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INTEGRATED STUDY MASTER'S THESIS

Leg Length Discrepancy after hip replacement for femoral neck fracture

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Abstract

Leg length discrepancy (LLD) is a common and often challenging complication after total hip arthroplasty (THA) or hemiarthroplasty (HA) for femoral neck fractures (FNF), leading to issues such as gait problems, back pain, and sometimes the need for further surgery. This thesis presents a narrative literature review exploring the anatomical, surgical, and technological factors contributing to LLD. Key determinants include preoperative skeletal asymmetry, surgical approach, implant selection, and intraoperative technique. Comparative analysis highlights that cemented implants generally offer better short-term stability and fewer complications than uncemented ones, though neither guarantees LLD prevention. Advances such as computer-assisted surgery and intraoperative fluoroscopy have improved leg length accuracy. The study emphasizes that individualized preoperative planning and precise intraoperative execution are essential to minimizing LLD and optimizing functional outcomes in FNF patients undergoing hip replacement.

Keywords

Femoral neck fracture, Total Hip Arthroplasty, Hemiarthroplasty, Leg Length Discrepancy, Surgical Approaches, Cemented and Uncemented, Intraoperative Measurement, Robotic-Assisted THA

1. Introduction

Leg length discrepancy (LLD) is a recognized and often problematic complication following total hip arthroplasty (THA) and hemiarthroplasty (HA) for femoral neck fractures (FNF). While hip replacement surgery is a well-established treatment for FNFs in elderly patients, achieving optimal limb length symmetry remains a challenge. Postoperative LLD is reported in up to 27% of patients undergoing THA for femoral neck fractures (1), with clinically significant discrepancies contributing to functional impairments, gait disturbances, and increased risk of musculoskeletal complications (2). In severe cases, LLD may necessitate long-term management or revision surgery, further complicating patient outcomes and increasing healthcare burdens (1).

The complexity of LLD in FNF patients arises from multiple interrelated factors. Preoperative considerations, such as underlying skeletal asymmetries and pre-fracture leg length differences, play a role in determining final limb length outcomes. However, intraoperative factors remain the primary contributors to postoperative LLD. Surgical approach is one of the key determinant factors, with studies highlighting significant differences in LLD incidence between the posterior and direct anterior approaches. The posterior approach, while commonly used, is associated with an increased risk of LLD due to challenges in maintaining proper femoral component positioning. Conversely, the direct anterior approach (DAA) has demonstrated improved accuracy in limb length restoration but requires greater surgical expertise and specialized instrumentation (3).

Beyond surgical technique, prosthesis selection plays a crucial role in minimizing LLD. Cemented and uncemented femoral stems offer distinct advantages and limitations, particularly regarding their impact on implant stability and subsidence. Cemented stems have been reported to provide greater immediate fixation, reducing early implant migration and lowering the risk of postoperative LLD (4). Uncemented stems rely on biological fixation, which, although beneficial in younger patients, may contribute to variability in limb length outcomes due to early implant subsidence (5). Additionally, implant design, head size, and acetabular component positioning all play a role in determining postoperative leg length outcomes (6).

Recent advancements in robotic-assisted THA, computer-assisted surgical planning, and intraoperative measurement tools have introduced new possibilities for reducing LLD incidence (7). Intraoperative fluoroscopy has been implemented to enhance measurement accuracy and reduce LLD-related complications in Direct Anterior Approaches for THAs (8) .

1.1 Aim of the Thesis

This narrative literature review aims to critically evaluate the causes, clinical significance, and management strategies of LLD following hip replacement for FNFs. By systematically analyzing the literature, this study will explore the impact of surgical approach, prosthesis selection, and technological innovations on LLD outcomes. This review seeks to assess the effectiveness of current intraoperative techniques in minimizing LLD and to identify areas for future research and improvement in clinical practice. Surgical decisions are optimized if postoperative LLD factors are better understood. Better patient outcomes can thus be achievable in femoral neck fracture management.

2. Methodology

2.1 Literature Search Strategy

To ensure a good review of the existing literature on LLD following hip replacement for FNF, a structured database-driven search was conducted. The goal was to identify relevant peer-reviewed studies that discuss the incidence, causes, management, and clinical outcomes of LLD after THA and HA after FNF.

2.2 Database Selection & Rationale

The literature search was done with multiple high-impact medical and orthopedic databases. PubMed/MEDLINE was selected due to its coverage of clinical trials, orthopedic research, and surgical outcomes. The Cochrane Library was included to identify systematic reviews and meta-analyses on LLD after hip replacement. These databases were chosen to maximize the inclusion of high-quality, peer-reviewed studies from orthopedic journals, surgical research, and rehabilitation sciences.

2.3 Search Terms & Boolean Operators

A combination of MeSH terms and free-text keywords was used to refine search queries. Boolean operators such as AND and OR were applied to ensure relevant studies were retrieved while minimizing irrelevant results. The following search string was used: ("Leg Length Discrepancy"[Mesh] OR "Limb Length Inequality"[Mesh] OR "Leg Length Difference"[tiab]) AND ("Hip Replacement"[Mesh] OR "Total Hip Arthroplasty"[Mesh] OR "Hip Prosthesis"[tiab]) AND ("Femoral Neck Fracture"[Mesh] OR "Hip Fracture"[tiab] OR "Intracapsular Hip Fracture"[tiab]). This search was conducted in each database separately to account for variations in indexing and search algorithm sensitivity.

2.4 Inclusion & Exclusion Criteria

To narrow down the selection, previous inclusion and exclusion criteria were applied. Studies were included if they were peer-reviewed, published within the last ten years, involved human subjects who underwent hip replacement for femoral neck fractures, and discussed LLD incidence, causes, prevention, or management. Only articles published in English were considered. Case reports, editorials, and expert opinions without empirical data were also excluded. Animal model studies were also excluded, since findings from such research may not be directly applicable to human patients. These criteria ensured a focused yet comprehensive selection of studies while filtering out irrelevant or lower-quality research.

2.5 Study Selection & Screening Process

The selection process followed a three-step approach. The initial search brought a broad range of studies. After reviewing titles and abstracts, a subset of articles was shortlisted based on relevance. Following this, a full-text review was conducted on the shortlisted articles, leading to the final inclusion of those that directly addressed the research questions. Additionally, citation tracking was done, in which references of included articles were manually screened to identify additional relevant studies through a snowball sampling approach.

2.6 Limitations & Potential Bias

While this search strategy aimed for comprehensive coverage, some limitations must be acknowledged. The exclusion of non-English studies may missed valuable research published in non-English journals. Publication bias is another potential limitation, as studies reporting significant results, such as successful interventions for reducing LLD, may be overrepresented compared to those with negative findings. Restricting the search to the last ten years may have excluded older foundational studies that could have contributed valuable historical perspectives on LLD mechanisms. Additionally, while PubMed, and Cochrane were chosen to maximize coverage, some orthopedic research may be published in journals not indexed by these databases. Despite these limitations, the combination of multiple databases, Boolean logic, and a structured screening process ensures that the review captures the most relevant and high-quality studies in the field.

3. Anatomy and Biomechanics of Hip Replacement in the context of Femoral Neck Fractures and Leg Length Discrepancy

3.1 Ligaments and Capsule & Osseous Structures:

The hip joint is a ball-and-socket synovial joint, formed by the articulation between the head of the femur and the acetabulum of the pelvis. The acetabulum is a cup-like depression located on the inferolateral aspect of the pelvis, deepened by a fibrocartilaginous collar known as the acetabular labrum. The head of the femur is hemispherical, fitting completely into the acetabulum. Both the acetabulum and the femoral head are covered with articular cartilage, which is thicker at the weight-bearing areas, facilitating smooth movement and effective load distribution (9).

The femoral neck plays a critical role in transmitting axial forces from the femoral shaft into the pelvis, allowing for efficient weight distribution during movement and standing. Due to its angled structure and compression forces, the femoral neck is particularly vulnerable to fractures, especially at Ward's triangle, an area with fewer strain-bearing trabeculations (9).

The hip joint's stability is significantly reinforced by three extracapsular ligaments: Iliofemoral Ligament: Originating from the anterior inferior iliac spine and bifurcating to insert into the intertrochanteric line of the femur, this Y-shaped ligament is the strongest of the three. It prevents hyperextension of the hip joint. Pubofemoral Ligament: Extending from the superior pubic rami to the intertrochanteric line, this triangular-shaped ligament reinforces the capsule anteriorly and inferiorly, preventing excessive abduction and extension. Ischiofemoral Ligament: Spanning from the ischium to the greater trochanter, this spiral-oriented ligament reinforces the capsule posteriorly, preventing hyperextension and securing the femoral head within the acetabulum. The joint capsule, a fibrous structure encompassing the hip joint, attaches proximally to the acetabulum and distally to the intertrochanteric line anteriorly and the femoral neck posteriorly. This capsule plays a crucial role in maintaining joint stability while allowing a range of movements. In the event of a hip fracture, particularly femoral neck fractures, the integrity of the joint capsule and its associated ligaments can be compromised, leading to joint instability and altered biomechanics (9).

3.2. Key Muscle Groups and Their Role in Hip Stability

The stability of the hip joint is maintained by several key muscle groups, each contributing to movement and joint integrity. Gluteal Muscles: The gluteus medius and gluteus minimus are primary stabilizers, preventing pelvic drop during walking by maintaining a level pelvis. The gluteus maximus assists in hip extension and lateral rotation, playing a crucial role in supporting the joint during weight-bearing activities. Iliopsoas Muscle: Comprising the psoas major and iliacus, this muscle is the strongest hip flexor. It originates from the posterior abdominal wall and inserts onto the lesser trochanter of the femur, contributing to hip flexion and postural stability. Adductor Muscles: The adductor longus, adductor brevis, and adductor magnus are responsible for drawing the thigh toward the midline. These muscles provide medial stabilization and are crucial for balance and controlled leg movements. Quadriceps Femoris: This group consists of four muscles (rectus femoris, vastus lateralis, vastus medialis, vastus intermedius) primarily involved in knee extension. The rectus femoris, however, also contributes to hip flexion due to its origin from the pelvis (9).

3.3 Neurovascular Supply of the Hip Joint

The blood supply to the femoral head is primarily coming from the medial and lateral circumflex femoral arteries, which are branches of the profunda femoris artery (deep femoral artery). These arteries form an anastomotic ring at the base of the femoral neck, giving rise to smaller branches that supply the hip joint. The medial circumflex femoral artery provides the majority of the arterial supply, while the lateral circumflex femoral artery must penetrate the thick iliofemoral ligament, limiting its contribution. Damage to the medial circumflex femoral artery—such as in FNFs—can lead to avascular necrosis of the femoral head due to insufficient blood flow. Additional arterial contributions come from the artery to the head of the femur and the superior and inferior gluteal arteries, though their role is minor. The hip joint receives nerve supply primarily from the sciatic, femoral, and obturator nerves. Since these nerves also innervate the knee, pain from the hip can be referred to the knee, which is a common postoperative concern after hip replacement surgery. (9).

3.4 Anatomical variations: Dorr Classifications, Canal Flare Index

Anatomical variations represent an important factor in understanding the causes of LLD after hip replacement. Features such as femoral shape, canal geometry, and pelvic tilt can influence implant alignment and the surgeon's ability to restore proper limb length. Incorporating classifications like Dorr types and measurements such as the canal flare index (CFI) helps in preoperative planning and risk assessment. Addressing these variations is therefore essential for achieving accurate and consistent leg length outcomes.

The Dorr Classification is a widely used system for evaluating proximal femoral bone quality, playing a crucial role in preoperative planning and implant selection for THA. Originally developed to differentiate bone morphology based on cortical thickness and canal shape, this classification helps surgeons predict implant stability and fixation outcomes. Since bone quality influences the risk of implant subsidence, loosening, and LLD, understanding the Dorr classification is essential in assessing postoperative outcomes. The system categorizes femoral bone into three types—A, B, and C—each with unique implications for THA stability and the likelihood of LLD (10).

The differences in femoral bone type are particularly noticeable in lateral radiographs. Dorr Type A is characterized by thick and distinct cortices, visible on both anteroposterior (AP) and lateral X-rays, resulting in a narrow diaphyseal canal and a "funnel-shaped" proximal femur. On lateral radiographs, this type presents with a thick, curved posterior cortex (posterior fin). The original study found that Dorr Type A femurs were more common in younger, heavier, and male patients. These femurs, sometimes referred to as "champagne flute" femurs, typically allow for the use of flat, tapered, proximally porous-coated stems (such as single-wedge or blade designs), though stem length and implant geometry must also be considered (10)

Dorr Classification:

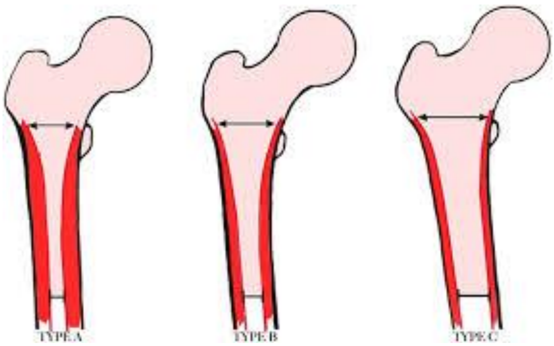

Figure 1. Dorr classification of femoral bone. Reproduced from: Wilkerson J, Fernando ND. Classifications in Brief: The Dorr Classification of Femoral Bone. *Clin Orthop Relat Res.* 2020;478(8):1939–44. Figure 1. (10)

Flat, tapered, proximally fitting stems achieve three points of fixation: two at the proximal femur, where the implant engagese the lateral shoulder and medial calcar, and a third point in the diaphysis at the distal end of the stem However, in some Dorr Type A femurs, the meta-diaphyseal diameter is extremely narrow, which may cause the implant to engage prematurely in the diaphysis before achieving optimal proximal fit. This may provide some axial stability but often results in an undersized femoral implant that lacks rotational stability within the metaphysis. Additionally, if the stem is restricted distally, it may sit too high (proud), leading to leg length discrepancy. In these cases, a shorter head or neck length may be necessary to restore equal leg length. Even though Dorr Type A bone is often dense and strong, excessive broaching of the tapered implant can still lead to fractures in the meta-diaphyseal region (10).

Dorr Type B is characterized by bone loss in the medial and posterior cortices, leading to a wider diaphyseal canal, and is more common in men than women. On lateral radiographs, these femurs show posterior fin erosion, flattened cortex, and proximal cortical defects ("rat bites") due to osteoclastic activity. In some cases, the posterior fin's distal end may be absent. These femurs can accommodate both cemented and uncemented stems, but flat, tapered stems depend on the quality of the proximal cortical bone and overall bone structure. Even if axial stability and proper cortical engagement are achieved, rotational stability may be inadequate if cancellous bone is weak or affected by improper broaching techniques. In such cases, using a metadiaphyseal or fully diaphyseal-engaging stem, or opting for cemented fixation, may be more suitable (10).

Dorr Type C femurs show significant loss of medial and posterior cortices, including the posterior fin, and appear less defined on radiographs, giving them a “fuzzy” appearance. These femurs, often referred to as “stovepipe” femurs, have a wider canal diameter and are most commonly found in elderly, thinner, and female patients. Due to their geometry and reduced bone quality, these femurs are typically better suited for cemented stems. Although some studies have reported successful outcomes using flat, tapered metadiaphyseal and diaphyseal stems in Type C femurs, relying on these implant designs may carry a higher risk of complications. The original study by Dorr et al. confirmed that these femurs are often associated with osteopenia, which increases the risk of fractures during implantation. Achieving mechanical stability with a tapered broach may lead to calcar fractures, while the use of diaphyseal-engaging stems could result in fractures in the diaphysis, either during reaming or final implant placement (10).

Additionally, the weakened bone structure in Type C femurs may fail to provide adequate support for uncemented implants, leading to axial or rotational instability during surgery or early postoperative subsidence. Cemented fixation is generally recommended in these cases, as it provides immediate mechanical interdigitation, reducing the risk of instability (10).

Canal Flare Index

The Canal Flare Index (CFI) is a radiographic parameter used to quantify the morphology of the proximal femoral medullary canal, calculated as the ratio of the canal width two centimeters above the intertrochanteric line to the canal width at the isthmus. This measurement is interesting in THA as it influences implant selection and stability, which in turn affects leg length restoration. A high CFI indicates a wide metaphysis and a narrow diaphysis, creating a more flared femoral canal, whereas a lower CFI suggests a more cylindrical shape. The relationship between CFI and LLD is particularly important in cementless metaphyseal fixation, where the shape of the femoral canal directly affects the vertical positioning of the femoral stem. According to Brumat et al., “higher CFI was an independent risk factor for postoperative LLD $\geq$ 5 mm with an odds ratio of 4.5 ($p = 0.03$) in 49 stems with cementless metaphyseal fixation”, meaning that patients with higher CFI values had a significantly greater risk of experiencing LLD after surgery (11). However, the study also found that “CFI has no significant impact on LLD in femoral stems with cementless diaphyseal fixation or cemented fixation” CFR influence. This suggests that while CFI is a critical factor in certain types of femoral implant fixation, its impact on LLD varies depending on the fixation method and implant design. Although this might appear paradoxical, it highlights the mechanical differences in fixation strategies, where only metaphyseal fixation is sensitive to variations in proximal femoral anatomy such as CFI. This finding underlines the importance of aligning implant choice with patient-specific anatomy to minimize the risk of LLD. (11)

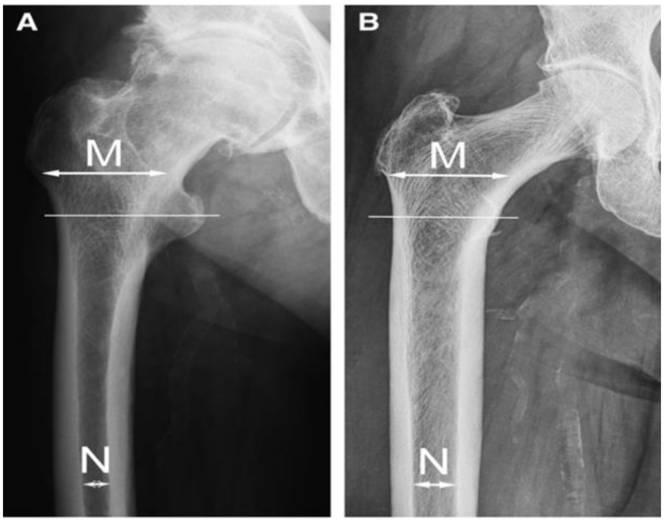

Figure 2. Impact of canal flare index on leg length discrepancy after total hip arthroplasty. Reproduced from: Brumat P, Pompe B, Antolič V, Mavčič B. The impact of canal flare index on leg length discrepancy after total hip arthroplasty. *Arch Orthop Trauma Surg.* 2018;138(1):123–9. Figure 1(11)

Canal flare index (CFI) is the ratio of the canal width (M) measured 2 cm above the intertrochanteric line to the canal width at the isthmus (N) on an AP pelvis X-ray. In the example, male patient A has a CFI of 3.8, and patient B (a 75-year-old female) has a CFI of 2.2 — both patients are 75 years old (11)

4. Overview of Femoral Neck Fracture

Hip fractures are frequently found in emergency departments, particularly among older adults with osteoporosis and changes in mental status. They can also occur in younger individuals involved in sports or high-impact injuries. Quick identification and treatment are importan to avoid serious complications involving the joint. In the U.S., hip fractures rank among the top 20 most costly medical conditions, with an estimated $20 billion allocated annually for their care. Projections suggest that by 2030, around 300,000 hip fracture cases will occur each year in the United States. FNFs fall under the category of intracapsular hip fractures. In cases where the fracture is displaced, the vascular supply to the femoral head—running along the femoral neck—becomes a critical factor in management. (12)

4.1 Etiology

Femoral neck fractures often result from low-impact falls, particularly among the elderly. In younger individuals, these injuries are typically caused by high-energy trauma, such as falls from significant heights or motor vehicle collisions. Factors that increase the likelihood of FNFs include being female, reduced mobility, and decreased bone mineral density. (12)

4.2 Epidemiology

Annually, around 1.6 million hip fractures occur worldwide. Women account for about 70% of these cases. The risk of hip fractures rises sharply with advancing age and is observed more frequently in white females. (12)

4.3 Pathophysiology

In displaced FNFs, this blood supply is at risk due to tearing of the ascending cervical branches from the arterial ring formed by the circumflex arteries. Damage to this vascular network can impair healing, leading to complications such as non-union or avascular necrosis. This issue is particularly critical in younger patients, for whom joint replacement may not be the preferred treatment. In cases treated with open reduction and internal fixation, avascular necrosis is the most commonly encountered complication. (12)

4.4 History and Physical Exmination

Most patients present following a recent traumatic event. In those with dementia or cognitive decline, the history may be unclear, making input from caregivers or facility staff essential. It's important to ask about recent falls and changes in mental status. Patients often report hip pain and limited mobility. Displaced fractures may result in visible shortening and external rotation of the affected limb, whereas non-displaced fractures might not show obvious deformity. (12)

The patient history is often closely linked to the underlying injury mechanism. In cases involving low-energy trauma, attention typically centers on the specific details of the fall, with particular interest in whether syncope may have played a role. When high-energy trauma is involved, the structured approach provided by Advanced Trauma Life Support (ATLS) often becomes relevant. In such scenarios, initial focus frequently lies on identifying any life-threatening non-orthopedic injuries, followed by evaluation of additional trauma on the same side of the body—common sites being the femur or knee. Injuries resulting from high falls often prompt careful examination of the ankle. The patient’s relevant medical history usually encompasses a range of factors, such as baseline mobility levels, prior dependence on walking aids, use of anticoagulant medication, as well as any known history of malignancy, pulmonary embolism, or deep vein thrombosis. Evaluation A full neurovascular exam of the injured limb should be conducted. Typically a plain X-rays is indicated, including anteroposterior (AP) views of the pelvis, hip, femur, and knee from both AP and lateral perspectives. A CT scan is useful in defining the fracture type or identifying subtle lines not visible on X-rays; also part of trauma workups and can be extended to include the femoral neck. Though not commonly used in emergencies an MRI can help diagnose stress fractures in the femoral neck. (12)

Laboratory workup should include standard blood tests (CBC, BMP, and coagulation studies), along with a chest X-ray and ECG. Older patients with known or suspected heart disease may require a cardiology evaluation prior to surgery. Optimizing the patient's medical condition before surgery is especially important in geriatric cases. (12)

4.5 Femoral Neck Fractures and Classifications

FNFs are classified based on displacement, fracture pattern, and biomechanical stability. These factors directly influence the choice of surgical treatment and the risk of postoperative complications, including LLD. Accurate classification using systems such as the Garden, Pauwels, and AO/OTA classifications provides a structured approach to determining the most appropriate surgical intervention, whether THA, hemiarthroplasty HA, or internal fixation. By examining these classification systems, this section establishes a foundation for understanding how fracture type affects implant selection, surgical technique, and strategies for minimizing LLD, ultimately improving surgical planning and patient outcomes.

There are different types of Femoral neck fractures that can be classified. The Pauwels classification divides its fractures based on the inclination of the fracture line in relative relation to horizontal line: Type I, less than 30°; Type II, 30° to 50°; and Type III, greater than 50°. The larger the angle of inclination the larger is the forces transition from being compressive to shearing (10)

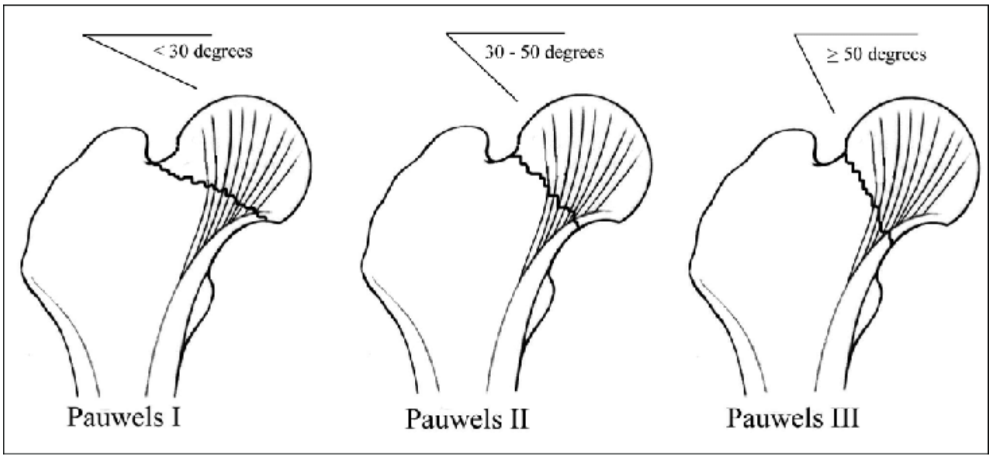

Figure 3. Techniques for optimizing stability in femoral neck fracture fixation. Reproduced from: Ye Y, Hao J, Mauffrey C, Hammerberg EM, Stahel PF, Hak DJ. Optimizing stability in femoral neck fracture fixation. In: Hak DJ, Stahel PF, editors. *Orthopedics.* 2015;38(10):625–30. Figure 3. (13)

Robert Symon Garden came up with another Classification of FNFs. The Garden classification considers displacements, fracture completeness and relationship of bony trabeculae in the femoral head and neck. His Classification goes up from Type 1 to type 4 and is based on the degree of displacement observed in anteroposterior radiographs : Type I: Incomplete fracture (valgus impacted), type II: Complete fracture without displacement, type III: Partial displacement, type IV: Fully displaced fracture. (10)

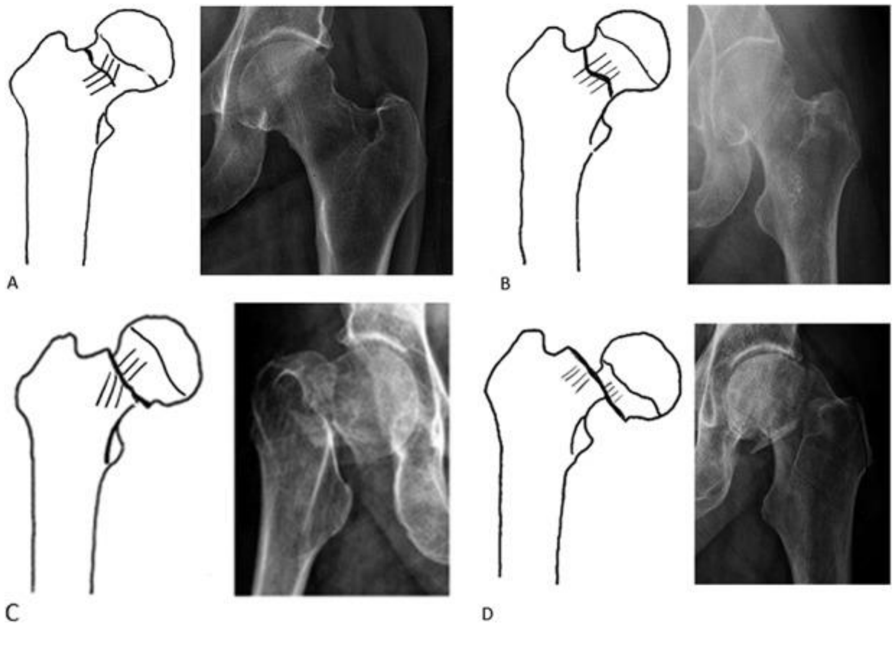

Figure 4. Garden classification of femoral neck fractures. Reproduced from: Kazley JM, Banerjee S, Abousayed MM, Rosenbaum AJ. Classifications in Brief: Garden Classification of Femoral Neck Fractures. *Clin Orthop Relat Res.* 2018;476(2):441–5. Figure 1. (14)

The Garden classification is depicted in the drawings and corresponding radiographs for Garden Types (A) I, (B) II, (C) III, and (D) IV femoral neck fractures (14).

AO/OTA Classification

This classification system divides femoral neck fractures into three primary categories: 31B1 (Subcapital fractures): These fractures occur just below the head of the femur and are further subdivided based on displacement and stability. 31B2 (Transcervical fractures): These fractures traverse the midportion of the femoral neck and are categorized by the angle of the fracture line, influencing stability and risk of complications. 31B3 (Basicervical fractures): These fractures occur at the base of the femoral neck, near its junction with the femoral shaft, and are associated with specific biomechanical considerations (15).

5. Conservative Treatment of Femoral neck Fractures

Garden I fractures, classified as non-displaced FNFs, account for 15–20% of all cases and are considered stable due to minimal disruption of the femoral head's blood supply. While surgical intervention is often recommended to prevent secondary displacement and complications such as avascular necrosis, the choice between surgery and conservative treatment remains a topic of debate, particularly in elderly patients. Research comparing these approaches has brough mixed results. Some studies show that conservative management can achieve satisfactory outcomes, with a significant percentage of patients avoiding complications. However, other findings suggest a high risk of early fracture displacement requiring subsequent surgical intervention. Despite the widespread preference for surgical treatment, no standardized guidelines exist for managing Garden I fractures, as current evidence is limited by small sample sizes and methodological inconsistencies. (16)

The study by Moulton et al. evaluates the outcomes of patients treated non-surgically and provides insights into their mortality, mobility, pain levels, and complications. The authors analyzed data from 32 patients with intracapsular femoral neck fractures who underwent conservative treatment between 2010 and 2012. Their findings indicate a high 30-day mortality rate of 31.3% and a one-year mortality rate of 56.3%, which is considerably higher than in surgically managed patients. However, among those who survived beyond the initial 30 days, mortality rates were similar to those observed in the surgical group. Despite a general decline in mobility, a notable proportion of patients retained some functional independence, with 30.8% mobilizing with a frame or two aids at hospital discharge. Pain management appeared to be effective, as 88.9% of patients reported being either pain-free or having pain well-controlled with medication. Additionally, complications such as pneumonia and sepsis were minimal, and there were no recorded cases of pressure sores or venous thromboembolism.

Interestingly, three patients who were initially deemed unfit for surgery eventually underwent surgical intervention after their condition improved, highlighting the potential for re-evaluating surgical candidacy in select cases (17) .

The study underscores the challenges of conservative management but also demonstrates that, with appropriate medical and nursing care, reasonable outcomes can be achieved, particularly in pain control and mobility preservation. The authors conclude that while surgery remains the preferred treatment, non-surgical management can be a viable option for high-risk patients, though it is associated with higher early mortality and reduced mobility compared to surgical intervention (17)

6. Surgical Treatment

6.1 Total Hip Arthoplasty vs Hemiarthoplasty after Femoral Neck Fracture

Hip arthroplasty, whether as HA or total hip arthroplasty THA, serves as the standard treatment for displaced femoral neck fractures within elderly patients, also it rapidly mobilizes patients furthermore giving favorable long-term outcomes. Still, these fractures have clinical practice variations. THA supporters highlight evidence suggesting superior functional outcomes along with an improved quality of life. In contrast, proponents of HA emphasize its shorter surgical time, reduced blood loss, and lower risk of dislocation, arguing that THA may not always provide a clinically significant advantage (18).

THA and HA hemiarthroplasty each present unique advantages with limitations. Therefore, the choice for FNFs between them represents a decision that is critical clinically. A selection that is well-informed is necessary in order to minimize postoperative complications, including LLD, and also the selection is important in order to achieve the best functional outcomes possible for the patient. A systematic review analyzing randomized controlled trials (RCTs) found that THA offers better hip function and also less acetabular erosion in addition to lower revision rates when compared to HA. These benefits make THA particularly suitable for active elderly patients who require long-term mobility and improved quality of life. However, THA is also associated with a higher risk of dislocation, particularly within the first six months postoperatively, which remains a primary concern in its selection. Furthermore, THA does tend to relieve pain in a better way and does score higher functionally, though studies found that there was no meaningful difference in overall reoperation rates or in postoperative infection rates, nor in peri-prosthetic fractures, and even in venous thromboembolism that did prevail between these two procedures. Alternatively, HA is still a better choice for weak patients if their activity declines because it limits surgical trauma and anesthesia risks so it is safer for those who have major comorbidities. HA patients risk acetabular erosion over time despite advantages, possibly leading to pain then converting to THA (18). Therefore, the decision between THA and HA should not be based solely on general clinical preferences but should take into account individual risk factors, functional demands, and the potential impact on postoperative leg length.

Ultimately, patient selection is key in determining the appropriate procedure. THA may provide superior long-term outcomes including Total Hip Arthoplasty for active elderly patients, whereas HA is often favored for those with lower functional demands and higher surgical risks. Given the higher early dislocation risk associated with THA, careful postoperative management and rehabilitation protocols are necessary to optimize outcomes (18).

6.2. Uncemented vs Cemented Hemiarthoplasty after Femoral Neck Fracture

The choice between cemented and uncemented hemiarthroplasty for intracapsular femoral neck fractures also remains a topic of debate, with considerations focusing on implant stability, complication rates, and functional outcomes including LLD. Cemented fixation has traditionally been favored since it is immediately stable, which does allow early mobilization plus it lowers the risk that implants loosen. Uncemented implants are preferred by some surgeons specifically in frail patients who have pre-existing cardiopulmonary conditions yet bone cement implantation syndrome (BCIS) concerns exist since it can cause hypotension, hypoxia, also cardiovascular collapse rarely. Uncemented hemiarthroplasty conversely fixes biologically because of bone ingrowth, an advantage for younger patients with good bone quality, yet it risks early subsidence plus periprosthetic fractures more highly if bone is osteoporotic (5).A randomized controlled trial comparing these two approaches found that cemented hemiarthroplasty provided better short-term functional outcomes and a lower periprosthetic fracture risk in patients aged 60 or older with intracapsular hip fractures. The primary outcome, health-related quality of life measured by the EQ-5D utility score, was greatly higher in the cemented group (0.371) compared to the uncemented group (0.315), because there existed an adjusted difference of 0.055 ($p = 0.02$), also this suggested clinically relevant benefits with cemented fixation (5). Periprosthetic fractures were greatly more common inside the uncemented group (2.1%) than inside the cemented group (0.5%), with an odds ratio of 4.37, which reinforces the risk of implant-related fractures when uncemented stems are used. Despite concerns regarding BCIS, the cemented group showed somewhat reduced mortality at 12 months (23.9%) versus the uncemented group (27.8%), though this difference did not reach statistical significance (5).

6.3. Cemented vs Uncemented Total Hip Arthroplasty after Femoral Neck fracture

The choice between cemented and uncemented THA for Femoral Neck Fractures remains a key topic in orthopedic surgery, as implant fixation methods directly impact long-term outcomes and complication rates. Understanding the differences between these two approaches is crucial for optimizing implant stability, minimizing postoperative complications, and ensuring better functional recovery in elderly patients.

Multicenter retrospective research contrasted cemented total hip replacement with uncemented. For elderly patients who had femoral neck fractures (AO/OTA type 31B/C), they were followed for a period of over five years. In the study, 268 patients were analyzed; 132 received cemented THA, and 136 received uncemented THA. Harris Hip Score that is (HHS) was the primary endpoint implant-related complications represented the secondary endpoint in reference (4).

Findings indicated that cemented THA provided superior long-term functional outcomes, with a significantly higher HHS at the final follow-up (79.39 vs. 74.18, $p = 0.011$). Additionally, the cemented group had a lower rate of prosthesis revision (7.6% vs. 16.9%, $p = 0.020$), less prosthesis loosening (9.8% vs. 19.9%, $p = 0.022$), and fewer periprosthetic fractures (5.3% vs. 13.2%, $p = 0.026$) compared to the uncemented group. Although earlier studies suggested that uncemented implants could shorten surgery and lower complication rates, this study found that the increased risk of implant failure and mechanical problems outweighs those benefits. These results reenforce the preference for cemented THA in elderly patients with FNF particularly given its improved implant stability and reduced complication rates (4).

However the study by Yassin et al. examines leg length discrepancy following total hip arthroplasty (THA), comparing outcomes between cemented and cementless techniques. LLD remains a common issue after THA and is a frequent source of patient dissatisfaction, functional impairment, and potential medico-legal disputes. The study acknowledges that even though absolute leg lengths are difficult for one to equalize, it is important for one to minimize discrepancies so as to optimize post-operative function. To reduce variability, the authors conducted a cross-sectional analysis on 26 patients who underwent either cemented or cementless THA between 2012 plus 2014, with surgeries performed by the same principal orthopedic surgeon. For assessment of LLD both before and after the operation, actual clinical measurements used a tape measure as well as put patients into equal, lengthened, and shortened limb groups. The results demonstrated that post-operatively, 42.3% of patients achieved equal limb lengths, 38.5% experienced lengthening, and 19.2% had shortening. When comparing cemented and cementless techniques, the mean post-operative LLD was -2.00 mm in the cemented group and 3.81 mm in the cementless group, though the difference was not statistically significant ($p = 0.361$). These findings suggest that neither cemented nor cementless fixation has a definitive advantage in preventing LLD, reinforcing that surgical technique, preoperative planning, and intraoperative adjustments play a more critical role than implant selection alone. Despite careful planning, discrepancies of up to 10 mm remain common and are generally well tolerated by patients, but larger discrepancies may necessitate corrective measures. The study highlights the complexity of LLD management in THA and underscores the importance of individualized approaches to ensure optimal biomechanical alignment and functional outcomes (6).

Therefore summarized we can say that while uncemented THA may offer certain intraoperative advantages, the evidence suggests that cemented fixation provides superior long-term implant stability and lower complication rates, it does not have a significant advantage in preventing LLD.

7. Different Methods of surgery posterior, lateral and anteriorlateral to the Proximal Femur

The surgical approach to the proximal femur is a fundamental aspect of hip replacement procedures and directly relates to the core focus of this thesis. Exploring different methods, such as posterior, lateral, and anterior approaches, provides important context for understanding how surgical technique may influence outcomes. This comparison supports a deeper evaluation of factors contributing to leg length discrepancy. Including this discussion is essential to build a comprehensive picture of the variables involved in postoperative alignment and patient recovery.

7.1. Anterolateral Approach (Watson-Jones) to the Proximal Femur

The Watson-Jones anterolateral approach provides access to the proximal femur through the interval between the gluteus medius and the tensor fasciae latae. Although it limits visibility of the hip joint, proper use of retractors and soft tissue releases enables reduction of displaced femoral neck and head fractures.The skin incision is slightly curved, starting 7 to 10 cm above the lateral greater trochanter and extending distally about 10 cm. The fascia lata is sharply opened over the femur and extended proximally along the posterior edge of the tensor fasciae latae. After exposing the greater trochanter and gluteus medius, the tensor fasciae latae is retracted anteriorly and the gluteus medius posteriorly. Blunt dissection is used to access the hip joint between these muscles. The superior gluteal nerve and vessels limit the proximal extension. Any vessels in this area may need ligation or cautery. For hip capsule exposure, a Hohmann retractor is placed between the gluteus medius and the femoral neck, with additional retractors enhancing visibility. External rotation of the leg improves access. The vastus lateralis origin is detached from the anterior-inferior trochanter, and the muscle is retracted downwards. The capsule is opened with a T-shaped incision, placing two retraction sutures for better visualization while protecting the labrum. If more exposure is needed, an inverted-T capsulotomy can be used. The wound is closed after cleaning and debridement, with layered suturing of capsule, vastus lateralis, fascia lata, and skin (19).

7.2 Direct Lateral Approach to the Proximal Femur

The direct lateral approach involves releasing the anterior third of the gluteus medius and minimus while preserving their posterior attachment. The superior gluteal nerve and vessels limit the proximal dissection, running 3 to 5 cm above the greater trochanter. Distally, the vastus lateralis fibers are elevated, and the hip capsule is detached from the femoral neck. A longitudinal or T-shaped capsulotomy improves exposure. A skin incision is made longitudinally with a slight posterior angle proximally. The fascia lata is divided over the trochanter and extended distally. The gluteus maximus fibers are split to reach the gluteus medius. Bursal tissue over the trochanter is removed if necessary. The anterior portion of the gluteus medius is released from the trochanter, extending into its tendinous insertion and splitting the vastus lateralis fibers distally. The incision is deepened through the gluteus medius and minimus, retracting them anteriorly. The dissection continues distally along the anterolateral femoral shaft, releasing tissues from the intertrochanteric area. The capsule is detached from the anterior femur, allowing good exposure of the femoral head and neck. Hip dislocation is achieved by gently externally rotating the leg and retracting the femur distally to remove the femoral head fragment. (20)

7.3 Posterolateral (posterior) approach to the hip

The posterolateral approach to the hip is performed with the patient lying on their side. The incision begins just behind the greater trochanter and extends about 5 cm down the femur, curving slightly upwards towards the posterior superior iliac spine. After cutting through the fascia lata and gluteal muscle, the hip is flexed and internally rotated to expose the short external rotators. These muscles are carefully detached close to their insertion on the greater trochanter, with strong sutures placed for later repair. The sciatic nerve lies nearby but is not usually exposed unless necessary. Once the short rotators are reflected, the hip capsule becomes visible. The capsule is opened along the femoral neck and can be extended with a T-shaped incision if more exposure is needed. Sutures are placed in the capsule to assist with retraction and later closure. After the procedure, the capsule and external rotators are securely repaired to the greater trochanter using the placed sutures, reducing the risk of dislocation. The quadratus femoris muscle, if cut, is repaired separately. Finally, the fascia and skin layers are closed individually to complete the procedure (21).

7.4 Overall Comparison of Approaches in regards to Leg Length Discrepancy

As part of understanding how surgical technique influences postoperative outcomes like LLD, it is important to examine how different approaches to THA compare in terms of functionality and safety. Comparative studies provide valuable insights into whether certain techniques offer greater control or consistency in restoring anatomical alignment.

Yan et al.'s study offers a thorough comparison of THA surgical approaches for it analyzes their effectiveness, safety, as well as patient outcomes. The results indicate that all approaches besides the direct lateral approach (DLA) improved hip function more than the posterior approach (PA). The direct anterior approach (DAA) required longer operative times yet demonstrated important advantages in short-term functional recovery. No meaningful differences existed between approaches for serious complications like infection, dislocation, or thromboembolism. These results imply techniques show similar safety records. Highlighted also by the study is just what the surgeon's expertise and experience are, which is important in determining surgical outcomes. Each approach has a learning curve, an important factor affecting optimal results. Some approaches offer up benefits in specific areas, but the findings reinforce that there is just no universally superior technique instead. The choice should be tailored toward patient-specific factors including anatomy functional goals and surgeon skill. (22).

7.5 Discussing different approaches of Total Hip Arthroplasty in terms of Leg Length Discrepancy

Lu et al. explores LLD after THA using the DAA and the PLA since they give helpful perceptions into precision during surgery and results for patients. Between 2016 and 2018, the authors analyzed 358 patients who underwent primary THA. They also did make a comparison that involved radiographic measurements for LLD among those surgical techniques. LLD was lower following DAA than PLA, their findings indicate, with a difference averaging 3.0 ± 5.9 mm versus 4.2 ± 4.5 mm ($p = 0.027$). Perceived LLD or pLLD was assessed within the study so meaning just the patient's subjective experience of leg length differences. At the six-week follow-up ($p = 0.001$), patients in the PLA group reported LLD greatly more than in the DAA group. However, the LLD perception did not differ to a large extent among the two groups at one year as well as at five years after the operation. The study interestingly found no direct correlation between radiographic LLD and pLLD so this suggests patient-reported outcomes are influenced by factors beyond objective leg length differences like preexisting musculoskeletal conditions and psychological perception. The authors did also examine acetabular component positioning, and this examination showed that the PLA group had a greatly greater acetabular anteversion (18.4° ± 2.9°) compared with the DAA group (12.9° ± 2.9°; $p < 0.01$), which may well contribute to differences within LLD outcomes. 80.1 ± 5.4, $p = 0.04$) along with three months (89.6 ± 8.4 vs. 86.4 ± 6.9, $p = 0.03$). Furthermore, it was these patients who were in the DAA group. 80. 5 with ± 6.6, $p = 0.015$). This indicates better early functional recovery now.Despite these short-term advantages, HHS scores were comparable between both groups at one and five years, suggesting that the initial differences in functional outcomes may diminish over time. The study emphasizes the importance of surgical technique in minimizing LLD and highlights that DAA may provide more precise leg length equalization due to intraoperative leg-length verification and fluoroscopic guidance. However, the authors acknowledge that both approaches have their challenges, with DAA requiring a longer operative time and PLA potentially increasing the risk of LLD due to adjustments made for joint stability. These findings reinforce the notion that while DAA may offer benefits in early LLD reduction and recovery, long-term outcomes are influenced by multiple factors, including implant positioning, surgical expertise, and individual patient characteristics (3).

8. Preoperative Factors of Leg Length Discrepancy After Hip Replacement for femoral neck fractures

The etiology of LLD following hip arthroplasty for FNF is multifactorial, involving both preoperative anatomical conditions and intraoperative factors. According to Faldini, pre-existing anatomical variations such as coxa vara, coxa valga, previous fractures, or pelvic asymmetry can predispose patients to LLD (1). Additionally, Huang et al. highlight that improper surgical techniques, such as incorrect femoral stem positioning, acetabular cup malalignment, or soft tissue tension imbalance, are primary contributors to postoperative discrepancies (23). Understanding the etiological factors of LLD is essential for reducing complications, improving patient outcomes, and preventing the need for revision surgeries.

8.1 Traditional calibration methods

During the taking of the medical history, the surgeon should inquire about the presence of anatomical or functional risk factors. This included a history of previous surgery or conservative treatment to the spine or lower extremities. Patients are asked if they sense LLD and if they compensate with a heel lift (1)

Physical examination must also address the lumbar spine in order to determine the presence of a low apex scoliosis that can result in pelvic obliquity. The presence of a clinical asymmetry and mobility of the hip joint is reassessed, most importantly in adduction and abduction, in order to determine the neutral position of the hip or the possible presence of symmetric or asymmetric reduction of one of them. Fixed hip attitudes in abduction with shortening, or adduction with lengthening, are evaluated as these are functional risk factors for postoperative LLD. There is a global assessment of the lower limb to ascertain any fixed flexion of the knee, or equinus deformity of the ankle, or any asymmetry with the opposite limb, including valgus or varus deformity of the knee or valgus or varus hindfoot.

Pelvic X-rays are commonly used to assess whether LLD originates from intra-articular or extra-articular factors. If a patient does not perceive asymmetry or if the asymmetry is linked to intra-articular anatomical risk factors, a standing pelvic X-ray is generally sufficient. However, when LLD cannot be explained by local, intra-articular, or anatomical causes, a full-length anteroposterior standing radiograph of the lower limbs and a lumbar spine X-ray are required to investigate potential extra-articular anatomical contributors. In cases where limb length discrepancy and pelvic obliquity are present but no skeletal abnormalities are identified, a thorough evaluation for functional risk factors is essential (1).

Preoperative planning, which has been enhanced through specialized software, relies on a standard pelvic X-ray with markers to properly scale the images and obtain accurate measurements. This process aids in predicting implant size, placement, and potential postoperative LLD by simulating the surgical procedure in advance (1).

Patients can be classified as either low- or high-risk for developing postoperative LLD based on their medical history, physical examination, and radiographic findings . Patients who do not use a shoe lift, feel symmetrical, have no spinal or pelvic abnormalities, and have a limb length difference of less than 1 cm are considered low risk for significant LLD after THR. Their preoperative X-rays typically show only mild joint deformities. On the other hand, patients with anatomical risk factors for lengthening-related LLD or those who already have LLD before surgery—whether intra-articular or extra-articular—are more difficult to manage. In these cases, restoring symmetry can be challenging without increasing the risk of dislocation (1).

For patients with anatomical factors leading to shortening, compensation during surgery is often easier, particularly if the deformity is at the head or neck of the femur, where THR is performed. However, when the shortening is due to extra-articular causes, restoring limb length is more complex. In such cases, the goal of THR is to reconstruct joint geometry rather than fully correct LLD. Lengthening through THR may result in a stiff hip, while shortening procedures can increase the risk of dislocation or instability (1).

8.2 Planning Hip Replacement with femoral neck fracture

Traditional calibration methods are more challenging in patients with femoral neck fractures due to the distorted proximal femoral anatomy, which makes it difficult to use standard anatomical landmarks for templating and implant positioning. The axial, sagittal, and coronal deformities caused by the fracture alter preoperative leg length assessment, making it necessary to rely on alternative methods for accurate implant selection and limb length restoration (24) Common reference points for preoperative planning in THA include the lesser trochanter to center of femoral head (LTC) and the femoral head diameter (FHD). Since the affected hip is unreliable for templating, surgeons often use contralateral hip measurements to estimate these parameters. The study by Anatone et al. compares two methods for predicting the LTC length in THA: the LTC:FHD ratio method, which derives the required LTC using a ratio from the contralateral hip, and the calibrated measurement method, which relies on preoperative radiographic calibration markers (24).

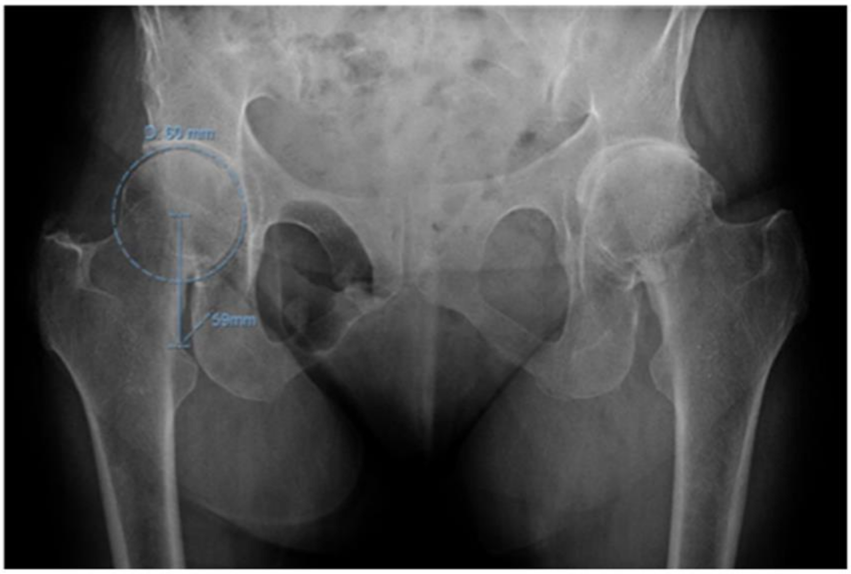

Figure 5. Methods for restoring neck length in hip arthroplasty. Reproduced from: Anatone AJ, Rahman R, Uppstrom TJ, Blevins JL, Sculco PK, Ricci WM. Comparison and validation of methods for restoring neck length in hip arthroplasty that can be applied for femoral neck fracture. *HSS J Musculoskelet J Hosp Spec Surg.* 2024. Figure 1. (24)

As illustrated in Figure 5, radiographic measurements of LTC and FHD were conducted on both the operative and contralateral hips in patients undergoing total hip arthroplasty (THA). The femoral head diameter (FHD) was measured by drawing a circle midway between the femoral head and acetabulum to account for the articular cartilage. The lesser trochanter to center (LTC) distance was measured from the proximal axilla of the lesser trochanter to the center of the femoral head.

The study by Anatone et al. demonstrates that the LTC:FHD ratio method more accurately predicts the intraoperative lesser trochanter to femoral head center (LTC) distance compared to the traditional calibrated measurement approach. Specifically, the ratio method showed almost no deviation from actual intraoperative measurements, with a mean difference of just 0.5 mm ($p = 0.31$), while the calibrated method had a significantly larger discrepancy of 3.0 mm ($p < .001$). This suggests that the ratio-based approach is less prone to errors caused by magnification or imperfect calibration marker placement, which are common challenges in preoperative planning—especially in trauma cases involving femoral neck fractures. By relying on each patient's unique anatomical proportions rather than absolute measurements, the LTC:FHD ratio method offers a more individualized and reliable strategy for predicting femoral head height and restoring leg length during hip arthroplasty. Given that accurate limb length restoration is critical to avoiding postoperative complications such as LLD, these findings highlight the clinical value of the LTC:FHD ratio as a templating tool for improving outcomes in patients with femoral neck fractures (24).

For preoperative patient evaluation, these findings suggest that contralateral hip measurements using the LTC:FHD ratio should be prioritized over traditional calibration techniques, especially in trauma patients with altered proximal femoral landmarks. This method enhances surgical accuracy, minimizes LLD risk, and provides better predictability for implant positioning during THA.

9. Intraoperative factors of Leg Length Discrepancy

9.1 Changes in Center of Rotation (COR)

During THA, the center of rotation (COR) can shift from its natural position, often moving downward and laterally. This displacement may result from using oversized acetabular cups or improperly seating the implant within the acetabulum. If the COR migrates upward, the limb may become shorter postoperatively. This is often caused by excessive acetabular reaming. The risk is particularly high in hip dysplasia cases, where a small-diameter cup is implanted. Ensuring proper implant positioning is essential to maintaining anatomical alignment and preventing leg length discrepancies (1).

Huang et al. (2023) analyzed a cohort of 161 patients who underwent primary cementless THA between January 2021 and March 2022, using either proximal-coated or fully coated femoral stems. To evaluate the impact of canal flare index (CFI), canal fill ratio (CFR), center of rotation (COR), and femoral offset (FO) on postoperative LLD, a multivariate logistic regression was conducted. Additionally, linear regression was applied to examine how these factors influenced clinical outcomes. Regarding COR Huang et al. (2023) emphasizes that improper COR reconstruction may not only lead to inconsistent leg length but also increase the risk of dislocation. One of the challenges in achieving accurate COR positioning is the lack of clear anatomical landmarks intraoperatively, making precise reconstruction difficult. Additionally, according to Huang the COR may migrate inwards and upwards, unlike Fladini who states that it may move downward and latererally, due to improper acetabular reaming, which is often performed to fit the prosthetic cup into the acetabulum (1). Huang's study identified low vertical COR displacement (ΔVCOR) as an independent risk factor for significant postoperative LLD, reinforcing the importance of careful intraoperative adjustments. However, horizontal COR displacement (ΔHCOR) did not show a significant effect on LLD, indicating that vertical changes in COR positioning play a more critical role in leg length discrepancies (23).

9.2 Acetabular Component

Excessive tension in the abductor mechanism can lead to pelvic obliquity and functional leg length discrepancy (LLD). This may result from an increase in femoral offset or the lateral displacement of the acetabular component, which in turn raises the global offset of the prosthetic joint (1). This underscores the impact of acetabular component mispositioning, particularly lateralization, in altering the center of rotation (COR) and contributing to functional LLD.

9.3 Femoral Stem Positioning

Improper seating or incorrect sizing of the femoral stem can result in either a stem that sits too high ("sitting proud"), leading to limb elongation, or a stem placed too deep, causing limb shortening. According to Faldini, several factors contribute to these errors, including an inadequate femoral neck cut, incorrect preparation of the proximal femur, and valgus or varus malpositioning of the stem, particularly in short-stem designs. Additionally, a mismatch between the width of the meta-diaphyseal canal and the size of the proximal femur can affect implant selection. For example, a Dorr A femur (narrow canal) may require a smaller stem, increasing the risk of limb shortening, while a Dorr C femur (wide canal) often necessitates a larger stem, which can lead to limb lengthening. These factors highlight the importance of proper femoral stem positioning in preventing postoperative LLD (1).

While Faldini focuses more on the effects of improper femoral stem depth, neck cut errors, and valgus/varus malalignment on leg length discrepancy (1), Huang et al. additionally emphasizes that Canal Fill Ratio (CFR) and Canal Flare Index (CFI) are key factors in determining how well the stem fits within the canal, affecting implant stability and the risk of subsidence. A poorly matched femoral stem can result in uneven load distribution, potentially leading to implant migration over time, which further contributes to postoperative LLD. Proper preoperative assessment of CFR, CFI, and femoral morphology is crucial for optimizing stem placement and preventing complications (23).

9.4 Surgeon-Dependent Factors

During THA, surgeons may adjust femoral offset or soft tissue tension to enhance implant stability. Faldini notes that challenges in component positioning and soft tissue balance can necessitate these modifications, which may inadvertently alter limb length. Although such adjustments are not necessarily errors, they highlight the delicate balance between stability and leg length restoration in THA. This reinforces the need for precise preoperative planning and intraoperative assessment to minimize (1).

An article by Stimolo et al. (2025) presents a multicenter survey investigating how orthopedic surgeons in Italy approach LLD following THA. While the study does not explicitly focus on the role of a surgeon’s experience in minimizing LLD, it does highlight variability in how different groups of surgeons—orthopedic physicians, trauma surgeons, and hip replacement specialists—manage postoperative LLD. The survey results indicate that hip replacement specialists are more likely to adhere to literature-based recommendations compared to general orthopedic physicians and trauma surgeons. The study suggests that experienced hip replacement surgeons are more consistent in their approach to LLD management, particularly when deciding on interventions such as physiotherapy, shoe lifts, or revision surgery. This implies that specialization and experience in hip replacement may contribute to better adherence to best practices in LLD management. However, the article does not directly quantify the impact of a surgeon’s experience on reducing LLD risk during surgery (25).

10. Diagnostic approach of LLD after Hip replacement

10.1 How to measure LLD, Actual vs apparent LLD

Following THA, many patients initially report a sensation that the operated leg is longer than the other. This perception is primarily due to pre-existing soft tissue contractures around the hip joint, which develop as a result of the underlying pathology. These contractures tilt the pelvis toward the diseased side, and during surgery, their release corrects this inclination, making the limb feel artificially lengthened postoperatively. However, this perceived LLD does not necessarily indicate an actual structural difference, and it generally improves over time with physiotherapy and soft tissue adaptation. As Kayani refers to Wylde, a study of 1,114 THA patients found that while 30% of patients reported experiencing LLD, only 36% of these cases were confirmed as true structural discrepancies through radiographic assessment. Therefore, patients should be reassured that their perception of LLD is unlikely to result in long-term functional impairment and typically resolves within six months post-surgery (26).

A detailed medical history and clinical evaluation are essential to assessing LLD-related symptoms and developing a patient-specific management approach. Individuals experiencing LLD after THA may present with pain, neurological symptoms, instability, abnormal gait mechanics, muscle spasms, and fatigue affecting the lower back or contralateral limb. The biomechanical impact of LLD often leads to increased energy expenditure during walking, as the body compensates for asymmetry by relying on secondary muscle groups, which in turn contributes to early fatigue and secondary joint pain (26).

10.2 Consequences of LLD After Hip Replacement

Although a minor difference in leg lengths might appear trivial, clinical evidence shows that even small discrepancies can significantly impact post-operative recovery and long-term function. The following two paragraphs explore distinct consequences of LLD as presented in separate research articles.

One of the most pronounced consequences of LLD after hip fracture repair is its detrimental impact on walking ability. Pearce et al. found a strong association between postoperative LLD and reduced gait speed in older adults. Their study observed that patients with greater discrepancies between leg lengths exhibited significantly slower walking speeds one year after surgery. Notably, this decline in gait speed persisted even after accounting for preoperative walking ability, body mass index, and surgical approach. The authors highlight that gait speed is a well-established marker of functional independence and mortality risk, indicating that LLD may not only impair mobility but also affect broader health outcomes. By diminishing one's ability to walk efficiently, LLD potentially compromises recovery quality and day-to-day functioning, reinforcing the importance of precise leg length restoration during surgery (27).

In addition lower back pain is a frequent and clinically relevant complication following THA, particularly in patients who develop a symptomatic leg length discrepancy (sLLD). The study by Waibel et al. demonstrates that while many patients undergoing THA experience minor leg length differences, it is the subjective perception of this discrepancy, rather than its exact anatomical measurement, that plays a crucial role in the development of postoperative lower back pain. Interestingly, their results showed that new-onset lower back pain was significantly more common in patients who reported being disturbed by their perceived LLD. This association existed independently of the absolute magnitude of the leg length difference. The study further suggests that discrepancies exceeding 10 millimeters may increase the likelihood of perceiving an LLD, yet lower back pain was present even in patients with smaller differences, as long as they felt symptomatic. These findings highlight that sLLD can disrupt the delicate balance of trunk and pelvic alignment, leading to compensatory changes in posture and movement, which may strain the lumbar spine. Consequently, postoperative lower back pain emerges as a complex, multifactorial outcome, shaped not only by surgical precision but also by the patient's sensory perception and adaptation to altered biomechanics (28). Together, these findings underscore the multifaceted consequences of LLD after hip replacement. From impairing gait to disrupting balance, LLD can significantly hinder post-operative recovery and long-term quality of life. These insights call for meticulous surgical technique and early therapeutic intervention to minimize discrepancies and their downstream effects.

10.3 Clinical Examination of Leg Length Discrepancy after Hip Replacement

A comprehensive clinical examination is essential for accurately assessing LLD following THA. This evaluation should include a detailed assessment of the spine, hip, and knee, along with a full neurological examination of both lower limbs to identify any nerve-related symptoms. Any postoperative findings related to LLD or joint contractures should be compared with preoperative assessments and discussed thoroughly with both the patient and rehabilitation team to determine appropriate management strategies (26).

Observing the patient's gait pattern can provide important diagnostic insights into compensatory mechanisms that develop in response to LLD. These adaptations may include toe walking on the shorter side, pelvic tilt, circumduction during the swing phase, or knee flexion in the stance phase on the longer limb. "Flexed knee syndrome" refers to patients who maintain a constant knee flexion on the longer leg, often due to overactivity of the quadriceps and hamstring muscles, which attempt to compensate for the discrepancy. Patients with functional LLD caused by a flexion-abduction contracture on the operated side will often have pelvic tilt toward that side. Conversely, if the patient has undergone appropriate intraoperative soft tissue releases but continues to have contractures on the contralateral side, the pelvic tilt may be directed toward the non-operated limb (26).

Accurate measurement of leg length is crucial, as standard pelvic radiographs typically only capture discrepancies in the proximal femur and may overlook subtrochanteric causes. Structural limb length measurements should be performed with the patient in a supine position, using a tape measure to compare distances from the anterior superior iliac spine (ASIS) to the medial malleolus on both sides. This method is considered highly reliable, with an accuracy of approximately 1 cm. Additionally, specialized tests such as Ober's test can assess iliotibial band contractures, while the Thomas test is useful for identifying fixed flexion deformities at the hip. To evaluate femoral vs. tibial contributions to LLD, further comparative measurements of the greater trochanters, patella, and medial malleoli should be conducted (26).

Apparent LLD can also be assessed by measuring distances from the xiphisternum to the medial malleoli while the patient is in a supine position. Another approach is block testing, where graduated 5 mm lifts are placed under the shorter limb until the patient perceives their legs as equal, and the anterior superior iliac spines (ASIS) are level. This method helps determine whether pelvic obliquity, flexible spinal deformities, or hip/knee contractures contribute to the perceived discrepancy. However, it is essential to recognize that some conditions, such as rigid scoliosis or concurrent hip abduction/adduction contractures, may not be corrected through block testing alone (26).

Spinal assessment is also crucial in LLD evaluation, as patients may develop compensatory scoliosis in response to limb length asymmetry. Examination should include evaluation of coronal and sagittal spinal alignment, as well as the Adams forward-bending test to check for thoracolumbar scoliosis. If compensatory scoliosis is present, placing a block under the shorter limb can help determine whether the spinal curve is flexible or rigid, which is essential for developing a targeted treatment plan (26).

10.4 Postoperative imaging of LLD after Hip Replacement

Postoperative anteroposterior pelvic radiographs are essential in assessing implant positioning and changes in LLD following total hip arthroplasty THA. Comparing templated preoperative measurements with the final implant positioning helps determine whether LLD originates from the acetabular cup or femoral stem. Common radiographic landmarks include the acetabular teardrop for assessing the cup position and the lesser trochanter for evaluating femoral stem placement. Additionally, the tip of the greater trochanter should be horizontally aligned with the femoral head center, as deviations may indicate malpositioning of components. In cases where more precise analysis is required, modified cross-table lateral radiographs or computed tomography (CT) scans can provide detailed insight into implant alignment and orientation. Moreover, if osteoarthritis is present in the contralateral hip, future THA on the opposite side could offer an opportunity to restore limb length symmetry (26).

There are two widely used radiographic techniques for measuring LLD, both of which rely on specific pelvic and femoral reference points. The first technique involves drawing a horizontal reference line through the inferior aspects of the acetabular teardrops. The femoral reference point is the vertex of the lesser trochanter, and the vertical distance between this landmark and the pelvic reference line is measured bilaterally. The difference between these measurements indicates the true LLD originating from the hip and proximal femur. This method is known for its high accuracy, with a measurement error of approximately ±1 mm. The second technique uses a horizontal reference line across the ischial tuberosities to determine LLD by calculating the vertical distance from the lesser trochanter to this line on both sides (26).

It is important to recognize that these measurement techniques assume the pelvis is not rotated, which could introduce errors in LLD assessment. Furthermore, these radiographic methods primarily evaluate limb length discrepancies at the proximal femur, without accounting for anatomical differences below the lesser trochanters that may contribute to overall limb length variations. Therefore, a comprehensive assessment, including clinical examination and additional imaging when necessary, is crucial for ensuring an accurate diagnosis and appropriate management of LLD after THA (26).

10.5 Conservative Treatment of Leg Length Discrepancy after Hip Replacement

In the early postoperative period, leg length discrepancy (LLD) after total hip arthroplasty (THA) is often functional rather than structural, arising from periarticular muscle contractures that lead to pelvic obliquity When the hip abductor muscles are tight, the ipsilateral hemipelvis tilts downward, creating the perception of a lengthened leg. Conversely, adductor muscle contractures can elevate the affected hemipelvis, leading to the impression of limb shortening Despite patient-reported LLD, radiographic and clinical evaluations often reveal no true structural discrepancy (26).

To manage functional LLD, patient education and targeted physiotherapy are key. Stretching exercises aimed at releasing soft tissue contractures can help restore pelvic alignment and correct functional discrepancies. Techniques such as the hula maneuver, where the patient crosses the affected foot over the contralateral leg and leans away, help stretch the hip abductor muscles and joint capsule. Additionally, anterior hip structures, such as the rectus femoris muscle, can be stretched by placing the patient in a prone position and hyperextending the hips. These exercises should initially be performed under supervision to ensure that they remain within a safe range of motion, minimizing the risk of joint instability or dislocation (26).

Recovery from functional LLD typically follows a predictable timeline. As Kayani refers to Ranawat and Rodriguez, a study of 100 primary THA patients found that 14% experienced functional LLD at one month postoperatively, but all cases fully resolved within six months. However, in 0.5–7% of patients, functional LLD persists despite ongoing physiotherapy. It is generally recommended to delay the introduction of shoe inserts for at least six months postoperatively, allowing periarticular muscles sufficient time to adapt and correct naturally (26).

10.6 Thresholds for Clinically Significant LLD and Use of Shoe Inserts

The degree of LLD following THA varies, with an average discrepancy ranging from -1 to 3.5 mm. However, there is no universally accepted threshold defining when LLD becomes clinically relevant. Studies suggest that one-third of the general population naturally exhibits LLD of 5 mm to 2 cm, often without any functional impairments. Furthermore, asymmetries of up to 2 cm after THA may not appear to significantly affect gait symmetry, step length, or stair climbing ability (26).

However, some research indicates that up to 50% of patients with an LLD greater than 10 mm experience symptoms such as discomfort, gait disturbances, or muscle fatigue, with 15–20% requiring shoe modifications. While structural LLD of up to 10 mm is usually well tolerated without orthotic intervention, larger discrepancies may require shoe inserts to artificially balance limb length. Shoe insoles can provide up to 9.5 mm of additional height before requiring customized footwear modifications. The use of shoe inserts post-THA has been shown to reduce pain, minimize muscle fatigue, and improve posture and gait mechanics, making them an effective non-surgical management option for patients with persistent LLD-related symptoms (26).

10.7. Revision Surgery

Revision surgery is required when LLD leads to neurological issues, instability, persistent pain, lumbar fatigue, or a significant decline in quality of life that does not resolve within 6–12 months postoperatively. There is no fixed threshold for when limb lengthening causes neurological symptoms, but research shows that peroneal nerve palsy occurs at 27 mm of lengthening, while sciatic nerve palsy develops at 44 mm. Despite this, studies indicate that one-third of THA patients report perceived LLD, and discrepancies up to 35 mm may remain asymptomatic. In cases of foot drop, management should include ankle-foot orthosis (AFO) and passive physiotherapy to prevent contractures and flexion deformities (26).

If femoral and acetabular components are properly positioned, the least invasive revision strategy is a modular component exchange, which involves adjusting the femoral head size, modifying neck length, and changing the acetabular liner. However, modular exchange carries risks, including liner dissociation, impingement, instability, and femoral head dislodgment from the stem. Patients undergoing this procedure require strict clinical and radiological follow-up to monitor implant stability and function (26).

If implant malpositioning is detected, surgical revision may involve acetabular cup repositioning or conversion to a modular head to correct LLD while preserving joint stability. In cases of soft tissue laxity, corrective measures include using larger femoral heads, lateralized acetabular liners, high-offset femoral components, or trochanteric advancement to restore proper biomechanics (26).

Revision surgery for LLD following THA is a complex procedure with highly variable outcomes. The success of surgical intervention depends on multiple factors, including the severity of the discrepancy, underlying implant positioning, and the presence of neurological or functional complications. Since outcomes are not always predictable, a meticulous preoperative approach is essential. Thorough imaging, including radiographic assessment and component positioning analysis, is crucial in determining whether the femoral or acetabular component is responsible for the discrepancy. Additionally, a well-structured surgical plan tailored to the individual patient's anatomy and functional limitations is necessary to optimize results and minimize complications. Given the potential challenges associated with revision surgery, patients must be properly counseled about the risks, benefits, and expected functional outcomes to ensure realistic expectations before proceeding with surgical correction (26).

10.8. Classification of LLD in Component Malpositioning

LLD following THA can result from two primary types of component malpositioning. The first category, direct malpositioning, occurs when the acetabular cup is placed too inferiorly, leading to excessive lengthening, or when the femoral stem is not properly seated in the proximal femur, resulting in limb shortening. The second category, compensatory changes, arises when excessive acetabular retroversion causes intraoperative instability. In such cases, surgeons may attempt to restore hip stability by lengthening the femoral neck or increasing offset, inadvertently leading to excessive limb lengthening. To achieve leg length equality while maintaining hip stability, meticulous preoperative imaging and intraoperative assessment are essential (26).

10.9 Managing Neurological Complications After Leg Length Discrepancy Revision

Neurological symptoms following LLD revision surgery can result from factors beyond limb lengthening itself, including retractor-induced nerve trauma, compression caused by hematoma formation, or thermal damage due to cement polymerization. In cases where patients develop peroneal nerve palsy with LLD below 6 mm, spontaneous recovery may occur within 6 to 24 months. If neurological deficits persist, postoperative diagnostic imaging, such as CT, ultrasound, or electromyography, may be necessary to evaluate nerve damage severity and predict the likelihood of recovery. During this period, interim management strategies include the use of an ankle-foot orthosis (AFO) to prevent contractures and passive physiotherapy to maintain joint mobility and function (26).

11 Advances in Technology and Future Directions

Advances in technology have significantly improved the ability to prevent and manage leg length discrepancy following total hip arthroplasty. Modern surgical techniques, computer-assisted navigation, and intraoperative imaging have contributed to more accurate leg length restoration. Despite these developments, LLD remains a relevant postoperative complication, highlighting the need for further innovation. Future directions focus on refining measurement tools, enhancing patient-specific planning, and developing new strategies to minimize the functional consequences of LLD.

11.1 EOS imaging

Conventional anteroposterior (AP) pelvic radiographs have long been the standard method for assessing LLD preoperatively in THA. However, their accuracy in measuring LLD has been increasingly questioned. Hardwick-Morris et al. found that measurements taken using the inter-teardrop to lesser trochanter (LT) distance on an AP weight-bearing pelvic radiograph do not correlate well with those taken on EOS imaging. This suggests that AP pelvic radiographs may not fully capture all sources of LLD, potentially leading to misjudgment of limb length and suboptimal preoperative planning (29).

Another study evaluating 43 primary unilateral THAs found that EOS predicted the exact acetabular and femoral component sizes in 71% and 66% of cases, respectively, and was within one size in 98% of cases. EOS templating was more accurate than conventional radiographs ($P < .05$), with excellent interobserver agreement for acetabular (Cronbach’s alpha = 0.94) and femoral (Cronbach’s alpha = 0.96) component sizing. Additionally, EOS exposes patients to less radiation, and its 3D applications could further enhance preoperative planning (30).

12 Intraoperative Advancements

12.1 Robotic & Computer-Assisted Total Arthroplasty

Robotic-assisted and computer-assisted orthopedic surgery (CAOS) have emerged as potential solutions for improving component positioning and reducing postoperative complications in THA. These technologies aim to enhance surgical precision, particularly in restoring leg length and optimizing implant placement.

Research suggests that robotic-assisted THA after FNF (rTHA) enhances acetabular cup positioning and femoral component alignment, potentially lowering the risk of dislocations and reoperations.

However, its direct impact on preventing LLD remains uncertain. In a study by O'Donnell et al rTHA was associated with a lower rate of dislocations (0%) and reoperations (0%) compared to conventional THA (dislocation rate 5%, reoperation rate 8%), yet there was no significant difference in mean LLD between the two groups ($p = 0.19$) (31) This suggests that while robotic systems improve component stability, they may not fully eliminate leg length discrepancies yet.

In contrast computer-assisted orthopedic surgery (CAOS) has been shown to improve leg length restoration accuracy. Clavé et al. demonstrated that CAOS achieved a postoperative leg length discrepancy of ≤5mm in 83.3% of cases, showing a strong correlation between navigation-based planning and radiographic LLD measurements (32). This underscores the potential of CAOS in improving surgical precision without increasing complication rates. However Clavé et al. also mentions that one of the main limitations of robotic and navigation-based systems is the learning curve required for surgeons.

12.2. Fluroscopy

Fluoroscopy is an advanced imaging technique. It can visualize anatomical structures in real time for when surgeons perform procedures. In THA, fluoroscopic guidance is particularly valuable because it assesses bone preparation, it ensures proper component positioning, together with it measures leg length and offset accurately. A main benefit involves precise acetabular cup placement because that placement matters greatly for hip replacements' lasting success. To position the acetabular component, surgeons usually rely upon anatomical landmarks. These reference points can be inconsistent so this leads to variations in placement. Improper positioning outside Lewinnek’s safe zone can result in higher dislocation rates, increased biomechanical stress, and excessive wear on implant surfaces, ultimately leading to complications such as instability and revision surgery (8).

The study by Daines and Yang highlights how fluoroscopy enhances accuracy in acetabular cup placement during the direct anterior approach (DAA) for THA. Fluoroscopic imaging has been shown to significantly reduce variability in cup inclination and anteversion, leading to more consistent positioning within the safe zone. Research comparing THA procedures performed with and without fluoroscopic guidance found that the use of real-time imaging increased the likelihood of achieving ideal cup alignment (8).

Furthermore, the study discusses some of the concerns that are in regard to radiation exposure during fluoroscopic-guided procedures. Fluoroscopy does introduce additional radiation exposure to the surgeon and the patient, but multiple studies have shown the levels remain safe.

In general, fluoroscopic guidance does improve precision during THA, most especially within the direct anterior approach. It also can reduce complications such as dislocation and wear since it improves on acetabular component placement. Research suggests levels are able to be manageable with the employment of appropriate precautions even though concerns about radiation exposure still exist. Hip arthroplasty patient outcomes are optimized as surgical accuracy is improved via fluoroscopy (8).

12.3 Intraoperative Calibration Gauges in Total Hip Arthroplasty

Intraoperative calibration gauges have emerged as a promising tool for improving leg length and femoral offset accuracy in THA. Enke et al. investigated the effectiveness of hip calibration gauges in a study of 101 unilateral THAs, comparing postoperative outcomes to preoperative templating and intraoperative measurements. Their findings showed that the use of a calibration gauge significantly reduced LLD from a preoperative average of 3.54 mm to 2.51 mm ($p = 0.018$). Additionally, 93.1% of patients achieved an LLD of ≤5 mm, demonstrating the precision of this technique. Compared to free-hand methods, which resulted in an average LLD of 4.42 mm, the calibration gauge proved to be significantly more accurate ($p < 0.001$) (33).

Beyond leg length restoration, the study also highlighted the importance of offset restoration, a factor often overlooked in THA. By using a calibration gauge, the mean postoperative offset difference was reduced to 2.39 mm, leading to better hip stability, improved abductor function, and reduced postoperative pain. The study suggests that precise intraoperative feedback through a gauge system can help surgeons make more informed decisions regarding implant selection and positioning, ultimately improving functional outcomes (33).

While not yet standard practice, the use of intraoperative calibration gauges represents a significant advancement in THA by enhancing surgical precision and minimizing postoperative complications associated with LLD and offset mismatch. Future research should further explore its role in optimizing implant placement and long-term patient outcomes (33).

12.4 Shoulder to shoulder technique

The "shoulder-to-shoulder" manual positioning technique represents a significant advancement in intraoperative methods to prevent postoperative LLD in hip arthroplasty for FNFs This technique relies on anatomic alignment between the marked "shoulder" of the femur and the "shoulder" of the prosthesis stem, ensuring accurate limb length restoration during surgery. The study evaluating this method was conducted on 52 patients with femoral neck fractures who required hip arthroplasty between July 2020 and March 2022 at Jinjiang Municipal Hospital, China. Patients were categorized into those undergoing THA and HA.

The method involved marking the femoral "shoulder" at the level of the lowest point of the piriformis fossa on the femoral trochanter and aligning it with the "shoulder" of the prosthesis stem during implantation to maintain leg length symmetry. Intraoperative measurements of the apex–shoulder distance were taken and later compared to postoperative imaging to assess the accuracy of this manual positioning technique. Statistical analysis showed no significant difference in postoperative limb lengths between the ipsilateral and contralateral sides, confirming the method's effectiveness in preventing LLD. Postoperative imaging confirmed that the method effectively maintained limb length equality, with no statistically significant discrepancies between the operated and contralateral limbs. This approach provides an important alternative to traditional measurement techniques, offering a simple yet effective solution to one of the most challenging aspects of hip arthroplasty (7).

12.5 Anterior minimally invasive total hip arthroplasty (AMIS)

The use of a compass device for intraoperative leg length assessment in anterior minimally invasive total hip arthroplasty (AMIS) represents a valuable advancement in the effort to minimize postoperative LLD. This method allows for precise measurement of the distance between fixed anatomical landmarks on the pelvis and femur, ensuring accurate limb length restoration without the need for intraoperative fluoroscopy. A study by Girolami et al involved 35 patients undergoing unilateral primary THA with the AMIS technique, where preoperative and postoperative leg lengths were compared using anteroposterior pelvic radiographs. The results demonstrated a significant reduction in postoperative LLD, with 88.2% of cases presenting discrepancies of less than 5 mm and 94.1% within 10 mm, indicating a high level of accuracy. This method is notably useful because it is fast, inexpensive, and reduces radiation exposure for surgeons and patients. By eliminating the reliance on fluoroscopy and providing reproducible intraoperative measurements, this approach enhances precision in limb length control, making it a promising advancement in THA surgery (34)

12.6 Enhanced Surgical Training

As already mentioned, surgical experience also plays a role in LLD after THA for FNF. Modern surgical techniques for THA have become increasingly complex, requiring advanced instrumentation and precise execution. These challenges necessitate effective and standardized training methods to ensure optimal surgical outcomes. Traditional training approaches, such as reading manuals and observing surgeries, offer limited hands-on experience, while cadaveric simulations require extensive resources. Virtual reality (VR) has emerged as a promising tool for surgical training, providing an immersive and interactive learning environment. By simulating the operating theater with motion-tracked controllers, VR allows trainees to develop both technical and procedural skills in a risk-free setting. This study by Logishetty et al. investigates whether VR training can enhance surgical performance in THA compared to conventional learning methods (35).

The study conducted a randomized controlled trial involving 24 surgical trainees with no prior experience in the anterior approach to THA. Half of the participants completed a six-week VR training program, while the others relied on traditional preparatory materials. Performance was assessed through a cadaveric THA procedure, evaluated by independent surgeons. The results demonstrated that VR-trained surgeons significantly outperformed their conventionally trained counterparts. They completed 33% more key procedural steps, achieved a 12° greater accuracy in acetabular component orientation, and performed the procedure 18% faster. Moreover, VR-trained surgeons required minimal guidance, whereas conventionally trained trainees needed substantial intervention. These findings highlight VR's potential to accelerate skill acquisition, improve precision, and enhance surgical efficiency and ultimatively improving postoperativeLLD, making it a valuable supplement to traditional training methods in orthopedic surgery (35).

13. Summary of results

LLD is a common complication after THA and HA for FNF. Up to 27% of THA patients experience LLD, which can lead to gait problems, back pain, and higher revision surgery rates. LLD results from both preoperative factors, like pelvic tilt or old fractures, and intraoperative factors e.g. implant positioning and surgical technique.

Understanding hip joint biomechanics, including the role of ligaments, muscles, and blood supply, is important for managing LLD. Classifications like Dorr classification and Canal Flare Index (CFI) can be helpful for preoperative planning. Different femoral bone types (Dorr A, B, C) present different risks for stem fitting and potential LLD.

Femoral neck fractures are most common in elderly women and have a high risk of complications if not treated properly. Classifications like Garden, Pauwels, and AO/OTA help guide surgical planning. Although conservative management can be considered for some non-displaced fractures, surgical treatment with HA or THA is preferred for most displaced fractures due to better outcomes.

Comparing treatments, THA generally provides better long-term function but has a higher risk of dislocation. HA is a better option for frail or low-demand patients. Cemented HA offers better stability and lower fracture risks compared to uncemented HA. Similarly, cemented THA has lower revision rates and better hip function scores over time, although it does not clearly prevent LLD better than uncemented THA.

Regarding surgical approaches, the DAA achieves lower LLD compared to the posterolateral approach PLA. DAA also allows for better early recovery but requires more surgical skill and longer operating times. However, in the long term, patients' perception of LLD is similar between the two approaches.

Several preoperative factors, such as existing asymmetries and inaccurate calibration, can increase the risk of LLD. Newer methods like the LTC:FHD ratio improve accuracy in surgical planning. During surgery, mistakes in reconstructing the center of rotation, acetabular cup placement, and femoral stem positioning are major causes of LLD. Poor fit between implant and bone (CFR and CFI mismatches) can also cause later migration of the implant.

Postoperatively, most early LLD cases are due to soft tissue issues rather than true bone length differences. Patients commonly experience gait abnormalities and back pain. Radiographic and clinical assessments are important to distinguish real from apparent LLD. Small LLDs (less than 10 mm) are usually well tolerated and can often be managed with shoe lifts or physiotherapy.

Finally, technological innovations such as robotic-assisted THA, computer navigation, EOS imaging, intraoperative calibration tools, and virtual reality training are helping to improve surgical accuracy and planning. However, these technologies have not completely eliminated the risk of LLD.

14. Discussion

LLD remains a persistent and clinically significant complication after hip replacement for FNF. Although modern surgical techniques and technological advancements have aimed to mitigate this issue, a critical analysis of the literature reveals that both patient-specific factors and surgeon-dependent variables continue to influence LLD outcomes substantially. This discussion will integrate and critically appraise the evidence presented in the preceding sections, highlighting the strengths and limitations of some of the mentioned studies.

Surgical Techniques and Their Impact on LLD

LLD. Lu et al. demonstrated that the (DAA resulted in significantly lower LLD compared to the posterior lateral approach PLA (3). Strengths of this study include a large number of patients and a combined focus on both radiographic and perceived LLD, providing a broad understanding of patient outcomes. However, there are some limitations. The follow-up period was relatively short; while early improvements were clear, it remains uncertain whether the benefits in LLD reduction continued beyond the five-year mark. In addition, the surgeries were performed by four different surgeons, which could introduce variation in surgical technique and affect the consistency of results. Although this setup reflects real-world clinical practice, it makes it harder to link the outcomes directly to a specific surgical approach.

While studies such as those by Fernandez et al. and Mao et al. support the use of cemented fixation for improved early stability, others like Yassin et al. report no significant difference in postoperative LLD between cemented and uncemented stems. It is important to note that the study by Yassin et al. included only 26 patients, which represents a relatively small sample size and limits the ability to draw reliable conclusions regarding clinical outcomes. However, one possible explanation for these inconsistent findings is the lack of standardized surgical techniques across studies. Different surgeons may use varying intraoperative methods, which can significantly influence implant positioning, stability, and ultimately LLD outcomes, regardless of the type of prosthesis fixation. Without controlling for surgical variability, it becomes difficult to attribute differences in outcomes solely to the choice of fixation method. This highlights the need for future research to adopt more standardized surgical protocols in order to generate more comparable and reliable results.

Technological Advances in LLD Prevention

Technological innovation represents a promising frontier for addressing LLD. Robotic-assisted and computer-assisted orthopedic surgery (CAOS) have demonstrated improved implant positioning accuracy. Clavé et al. (33) showed that CAOS achieved postoperative LLD ≤5 mm in 83.3% of cases, a significant improvement compared to freehand methods. However, O'Donnell et al. (32) indicated that robotic assistance did not significantly reduce LLD despite lowering dislocation rates, suggesting that while technology enhances overall surgical precision, it may not completely eliminate discrepancies caused by intraoperative variables.

The use of intraoperative calibration gauges, as studied by Enke et al. (34), offers another practical solution. The strength of their study lies in the direct comparison between calibrated and freehand measurements, demonstrating a statistically significant reduction in LLD with calibration gauges. However, broader adoption remains limited, due to increased surgical time and the need for additional training.

Additionally, it should be questioned whether the financial investment in new technologies is justified, given that the improvements in LLD often involve only a few millimeters. This is especially important when considering that the patient's perception of LLD does not always correlate directly with the actual measured difference. Careful thought should be given to whether healthcare systems should routinely invest in these innovations for all THA procedures following femoral neck fractures, or whether they should be reserved for more complex cases. This also raises the question of how much public health priorities and budgets should influence the decision to use expensive technologies that may only provide small clinical benefits.

Preoperative and Intraoperative Factors

Preoperative planning remains a cornerstone for LLD prevention. The study by Anatone et al. (24) critically evaluates methods for predicting femoral head center positioning, favoring the LTC:FHD ratio over traditional calibration techniques. A strength of this study is its focus on individualized planning based on patient-specific anatomy, which is crucial in cases of distorted proximal femoral anatomy after fracture. However, it should be noted that even high quality preoperative templating cannot fully account for intraoperative adjustments necessitated by unforeseen challenges, such as poor bone quality.

Intraoperative variables, particularly changes in center of rotation (COR) and femoral stem positioning, play pivotal roles. Huang et al. (23) identified low vertical COR displacement as an independent risk factor for LLD, reinforcing the necessity of careful intraoperative technique. However, a limitation in many studies on this topic is the absence of standardized intraoperative protocols, which makes it difficult to isolate the true impact of COR changes on LLD.

Patient Perception vs. Objective LLD

An intriguing and important aspect highlighted by Kayani et al. (26)) is the discrepancy between radiographic LLD and patient-perceived LLD. Many patients experience functional impairments and dissatisfaction even with minor measurable discrepancies, underscoring the psychological and biomechanical complexity of LLD. This suggests that surgical success should not solely drawn back to by radiographic parameters but must also integrate patient-reported outcomes. The evidence emphasizes the need for patient education and realistic expectation setting prior to surgery.

Research Gaps and Future Directions

Despite significant advances, several gaps persist in the current literature. Firstly, the long-term efficacy of robotic and computer-assisted systems in consistently preventing LLD over decades remains unclear. Most existing studies have relatively short follow-ups. Secondly, more high-quality randomized controlled trials (RCTs) are needed to compare intraoperative measurement methods across diverse patient populations. Finally, there is a need to better understand the psychosocial aspects of LLD, including why certain patients tolerate discrepancies better than others.

Future studies should focus on:

- Longitudinal analyses comparing robotic-assisted and conventional THA outcomes.
- Standardizing intraoperative protocols for COR and stem positioning.
- Exploring neuroplastic and psychological factors influencing perceived LLD.

15. Conclusion

In conclusion, LLD after hip replacement for femoral neck fractures is a complex, multifactorial issue influenced by surgical approach, implant choice, technological integration, and patient-specific factors. While advancements in surgical technology and preoperative planning have improved outcomes, a critical and deep understanding of both technical and patient-centered factors remains important. Further research is required to standardize best practices, optimize intraoperative decision-making, and ultimately improve patient satisfaction and functional recovery.

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