mobility, and compliance with postoperative physical therapy can lead to deficits in functional recovery and an increase in complications [55]. Furthermore, management of pain in this population can be difficult secondary to cognitive impairment in the setting of underlying dementia. Older adults may be unable to effectively communicate the level of pain they are experiencing, and care providers are typically cautious about using narcotics and other sedating medications for fear of acutely worsening preexisting cognitive deficits. For these reasons, special consideration must be given to pain management in geriatric patients with hip fractures.

There are several options available for treatment of pain that can be used in patient-specific strategies, from admission to discharge. Opioid analgesia, delivered via oral or parenteral routes can be effective. With regard to the use of opioids in older adults, it is of particular concern to minimize development of postoperative delirium. In some studies, opioid analgesia given intravenously has been linked to an increased risk of developing delirium [56]. Other studies demonstrated that there is no difference in cognitive outcome comparing different opioid formulations, aside from meperidine, which has shown a definite association [13, 57]. This increased risk has been shown to be neutralized with the use of patient-controlled analgesia systems that allow for patient-specific delivery of intravenous and epidural opioids [58, 59]. Unfortunately, cognitive reserve and dementia can limit a patient's ability to manage IV PCA. In addition, due to underlying comorbidities, the use of opioids in this manner requires slow titration as patients are predisposed to respiratory depression. Pain must be adequately controlled, and studies have shown that judicious use of opioids and undertreatment/overtreatment of pain can lead to increased delirium [60]. Opioid use thus requires close monitoring to titrate to an effective level of analgesia and to allow for ongoing participation in rehabilitation programs.

In addition, regional peripheral nerve blockade and local compartment blocks, initiated preoperatively or intraoperatively, can help minimize opioid requirements and their side effects. Peripheral blocks have been shown to be effective for hip fractures, either as a one-time injection or catheter that can be maintained for continued usage on the ward [61, 62]. As discussed earlier in the chapter, one of the most effective uses of regional nerve block and compartment blocks is in initial fracture pain management, when provided upon admission to the ED [62].

As pain requirements decrease throughout recovery, and transition off of intravenous and regional analgesia is warranted, a multimodal approach to oral pain control should be used [22]. Again, in an effort to minimize opioid use, non-opioid analgesics should be given consideration to minimize requirements while optimizing pain control. The use of nonsteroidal anti-inflammatory medications and acetaminophen can augment the effects of opioids [63]. These medications carry side effect profiles of their own, and close monitoring is required, given the risks of polypharmacy in the geriatric population. The AGS Beers Criteria are a useful tool for identifying potentially hazardous medications and interactions to decrease adverse drug-related events when using a multimodal analgesic approach in the postoperative period [64].

In general, analgesia in the geriatric patient with hip fracture should be approached in a multimodal fashion, and each patient should be addressed individually based on his or her pain threshold and physiology. Appropriate treatment of fracture and surgical pain should begin immediately in the emergency department, and a plan for postoperative analgesia should be outlined and adjusted throughout the patient's recovery.

## Pressure Sore Prevention

Pressure sores can create significant setbacks in functional recovery for geriatric patients with hip fractures. From pain exacerbation to infection, the development of decubitus ulcers and skin breakdown predisposes patients to an extended hospital stay, further surgery, and possibly an increased risk of death. Screening with a head-to-toe skin examination upon admission to document any at-risk areas should be part of the admission physical examination. Prediction tools can assist in identifying these areas and assess risk based on sensation, activity, nutritional level, moisture, mobility, and other forces. The Norton and Braden scales are two such tools that can assess risk [2]. Frequent turns and repositioning while the patient is ordered on bedrest can alleviate pressure in these locations. Pressure-generating sources such as stockings, braces, tight clothing and gowns, and wet cloth should be avoided. Once fractures have been treated surgically, mobilization and ambulation should be strongly encouraged. Prevention of ulcer formation when risk is high is paramount because once an ulcer develops, treatment is difficult.

Treatment strategies for ulcers, once they develop, are varied and conflicting. The first thing that should be done is staging of the ulcer. The Braden scale, based on ulcer thickness and depth, has been used for this purpose. Once thickness is determined and the ulcer is staged, treatment, often multimodal, can be initiated. Frequent wound care, with a variety of different solutions, creams, lotions, ointments, and combinations of ingredients have been used historically to help augment wound healing. Literature is conflicting regarding surgical intervention for pressure sores [65]. There is questionable benefit from low-pressure contact surfaces and mattresses (source). Nutritional status plays a role in wound healing and thus should be optimized to allow for healing of decubiti. Optimizing nutritional status cannot only help prevent skin breakdown but can heal sores to a greater extent [66]. In many hospitals, a wound care team or service, consisting of nurses or members of the plastic surgery team, can assist in daily management of ulcers. Prevention is the most important intervention in regard to this complication of impaired mobility, and careful monitoring of patients with a high suspicion for development of ulcers in this at-risk complication can help prevent more devastating outcomes.

## Thromboprophylaxis

Thromboembolic events are a significant cause of morbidity and mortality in geriatric patients with hip fractures, as impaired mobility in the setting of long bone fracture creates a physiologic environment for thrombosis by the principles of Virchow's triad. Recent estimates indicate that symptomatic DVT would occur in 1.8% and PE in 1.0% in the first 7–14 days following hip surgery [67]. Guidelines and recommendations have reviewed the volume of literature about prophylaxis, yet there is disagreement on the best agent and approach.

Physical means of prophylaxis have demonstrated success in preventing DVT but come with the risks. Sequential compression devices decreased the incidence of DVT and PE but can cause problems with skin breakdown and compliance [68]. SCD tubing can tether patients to the bed, when mobility is an integral component of rehabilitation, and can exacerbate symptoms of delirium. Routine use of compression stockings is currently not recommended, if other means of anticoagulation can be given postoperatively. There is no evidence to support the use of stockings [69]. Early surgery and ambulation have demonstrated effectiveness in reducing thrombosis, in addition to other postoperative complications [70]. While these studies have shown inconsistent results and flawed methodologies in demonstrating definitive benefit to mechanical prophylaxis, there is enough evidence to show that sequential compression devices and early ambulation can serve as an important adjunct to pharmacological prophylaxis.

The 2012 guidelines from the American College of Chest Physicians for prevention of VTE in patients who are undergoing hip fracture surgery currently recommend pharmacologic DVT prophylaxis with one of the following: low molecular weight heparin, fondaparinux, low-dose unfractionated heparin, a vitamin K antagonist, aspirin, or intermittent pneumatic leg compression [67]. They currently support low molecular weight heparins as the preferred agent of pharmacologic prophylaxis. The AAOS clinical practice guidelines for hip fractures support these recommendations with a moderate recommendation of their own of the use of VTE prophylaxis in hip fracture patients [22].

Heparins have been used as an effective means of prophylaxis for years. Many studies have reproduced quality results, confirming reduction in incident of thrombotic events, [68, 70, 71]. Care providers should monitor for increased risk of bleeding events and hematoma while using these medications. Low molecular weight heparins can be given as a once-daily subcutaneous injection and are currently more costly than many of the available alternatives. Unfractionated heparin can be given as a twice-daily subcutaneous injection, is inexpensive, and can quickly be pharmacologically reversed in the setting of a bleeding event. Heparins also carry the risk of heparin-induced thrombocytopenia, and, therefore, patients should be followed with platelet counts while on prophylaxis. The success of these medications in preventing thrombosis is evidenced by their wide use not just in orthopedic surgery but in other hypercoagulable states for prevention.

The vitamin K antagonist warfarin is an inexpensive option for DVT prophylaxis; however, there are several concerns about its use in this population. First, is the slow onset of action and long half-life. While this makes it an easy medication to take, its patient-dependent metabolism requires frequent monitoring with expensive and inconvenient laboratory work (prothrombin time and INR) and dosing changes. For patients who are at high risk of thromboembolic event, bridging prophylaxis may need to be given, while warfarin dosing is titrated to a therapeutic INR level. Supra-therapeutic levels can predispose patients to bleeding events in a patient population that is prone to falls and injury. One benefit to warfarin is that it is easily reversed with oral or intravenous vitamin K, in the event of bleeding or need for further surgery.

Newer agents, factor Xa inhibitors and direct thrombin inhibitors, have shown promise in prevention of thrombosis in orthopedic surgery, but not necessarily in the specific setting of hip fracture. Fondaparinux, a subcutaneous injection, however, has demonstrated effectiveness after hip fracture surgery [72, 73]. Like low molecular weight heparins, these can be cumbersome for older patients to manage and are more expensive than other available agents. More recently developed oral agents, like rivaroxaban and apixaban, have demonstrated safety and effectiveness but are not currently approved in the United States for prophylaxis after lower extremity fractures [74]. Unfortunately, many of these agents are studied in the setting of arthroplasty, and further studies about the use in lower extremity fractures are needed. The oral route would be preferred in this patient population, and these medications do not require frequent lab work and monitoring like the other oral agent available, warfarin. Unfortunately, there are no currently available reversal agents for these drugs.

Aspirin is a less effective prophylactic agent in the setting of hip fracture. It has demonstrated similar or higher incidence of thrombosis as placebo and as the above-discussed drugs, without evidence of reduction in bleeding complications [75–77]. It is not currently recommended as a sole agent for DVT prophylaxis but may be used in conjunction to other methods.

As a rule, DVT prophylaxis should be used in any patient with lower extremity fracture, unless a major contraindication exists. The devastating complications of thrombosis, or subsequent embolism, should be minimized using mechanical and/or pharmacologic means.

## Nutrition

Adequate nutrition is an important component of healing and recovering from a hip fracture but also in the general health and well-being of the geriatric patient. Outcomes following hip fracture in poorly nourished patients are improved with the addition of supplements in the postoperative period, and results, in general, are poor in patients who are malnourished and sustain this type of injury (Bonjour, Pioli). Malnutrition has been demonstrated to be a risk factor for hip fracture, and therefore, many patients present to the hospital in a malnourished state [78, 79]. A Cochrane review of nutritional supplementation in patients with hip fracture revealed that evidence is poor, but there is some support for protein and energy supplementation [80].

Screening for malnutrition as part of the initial workup does not as reliably identify at-risk patients as a comprehensive nutritional assessment [81]. Serum levels of electrolytes and albumin can hint toward an underlying malnourishment and should be obtained as part of the initial laboratory evaluation of geriatric patients. Optimizing nutrition with an early comprehensive nutritional evaluation and consultation with a nutritionist as part of the multidisciplinary care team can improve outcomes.

## Rehabilitation and Weight Bearing

The focus of treating geriatric hip fractures should be on functional recovery. In order to minimize adverse outcomes from these injuries, emphasis should be placed on early surgery and mobility from admission as many of these patients, up to 50%, do not return to preinjury ambulatory status [82]. The surgical treatment should allow the patient to bear weight immediately after surgery and allow for ambulation. Immediate weight bearing after fixation of intertrochanteric and femoral neck fractures has been shown to be safe with low rates of revision due to loss of fixation or nonunion (Koval) [83]. Early weight bearing not only reduces the incidence of medical complications from surgery but also leads to improvement in functional performance in the long term and improves survival [20, 84, 85]. Patients should be seen on postoperative day 1 by the inpatient physical therapy team on the ward to begin rehabilitation and anticipate discharge needs.

The factor that primarily limits patients during rehabilitation is cognitive function, and therapy should specifically target patients based on cognitive status [86–88]. Other factors which contribute to recovery from hip fracture include age, medical comorbidities, hip pain, poor self-rated health, and previous employment in a prestigious occupation [86]. Oftentimes, patients limit themselves due to fear of falling, and this can lead to diminished gains during intensive rehabilitation [89]. These factors must be considered when planning each patient's rehabilitation course.

Reductions in post-injury disability and physical performance have been shown to be lowest in long-term, extended physical therapy programs [90]. While many elderly, frail hip fracture patients require more skilled therapy and nursing care at discharge, patients who are discharged home tend to have improved outcomes with regard to independence, ability to perform activities of daily living, and even have improved mortality [91]. Unfortunately, these patients also require more help and assistance at home, which can place increased burden on relatives, friends, and/or neighbors. Patients who are able to return home should still participate in an intensive rehabilitation program. Even patients with mild or moderate dementia demonstrated improved functional recovery when discharged home, as long as intensive rehabilitation continued with home physical therapy [92]. Interestingly, outcomes were not improved by a multicomponent rehabilitation program as compared to the usual home physical therapy program [93]. An inpatient multidisciplinary care team can expedite the process of functional recovery by allowing physical therapists, occupational therapists, social workers, and physicians to determine the safest and most effective long-term rehabilitation plan and effectively implement the early stages of ambulation and strengthening while coordinating the most appropriate discharge plan.

## Delirium

Delirium is a common complication of surgery in the elderly. There have been many factors that contribute to the development of delirium, both preoperatively and postoperatively. In addition, the development of delirium can lead to worsened outcomes not only from a surgical perspective, but it may hint at an underlying medical problem such as electrolyte abnormalities, illness, or adverse medication side effect. Delirium can prolong hospital stays and lead to increased costs. Care providers must understand the causes of delirium and be able to recognize delirium when it develops to manage it appropriately.

Postoperative delirium has been defined as an acute change in cognitive status characterized by fluctuating consciousness and inattention occurring within 30 days of an operation [94]. Preoperative factors associated with the development of delirium include older age (greater than 70), preexisting cognitive impairment, preoperative functional limitations, a history of prior delirium, and preoperative use of alcohol and/or narcotic analgesics [95, 96]. Intraoperative factors such as greater intraoperative blood loss, more postoperative blood transfusions and low postoperative hematocrit were all associated with an increased risk of delirium. Route of anesthesia and intraoperative hemodynamic complications have not been associated with delirium [13, 97, 98]. Postoperative factors that contribute to alterations in cognition after hip surgery include pain management, use of anticholinergic medications, blood and fluid abnormalities, and occult infection or other underlying medical comorbidities and complications [2]. A review of the literature concerning postoperative delirium after hip fracture by Bitsch et al. identified no "strong" risk factors for development of delirium; however, some evidence did suggest that postoperative delirium was linked to several preoperative conditions and perioperative factors (Table 13.1) [97]. The National Institute for Health and Care Excellence (NICE) has published risk stratification models that can be useful in identifying patients at risk for developing delirium perioperatively [99].

Prevention of delirium should be a goal of care beginning with presentation to the ED. Delirium has been shown to not only be associated with poorer functional recovery and outcomes but also with a significantly incremental increase in in-hospital length of stay and episode-of-care costs [100]. Cost increase was reported as high as $8000 in one study [101]. One intervention that has shown to decrease the incidence of delirium has been early geriatrics consultation. This fits with the effectiveness of the geriatric comanagement model and has been shown to reduce the incidence of delirium by over one third [13]. Nonpharmacologic interventions such as multidisciplinary interventions, music therapy, bright light therapy, and educational interventions have been shown to prevent delirium but not treat delirium once it has developed [102]. Medication and order surveillance helps identify any psychotropic medications that can contribute to altered cognition. The Beers Criteria are a useful tool in identifying potentially inappropriate medications. Frequent observation and evaluation should be performed for patients who are identified as "at risk," and the entire multidisciplinary care team from nursing to physicians should have a high suspicion for this in these particularly susceptible patients.

When treating delirium, the underlying cause for the development of delirium should be sought and managed accordingly. The American Geriatrics Society has published a clinical practice guideline on the management of postoperative delirium in older adults [103]. The recommendations focus on primary prevention but also discuss potential pharmacologic interventions [103]. Antipsychotics may be used at the lowest possible effective dose and for the shortest possible duration in patients who are severely delirious or combative. Benzodiazepines should not be used except when specifically indicated, as in the treatment of acute alcohol withdrawal. Pharmacologic inter-

**Table 13.1** Risk factors for postoperative delirium

| Risk factor | Preventative measures |
|---|---|
| Age greater than 65 years | |
| Preoperative cognitive impairment | Screening with MMSE (helps assess risk) |
| Severe illness or comorbidity | Geriatric medicine comanagement/consultation, preoperative geriatric medical assessment, appropriate management of underlying comorbidities |
| Hearing or vision impairment | Improve access to assistive devices, optimize environment |
| Current hip fracture | |
| Presence of infection | Preoperative lab work, screening for UTI, preoperative chest X-ray; treat accordingly |
| Inadequately controlled pain | Pain scales, frequent monitoring, and assessment; multimodal anesthesia regimen |
| Depression | |
| Alcohol use | Full preoperative history (social history); CIWA protocol, if at risk |
| Sleep deprivation or disturbance | Minimize overnight disturbances (evening lab work), optimize environment, melatonin |
| Renal insufficiency | Preoperative geriatric medical assessment, adequate fluid resuscitation, avoidance of nephrotoxic medications |
| Anemia | Preoperative lab work, strictly defined transfusion requirements |
| Hypoxia or hypercarbia | |
| Poor nutrition | Comprehensive nutritional evaluation, nutrition supplementation |
| Dehydration | Awareness, fluid resuscitation on admission |
| Electrolyte abnormalities | Preoperative lab work, geriatric medical comanagement |
| Poor functional status | Early mobilization, interdisciplinary care with physical and occupational therapy |
| Immobilization or limited mobility | Early mobilization, interdisciplinary care with physical and occupational therapy |
| Polypharmacy and use of psychotropic medications | Complete medication reconciliation, identification of risky medications (Beers criteria); comprehensive medical evaluation |
| Risk of urinary retention or constipation | Prophylactic bowel regimen, early ambulation, voiding trials and outlined approach to urinary retention |
| Presence of urinary catheter | Use of catheters in fracture treatment protocol? Early discontinuation of catheter use, voiding trials and treatment protocol |
| Aortic procedures | |

vention should be limited to the acute setting and for short durations, with the focus of treatment aimed at identifying and treating the underlying cause of altered cognition [103].

## Standardized Order Sets and Nursing Care

The importance of standardizing certain aspects of care for geriatric fracture patients is evidenced in the success seen in the geriatric fracture center care model [16]. In this model, as one of five principles of care, standardized elements reduce the incidence of postoperative delirium, by avoiding medications that have been shown to induce alterations in mental status, providing a standardized pain regimen, and by having nursing care specifically trained in monitoring older patients who are at risk for developing delirium [15]. In addition, standardized orders can lead to a lower perioperative risk of infection by decreasing dependence on Foley catheter use and screening for UTI with urinalysis on admission [11, 104]. Examples of standardized order sets used in this model address DVT prophylaxis, pain control and assessment, use of beta-blockers, weight-bearing status, perioperative antibiotics and catheter use, and therapy and rehabilitation (Table 13.2) [15]. As discussed earlier in the chapter, specific training and support in caring for geriatric patients and in standardized perioperative assessment protocols is available

**Table 13.2** Order sets

| Orders | Rationale for use | Benefit to patient |
|---|---|---|
| Weight bearing | Notify the multidisciplinary team of expected weight-bearing status for rehabilitation purposes. Again, weight bearing as tolerated should be enforced whenever able | Minimize perioperative complications |
| Positioning—reposition every 2 h | Pressure ulcer prevention | |
| Diet—geriatric, NPO except for medications (preop) | Important to clarify in orders that even while NPO, patients should be receiving important medications including beta-blockers and other cardioactive medications | Prevent exacerbation of chronic medical comorbidities |
| Catheter—discontinue on postoperative day 1 | Discontinue catheter use as soon as possible postoperatively to minimize risk of catheter-associated UTI | Minimize risk of catheter-associated UTI |
| Obtain prior medical records | Many patients come from nursing homes or outside facilities, obtaining a copy of previous records helps facilitate identification of past medical history, medical decisionmakers, and medication lists | Comprehensive medical evaluation and medication reconciliation |
| Avoid hypnotics and antihistamines | Minimize exposure to risk factors for developing delirium | Minimize risk of delirium |
| Aspiration precautions, elevate the head of bed | Minimize risk factors for aspiration, a concern in patients with altered cognition | |
| Consults—geriatrics, social work | Ensure early involvement of the geriatrics team. Involve social work early to facilitate discharge planning | |
| Urinalysis | Screening for UTI controversial but performed regularly at our institution | |
| Labs—CBC, BMP, PT/INR, vitamin D2 and D3, PTH, TSH, albumin | Standard preoperative laboratory work, with addition of lab work to quantify/qualify any degree of underlying metabolic bone disease | |
| Imaging—chest X-ray, EKG | Evaluate for acute cardiopulmonary medical instability | |
| Analgesia—Tylenol, oxycodone, morphine | Treat pain effectively while minimizing use of medications associated with delirium | |
| Antipsychotic PRN (haloperidol, atypicals) | For judicious use to manage patients who are acutely delirious | |
| DVT prophylaxis—Lovenox | Indicated for all patients suffering long bone, lower extremity fractures; can be given if greater than 12 h prior to planned surgery | |
| Insulin sliding scale | Perioperative management of diabetes. Tight control minimizes risk of wound complications | |

and can improve outcomes by minimizing the development of delirium.

## Discharge Issues and Follow-up Care

Another principle of focus in the geriatric fracture center model that has shown success is early discharge from the acute inpatient phase of care. A shorter length of stay has been associated with improved outcomes [21, 105, 106]. Therefore, emphasis is placed on discharge planning immediately upon admission for hip fracture. Throughout the postoperative inpatient period, the social workers, discharge coordinators, and physical therapists determine the optimal discharge plan based on recovery and strength after surgery.

Limitations and setbacks in discharge planning occur with insurance providers must be anticipated by the multidisciplinary care team. Currently in the United States, qualification for post-acute rehabilitation care depends on the patient's level of functioning and diagnosis. For a patient to be transferred to skilled nursing facility, a medically necessary minimum 3-day stay must occur, including three midnights in the hospital. The services provided must be appropriate for the patient's diagnosis, and the patient must be able to participate in 1–3 h of therapy per day. Acute rehabilitation facility requirements do not require a 3-day hospital stay, but coverage is only approved for a select few diagnoses [107]. Other private insurance providers may have their own stringent requirements.

Once the patient is discharged, appropriate follow-up must be arranged with the surgeon and the patient's primary care provider. More frequent follow-up visits may be necessary based on any inpatient exacerbations in chronic medical conditions or if any setbacks or delays in rehabilitation occur with fracture healing. Patients should be followed throughout the entire healing and rehabilitation phase until a point of maximal recovery is reached.

## Osteoporosis

A specific emphasis must be placed on the diagnosis and treatment of osteoporosis as an underlying risk factor for fragility fractures in general. While less important in the acute inpatient care of patients with hip fracture, once a patient sustains a fragility fracture, the risk of future fragility fracture is increased both immediately postoperatively and in the long term. Any non-hip fracture predicts subsequent hip fractures [108]. Despite this data, diagnosis and initiation of treatment of osteoporosis after a fragility fracture remains low, with a small proportion of these patients receiving an appropriate evaluation for osteoporosis [109].

All patients with a fragility fracture should be assessed for osteoporosis, if not already undergoing treatment. Laboratory work to assess for secondary causes can be completed during the inpatient hospital stay, includes serum calcium, estimated GFR, 25-hydroxy vitamin D levels, intact PTH, TSH, and testosterone levels for men. In patients with known renal disease, a 1,25-dihydroxy vitamin D level should be added. Markers of bone turnover, such as bone-specific alkaline phosphatase, urine *N*-telopeptide, and serum C-telopeptide, can be useful when considering treatment options; however, these markers can be elevated in the acute period following fracture as healing occurs [2].

In patients who are not presenting with fracture, when risk for fracture is of concern, the National Osteoporosis Foundation suggests women age 65 and older and men age 70 and older or women and men age 50 or older with risk factors for osteoporosis should have a bone mineral density test (DEXA) and an assessment for fracture risk by a provider trained in treatment of osteoporosis and fragility fractures [110].

Prevention and treatment of osteoporosis involve supplementation of vitamin D and calcium. Current recommendations vary widely in the literature for patients with osteoporosis or with significant risk factors. A more conservative recommendation of 800–1200 IU of vitamin D supplementation in addition to dietary intake is appropriate [110]. More aggressive recommendations are upward of 2000 IU of supplementation daily [111]. Levels of supplementation should vary based on dietary intake and sunlight exposure, with attention to regional variations in daylight and season. The recommended discharge regimen for patients after fracture is 2000 IU of vitamin D3 daily and 50,000 IU of vitamin D2 weekly, with dosing based on the patients serum vitamin D levels [2]. Calcium supplementation should be initiated at 500 mg daily, or upward of 1200 mg daily if dietary intake is poor or malabsorption problems coexist, and intake from all sources should not exceed 1500 mg/day. Medications used for the treatment of osteoporosis are aimed at maintaining bone mass and limiting bone loss. Bisphosphonates (alendronate, risedronate, zoledronic acid), estrogen replacement therapy and selective estrogen receptor modulators (raloxifene), and RANK ligand inhibitors (denosumab) have all shown effectiveness in minimizing bone loss in diagnosed osteoporotic patients at risk for fracture. Teriparatide is a synthetic form of PTH that is available and is the only currently available anabolic agent [2]. Pharmacologic therapy should be initiated in all patients once the diagnosis of osteoporosis is made.

Osteoporosis prevention programs around the United States have shown effectiveness in increasing awareness and education about osteoporosis and fragility fractures [2]. Such programs coordinate diagnosis, treatment, and education about the disease among patients, orthopedic surgeons, and other care providers who are involved in the management of community osteoporosis. Current models in the United States are Kaiser Permanente's Healthy Bones program and the AOA's "Own the Bone" online [2, 112, 113]. These programs can be difficult to implement from an administrative standpoint, but the benefits have been demonstrated, and efforts should be made by all providers involved to work with hospital administration to develop a comprehensive care model for patients with osteoporosis.

## Fall Awareness: Preventative Measures

Falls are one of the leading causes of fragility fractures. Fall prevention strategies are integral aspects of care in the prevention of fragility fractures and should be considered in the comprehensive management of patients at risk for fracture. The geriatric population is at particular risk as the incidence of falls is known to increase with age [114]. More than 90% of hip fractures occur as a result of falls [115]. Thus, the importance of fall prevention education in this population is clear.

Prevention begins with a risk assessment. Review of the literature has demonstrated both modifiable and non-modifiable risk factors for falls in elderly patients (Table 13.3) [116–118]. Focus should be on modifiable risk factors such as visual impairment, gait impairment, depression, orthostatic hypotension, pain, and urinary troubles in an effort to eliminate these risk factors in patients. A thorough history and physical can elicit these risk factors as well as other predisposing factors such as chronic medical conditions and polypharmacy. Diagnostic laboratory work and special tests including ECG, or even head CT or brain MRI can be helpful to evaluate any medical conditions and neurologic abnormalities identified on exam leading to gait and balance concerns, particularly in the setting of loss of consciousness [2]. Interventions include physical therapy to improve strength and balance and risk factor modification. For reference, the AGS, BGS, and AAOS formed a panel to form a guideline for the prevention of falls in the elderly that can be used in formulating new protocols [119]. Given the prevalent evidence in

**Table 13.3** Falls risk factors

| |
|---|
| *Socioeconomic risk factors* |
| Advanced age |
| Female sex |
| Living alone |
| History of prior falls |
| Physical limitation |
| Physical disability |
| Instrumental disability |
| Lower BMI |
| Low education level |
| Prior use of walking aid |
| *Medical and psychological risk factors* |
| Cognitive impairment |
| Depression |
| History of cerebrovascular accident |
| Urinary incontinence |
| Rheumatic disease |
| History of dizziness and vertigo |
| Hypotension |
| Diabetes |
| Comorbidities |
| Poor self-perceived health status |
| Pain |
| Fear of falling |
| Parkinson's disease |
| *Medication risk factors* |
| Increased number of medications |
| Use of sedatives |
| Use of antihypertensives |
| Use of antiepileptics |
| *Mobility and Sensory risk factors* |
| Gait problems |
| Vision impairment |
| Hearing impairment |

support of fall prevention strategies, evaluation and education should be part of the treatment strategy for every patient who sustains a hip fracture [120, 121].

## Infection Prevention (Preoperative and Intraoperative Factors)

An infection can be a devastating complication of hip fracture surgery. Perioperative infections can range from catheter-associated urinary tract infections to a prosthetic joint infection. As such, infection prevention should be a priority at every stage of the treatment process. Every member of the team must consider infection prevention strategies when taking care of geriatric fracture patients.

Certain risk factors for developing a perioperative infection can be considered modifiable; however, providers must be able to identify patients who are predisposed based on medical comorbidities or preexisting infectious processes. Preoperatively, patients must be assessed and evaluated for existing sites of infection such as underlying urinary tract infection, pneumonia, GI infections, or dental infections, which can all serve to seed implants via a hematogenous route. Again, as part of a full medical history, a medication list and full social history should be elicited.

Chronic medical conditions can be considered modifiable risk factors in most settings, as oftentimes interventions are available to optimize patients for the operating room. Hyperglycemia is a modifiable risk factor for surgical site infection. A history of diabetes should be elicited during the initial workup, and close perioperative glycemic control can help prevent the development of infection [122, 123]. Nutritional status should be evaluated on admission, as discussed earlier in the chapter, with serum albumin levels and a discussion with patients and caregivers about home nutrition. Optimizing nutrition can improve wound healing rates and help to minimize wound breakdown as a predisposition to surgical site infection as severe protein-calorie malnutrition has been associated with infections [124–126]. Morbid obesity has been identified as an independent risk factor. Exposure to, and colonization by, methicillin-resistant *Staphylococcus aureus* (MRSA) increases susceptibility of patients to a potentially more serious infection [125]. MRSA infections have led to prolonged hospitalizations (with higher costs) and higher mortality rates [127]. MRSA colonization is a risk factor for surgical site infection and identification of carriers can allow for treatment with mupirocin nasal ointment to effectively reduce the rate of infection [128–133]. Smoking cessation should be encouraged for all patients as there is clear evidence demonstrating delayed or incomplete wound and/or bone healing [124, 125]. Any preexisting skin conditions including breakdown, trauma, rashes, or lesions serve as potential sources of inoculation of soft tissues [124, 125].

Certain medications can predispose patients to infection. Evidence regarding steroid use, and other immunosuppressive agents, has shown some association with SSI risk, but study results have been inconsistent [125, 126, 130]. Disease-modifying antirheumatic drugs (DMARDs) now frequently used for treatment of rheumatoid arthritis and other autoimmune disorders due to their success have also been linked to delayed wound healing and SSI [125]. If it can be tolerated, most surgeons discontinue these medications prior to any major surgery, especially when orthopedic implants are to be used [125, 134]. The risks and benefits of holding these medications should be considered and discussed with patients prior to orthopedic fracture surgery.

Given the potential impact on surgical outcomes, modifiable risk factors for surgical site infection should be elicited in the thorough admission history and physical. Risk factors which can be minimized in an efficient manner should be addressed, but only if this does not lead to an unnecessary delay in surgical intervention.

## Intraoperative

Several variables in operating room preparation and patient care have been evaluated for their roles in the pathogenesis of SSI. Once surgical intervention is planned, the appropriate evidence-based steps must be taken to minimize risk of developing an infection.

Prior to bringing the patient to the operating room, the appropriate antibiotics must be selected and given. Most patients undergoing orthopedic surgery will receive adequate prophylaxis with a first-generation cephalosporin (cefazolin) or vancomycin if patients have a penicillin allergy or other documented adverse reaction to penicillins and/or sulfa drugs (Classen, Pavel Prokuski, Hill, Burnett) [135–138]. Antibiotics should be continued for less than 24 h postoperatively but have not shown increased benefit when given for a longer duration [139]. Antibiotics should be redosed intraoperatively if surgery lasts longer than 3–4 h [2]. Hair removal has shown no benefit in infection prevention, and the studies available for review are of poor quality [140].

Factors believed to contribute to infection inside the operating room can be difficult to control for, at times, and studying these factors is oftentimes unethical. Infection prevention in the operating room begins from the second the patient is brought back to the operating room with standard precautions including handwashing between patients and use of gloves. One frequent source of infectious organisms is the patient's own skin flora. Prevention with adequate skin prep has been studied. A pre-scrub is helpful to mechanically remove bacteria from the skin, as well as to debride any sloughing skin or debris. With regard to formal skin prep, some studies support the use of 2% chlorhexidine gluconate and alcohol solutions as compared to povidone-iodine or alcohol, whereas others show no difference in infection rates [124, 141–143]. In one meta-analysis, chlorhexidine preparation was associated with significantly fewer SSIs and fewer positive skin culture results, and switching to chlorhexidine even led to a cost savings of approximately $400,000/year [144]. Another study showed that ChloraPrep (chlorhexidine and alcohol) was most effective for eliminating bacteria preoperatively in foot and ankle surgery [145]. Available hand antiseptic agents for surgical team scrubbing include alcohol rubs with or without additives, chlorhexidine gluconate, iodine/iodophors, and phenol compounds. Results of studies comparing various agents are variable based on the study, but a recent Cochrane review demonstrated no difference in infection rates but did show a decreased bacterial load on hands with CHG [146]. Other practices such as irrigation with antibiotics or other additives, irrigating with high-pressure systems, using special iodine-impregnated drapes may or may not decrease bacterial burden and reduce infection rates [2].

Meticulous surgical technique should be emphasized and clearly shows benefit in diminishing bacterial load in surgical wounds. Maintaining hemostasis, preventing hypothermia, gentle handling of tissues, removing devitalized tissues, and appropriately using drains and other foreign bodies are all techniques that should occur. Considering the association of surgical time with development of surgical site infection, surgical skill and experience plays a role in decreasing surgical times [147]. While vancomycin powder has demonstrated some effectiveness in the spine surgery literature, there is no clear benefit in orthopedic surgical wounds otherwise [148]. At the conclusion of surgery, a sterile dressing must be applied to incisions prior to removal of sterile drapes.

Environmental and equipment factors can also contribute to infection rates. Proper cleaning of operating room surfaces, gowning and gloving with sterile supplies, and careful sterile draping technique should be routined in all cases [140]. Operating room traffic is a factor that has been clearly associated with increased infection rates in the literature and therefore should be kept to a minimum [140, 149–151]. In orthopedic surgery, double gloving is recommended. All members of the surgical team should be aware of appropriate antiseptic techniques and should be aware of activity in the operating room to minimize missed contamination events. Instruments should all be sterilized with a full cycle of sterilization in the sterile processing department, and flash sterilization should be avoided [124, 152].

### Postoperative

As discussed earlier, less than 24 h of perioperative prophylactic antibiotics is considered standard in most major orthopedic surgical procedures, based on available literature demonstrating clear benefit with reduction in postoperative surgical site infection. Careful wound management at follow-up should be encouraged to monitor for any early signs of infection or breakdown. Soft tissues should be monitored for development of hematoma, especially in patients who are on anticoagulation for any reason. Sterile dressings should remain in place for a few days postoperatively to allow bridging tissue to form as a barrier to infection and any wound examinations or dressing changes should be preceded by handwashing and glove use. Prolonged soaking in water should be avoided for a few weeks after surgery. Sutures and staples should be removed only after the incision has healed fully, to prevent dehiscence.

Some studies have associated postoperative blood transfusion with increased rates of SSI [153, 154]. Glycemic control should be emphasized postoperatively with close monitoring of fingerstick blood glucose levels and appropriate treatment. Physical therapy and balance training should be initiated early to minimize risks of falls [2].

In addition to surgical site infection, other infectious processes that geriatric patients are susceptible to in the postoperative period should be avoided as best as possible. With prolonged bedrest and respiratory splinting secondary to surgical and fracture pain, patients are susceptible to pneumonia. Any atypical postoperative fevers in combination with respiratory symptoms such as productive cough and dyspnea should be evaluated with a chest X-ray and cultures as indicated. Incentive spirometry should be encouraged to minimized development of atelectasis. Perioperative Foley catheter use should be discontinued as soon as possible to minimize risk of urinary tract infection. In patients who require antibiotics for longer than the typical 24 h duration, antibiotic associated colitis and *Clostridium difficile* infections are of particular concern. The development of any type of infection in the postoperative period can be a devastating complication that can severely impact the outcome of surgical intervention and patient recovery.

## Measuring Outcomes: How Do We Define and Quantify Improvement?

### How Do We Evaluate Patient Outcomes in Geriatric Fracture Surgery?

In an ongoing effort to improve functional outcomes and decrease costs associated with hip fractures in the growing elderly population, physicians and researchers need to critically assess the current available evidence and studies on quality improvement. The literature needs to evaluate outcome measures that accurately reflect true patient results in order for the data to be useful in shaping improvement strategies. While clinicians focus on improving patient outcomes, hospital administration uses patient outcome data to screen for inefficiencies that can be improved with process adjustments. This, in turn, leads to cost savings, through value analysis. In this respect, clinicians tend to define health measures in line with the International Classification of Functioning, Disability and Health and health-related quality of life definitions. Administrators, from a business perspective, focus more on the cost-to-benefit analyses related to health-care and patient outcomes, as the result of the health-economic pressures of an aging population. Therefore, improving the outcomes we measure in collecting data with regard to geriatric hip fractures can lead to better quality research and improved quality of care.

Most of the research available for review currently evaluates patient outcomes with two types of measures: performance-based measures and subjective patient self-reported measures. The properties that characterize effective outcome measures are reliability, validity, sensitivity to change, and responsiveness [155]. Latham et al. have shown that both types demonstrate validity and sensitivity when improvement in function is a primary endpoint [156]. Therefore, in addition to complication rates and mortality, the measures discussed above can be useful in analyzing patient data, and subjective patient results can be used in outcomes analysis.

In evaluating the usefulness of quality improvement interventions, such as the institution of a geriatric fracture center care model, appropriate outcomes must be used to identify strengths and weaknesses of such programs. A recent literature review reported the most frequently used clinical outcomes in evaluating these care models as in-hospital mortality, length of stay, time to surgery, place of residence, and complication rates [157]. The most common patient-reported outcomes were activities of daily living and mobility scores. The authors of that study reported what they felt to be the most useful outcome parameters and the assessment tools best suited to evaluate each parameter [157]. Regardless of what researchers feel are the best measures to use, there must be an agreement on which parameters should be analyzed, so that conclusions can be drawn across many different centers in many different geographical regions and internationally [158]. In order to build support for changing the established paradigm in geriatric fracture management, the evidence must be concrete in support of new, more efficient care models.

## Program Certifications

The Joint Commission has developed a disease-specific care certification to evaluate health-care agencies that provide care for patients with specific medical problems. With respect to orthopedic care, they provide certifications that represent an approved level of quality of care for problems ranging from low back pain to fragility fracture, hip fracture, and osteoporosis [159]. The commission suggests that certification not only standardizes care but also provides an objective assessment of clinical care of specific disease processes. Certification is obtained through site visits and program reviews to identify revisions to current program structures and ensure that clinical practice guidelines are followed to maximize highlighted performance measures. Certification benefits hospitals by facilitating marketing and improving community confidence in hospital care.

The International Geriatric Fracture Society is another entity that offers certification of geriatric fracture care programs. The society has developed the CORE certification program that also collects data from fracture care programs that is used to set benchmarks for outcome improvement and to evaluate the concepts of geriatric fracture care established in published literature [160]. The CORE program is a more focused means of evaluating fracture centers, specifically. By collecting data focused on interdisciplinary care provided to these patients, the certification program aims to improve outcomes by translating the published evidence into actual patient care. Hospitals that obtain certification will aim to implement changes outlined in the Blue Book of geriatric fracture care management to improve care of these patients (Table 13.4) [2].

**Table 13.4** Summary of quality and safety improvement measures

| Category | Intervention |
|---|---|
| Care models | A multidisciplinary care model with geriatric medicine and orthopedic comanagement is effective in improving outcomes |
| Anticoagulation and coagulopathy | The geriatric population carries a high prevalence of patients on long-term anticoagulants. These should be held in preparation for surgery, and chemical reversal agents should be given to reverse any anticoagulation, if safe from a medical standpoint |
| Preoperative cardiopulmonary evaluation | Ensure patient is medically optimized for surgery with geriatric evaluation, proper use of perioperative beta-blockers, and management of any acutely unstable cardiopulmonary issues |
| Anemia and transfusion | Recent evidence suggests patients may tolerate a higher threshold for transfusion (8 g/dL, or symptoms of acute blood loss anemia). Efforts should be made to minimize transfusions |
| Hydration | Most patients are dehydrated on presentation, ensure appropriate fluid resuscitation upon presentation and monitor with lab work and intake/output recordings |
| Anesthesia | Efforts should be made to coordinate alternative anesthetic plans to minimize the use of general anesthesia. Spinal, regional, and peripheral nerve blockades have all been effective, but the anesthetic approach to each patient should be individualized and coordinated with the anesthesia team |
| Pain management | Pain control is paramount in preventing postoperative delirium. Opioid analgesia is safe with the exception of a few select formulations. Pain is often undertreated, and this leads to poor outcomes |
| Pressure sore prevention | Frequent skin checks, screening, risk assessments, and pressure sore prevention techniques should be reinforced on the surgical ward |
| Thromboprophylaxis | All patients without a medical contraindication should be given appropriate DVT pharmacologic prophylaxis, and early ambulation should be enforced. There is no consensus agent of choice; however, the ACCP recommends enoxaparin |
| Nutrition | Early nutritional status evaluation and nutritionist consultation can help maximize healing potential and improve outcomes |
| Rehabilitation and weight bearing | Strict emphasis should be placed on early ambulation and full weight bearing after surgery. This helps facilitate rehabilitation and minimizes development or exacerbation of medical comorbidities. A multidisciplinary care team can help facilitate disposition as well as early mobilization |
| Delirium | Minimize use of medications associated with delirium, treat postoperative pain adequately, and take all measures to prevent delirium. If it develops, antipsychotics may be used judiciously to treat, but avoid benzodiazepines at all costs unless specifically indicated |
| Standardized order sets | Standardizing care, in general, enables the provider to treat and prevent common complications associated with hip fractures. Standardized order sets and training modules for geriatric fracture care nurses should be instituted to facilitate care for these patients |
| Discharge issues and follow-up | Using a multidisciplinary care team can facilitate discharge planning and minimize time in the hospital. Patients should have follow-up arranged with the surgeon and the primary care provider after being treated for a fracture |
| Osteoporosis | All geriatric fracture patients should be assessed for osteoporosis with lab work or with appropriate screening tests as an outpatient. Vitamin D and calcium supplementation should be initiated in any patients who are deficient, and treatment should be initiated if the diagnosis of osteoporosis is made |
| Fall awareness | Fall prevention should be reinforced and measures should be taught to minimize risk factors in elderly patients |
| Infection prevention | Preoperative, perioperative, and postoperative risk factors for infection should be minimized. Appropriate interventions to prevent infection include MRSA screening, nutritional evaluation, a full medical history and reconciliation, preoperative antibiosis, skin prep, meticulous surgical technique, and minimizing blood transfusion |

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# Index





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