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EXPERT'S OPINION • HIP - FRACTURES

Tips and tricks for ORIF of displaced femoral neck fractures in the young adult patient

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Abstract Femoral neck fractures in the young adult are a less common, but potentially functionally significant injury commonly occurring after high-energy trauma. The management goals of these injuries are the maintenance of a native hip joint absent avascular necrosis and nonunion. The primary determinant to this end is an anatomic reduction in displaced fractures with stable fixation. In this paper, the authors provide a set of technical tips and tricks to aid orthopedic surgeons in the surgical management of these injuries while reviewing the most recent literature available to inform clinical decision making. The paper includes the recommendations of the authors from the Denver Health Orthopaedic Trauma Service.

Keywords Femoral neck · Fracture · Young adult · Techniques · Trauma

Introduction

Intracapsular femoral neck fractures occur in a bimodal distribution. The most common peak occurs in elderly patients, generally in their eighth decade [1]. Such an injury is typically a fragility fracture [2]. Conversely, femoral neck fractures in the young adult are less common and frequently the result of high-energy mechanisms such as motor vehicle collisions or falls from height [3–6]. A subset of femoral neck fractures in the young are from repetitive activities, such as athletes and military recruits [7].

As such, femoral neck fractures in the young patient are a distinct clinical entity from those in the elderly requiring different evaluation and management considerations. A recent meta-analysis describing complications of femoral neck fractures in young adult patients found a reoperation rate of approximately 18 %, nonunion rate of 9 %, avascular necrosis rate of 14 %, and an implant failure rate of nearly 10 % [8]. These rates are consistent with previously published rates in the literature [5, 9–11]. With that in mind, clinical decision making, judgment, and surgical technique are of utmost importance to reduce those complications. Despite this, timing of surgery, reduction strategies (open versus closed), implants of choice, and fixation configuration remain topics of great debate in the orthopedic trauma literature. The aim of our paper is to present our surgical strategies in the form of tips and tricks so as to strive for anatomic reduction and stable fixation of such a complex injury.

Clinical and radiographic evaluation

The association of femoral neck fractures in the young with high-energy trauma mandates a thorough evaluation for associated injuries and adherence to advanced trauma life support (ATLS) protocols [5, 11]. Femoral neck fractures occur in the setting of femoral shaft fractures two to six percent of the time, but are initially missed in as many as 30 % of those combined injuries [12]. Patients present with an externally rotated and shortened lower extremity [13].

Radiographic workup consists of full-length plain radiographs of the femur in the anteroposterior and lateral planes [14]. A cross-table lateral is preferable in the setting

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of acute trauma to the hip. An anteroposterior view of the pelvis should be included [13].

The Garden and Pauwels' classifications are the most commonly utilized systems. In the Garden classification, four types are described by degree of displacement. Type I is valgus-impacted or an incomplete fracture. Type II is complete and non-displaced. Type III is complete and partially displaced. Type IV is completely displaced [15].

Pauwels' classification describes the angle of the fracture with respect to the horizontal. Type I is <30°; type II 30°–70°; and type III >70° [16]. In practice, the inter- and intraobserver reliabilities of both systems are sufficiently low that fractures are grouped into non-displaced and displaced variety to help guide treatment decisions [17].

Various radiographic findings should be considered. A high Pauwel's angle (>50°) is associated with posteroinferior comminution in as many as 96 % of cases. They are also associated with major fracture plane obliquity and loss of calcar integrity [18]. These fracture patterns present an increased risk of nonunion, malunion, avascular necrosis, and early failure [16, 19–21].

Treatment options and considerations

Once other life- and limb-threatening injuries have been addressed, expedient management of femoral neck fractures in the young patient should be undertaken. Recent literature has failed to demonstrate that mild delays (>48 h) in operative intervention increase the risk of AVN or nonunion [9, 22–24]. These findings, however, are in the context of previous studies documenting higher rates of avascular necrosis with delays in surgical fixation [6, 25]. Salvage options in the young patient are not tolerated as well as in the elderly population and thus maximizing the probability of maintaining a native hip joint without altered biomechanics is a priority [5, 10].

In the young patient, internal fixation is the primary mode of treatment. An anatomic reduction is mandated by either closed or open means. Multiple previous investigations have demonstrated that a non-anatomic reduction increases the risk of lower functional outcome, healing complication and reoperation [9, 26–29]. Specifically, varus malreduction and inferior offset are risks of failure [28, 29]. Minimal valgus alignment has not been shown to have a deleterious effect on outcome [30].

Surgical approach

There are many possible surgical tactics for fracture visualization and reduction. We believe that an anatomic reduction in the femoral neck and subsequent stable internal fixation is the most important goals of surgical treatment of these injuries. The surgical approach and choice of implant go hand in hand. Some implants cannot be placed through certain open approaches to the hip; therefore, the choice of approach and implant must be part of a thorough and thoughtful preoperative plan. For instance, sliding hip screw (SHS) constructs cannot be placed through a direct anterior (Smith-Petersen) approach, so an additional approach to the lateral femur is necessary for hardware placement if this type of implant is selected. One advantage to the anterolateral (Watson-Jones) approach is that it allows visualization and reduction in most basi-cervical and trans-cervical femoral neck fractures as well as access to the lateral femur through the same incision. Some authors believe that visualization of the subcapital region of the femoral neck through the Watson-Jones approach can be limited, but the benefits of a single incision for fracture reduction and hardware placement make this an attractive option for the surgeon comfortable with this approach [9].

Our preferred approach is the direct anterior (Smith-Petersen), an internervous approach between the femoral nerve and superior gluteal nerve territories. This approach provides excellent visualization of the entire femoral neck for fracture reduction. The patient is positioned supine on a radiolucent flat-top table after adequate anesthesia has been achieved. A small bump is placed under the affected flank to elevate the operative hip to allow easier visualization with fluoroscopy, which comes in from the opposite side of the table. The ipsilateral upper extremity may be secured across the patient's chest or positioned on an arm board. In this "bumped" position, the femoral anteversion is compensated for by the interna, rotation of the patient's hemipelvis. That is, a true AP image of the femoral neck is obtained when the C-arm is in a vertical position, and a true lateral of the proximal femur can be obtained by rolling the C-arm under the table 90°. If the patient were positioned flat on the operating table without a bump, the C-arm must "roll over" approximately 15° to account for femoral anteversion in order to get a true AP view of the femoral neck, and a lateral view of the proximal femur can be obstructed by the contralateral thigh.

A 12- to 15-cm skin incision begins approximately 2 cm lateral and 1 cm distal to the ASIS and is carried distally toward the lateral aspect of the knee (Figs. 1, 2). The skin and subcutaneous tissues are incised sharply, taking care to identify and protect the fascia. A lap sponge is used to clear the fascia of any remaining subcutaneous fat (Fig. 3). The lateral femoral cutaneous nerve is not routinely identified, but it exits beneath the inguinal ligament and would be found in the tissues medial to the Smith-Petersen approach. The "blue line" is identified in the fascia, which is the border between tensor fascia lata (TFL) and sartorius. A

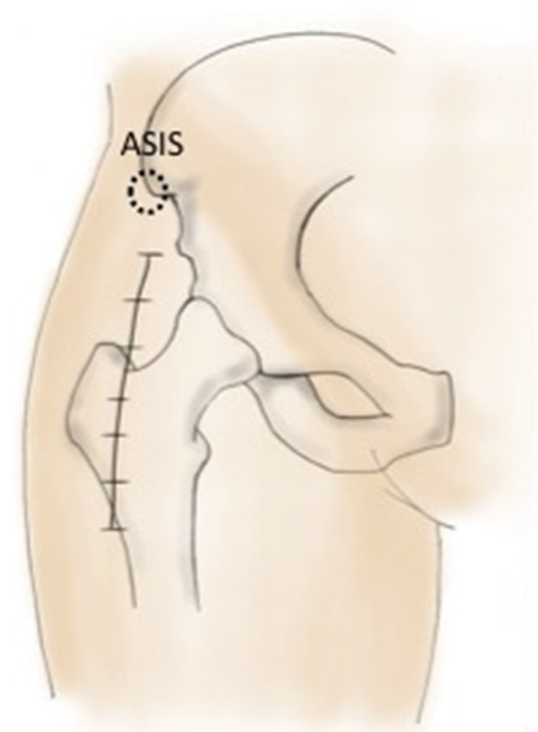

Fig. 1 Schematic drawing of the direct anterior (Smith-Petersen) approach to the hip; ASIS denoted by *dashed circle*

Fig. 2 Skin incision begins ~2 cm lateral and 1 cm distal to the ASIS and extends distally for 12–15 cm toward the lateral aspect of the knee

Fig. 3 Fascia is identified and cleared of subcutaneous fat

new knife is used to lightly incise through this fascia just lateral to the blue line (Fig. 4). An Allis clamp is used to secure and elevate the medial edge of the fascial incision, and blunt digital dissection is performed to deepen the interval between sartorius and TFL. The next step is identification and protection of the ascending branch of the lateral femoral circumflex artery. In arthroplasty cases utilizing the direct anterior approach, this artery is typically controlled with electrocautery or ligation, but in cases where viability of the femoral head is of utmost importance, every attempt should be made to preserve this contribution to the blood supply of the femoral head. It is typically found in the midportion of the incision (3–4 branches crossing perpendicular to the incision), and blunt dissection will aid in its identification and preservation.

The internervous plane is then deepened between gluteus medius (superior gluteal nerve) and rectus femoris (femoral nerve) (Fig. 5). Two cobra retractors are placed, one above and one below the femoral neck (extra capsular). A Cobb and lap sponge can be used to clear any remaining tissue off the anterior surface of the joint capsule, which will be between the two cobra retractors. The reflected head of the rectus femoris will occasionally obstruct the surgeon's view of the capsule, and it can be sharply taken down from its origin on the AIIS to improve visualization. There is typically a substantial intra-articular hematoma which can distend the capsule giving it a "tense" feeling. A

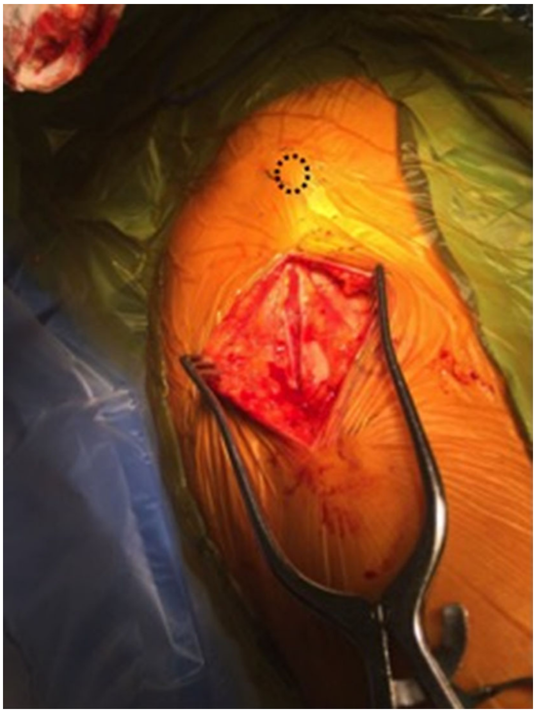

Fig. 4 Fascia is identified and incised just lateral to the interval between sartorius and TFL

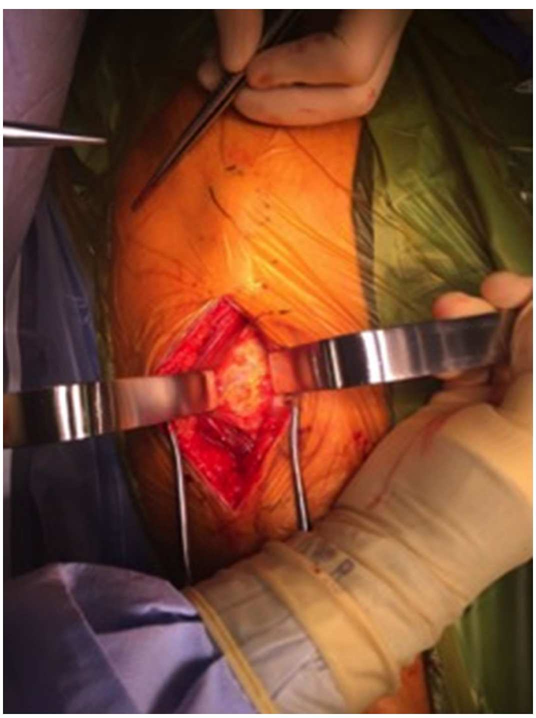

Fig. 5 Interval between gluteus medius and rectus femoris is developed, exposing the anterior joint capsule. Hibbs retractors can be used for soft tissue retraction

"T"- or "L"-shaped capsulotomy is made sharply through the anterior capsule, with the long limb of the capsulotomy in line with the femoral neck and the other limb along the capsule–labral junction. The hematoma is evacuated. The capsule can be tagged with heavy suture to aid with elevation and retraction of the capsule as it is dissected free from the femoral neck. The 2 cobra retractors are then repositioned inside the capsule, one above and one below the femoral neck, giving an excellent view of the entire femoral neck and fracture (Fig. 6). External rotation of the leg can assist with elevation of the capsule along the inferomedial neck toward the lesser trochanter, which is essential for placement of a medial buttress plate, if used.

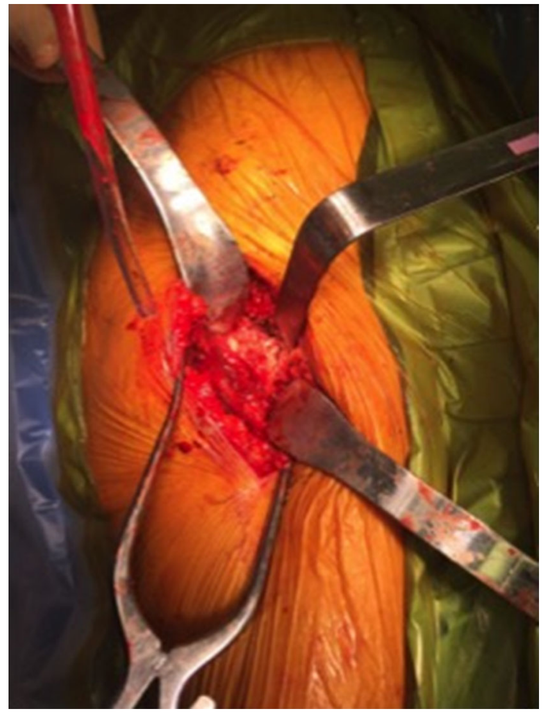

Fig. 6 Once the capsulotomy has been made, the cobra retractors can be placed within the capsule, providing a view of the femoral neck fracture

The role of capsulotomy continues to be controversial. Multiple studies have demonstrated increases in intracapsular pressures with femoral neck fractures with improvement after aspiration or capsulotomy and resultant increases in osseous perfusion pressure [31–33]. However, in a large series Haidukewych et al. [9] failed to demonstrate any outcome differences in patients who did or did not undergo capsulotomy at the time of fixation. Ly and Swiontkowski [13] reviewed the management of young femoral neck fractures in 2008 and highlighted that clinical studies did not readily demonstrate an association between capsulotomy and rates of AVN. We do not routinely perform percutaneous capsulotomies in this injury pattern; however, in the setting of displaced femoral neck fracture rarely do we feel comfortable obtaining an anatomic reduction without an open approach, and thus, a capsulotomy is generally performed as part of the approach.

Reduction technique

Once the fracture has been exposed, the fracture edges are cleared of fracture hematoma. Often, high-energy femoral neck fractures in young adults will have a high Pauwels angle, making them particularly unstable to shear forces (Fig. 7). Depending on the level and obliquity of the fracture, a Schanz pin or large K-wire may be placed just lateral to the articular cartilage (Fig. 8). A combination of internal rotation of this K-wire in conjunction with external rotation of the leg will book open the fracture sufficiently to allow all debris to be cleared from the fracture site. This maneuver can be reversed (external rotation of the K-wire and internal rotation of the leg) to affect a provisional reduction. Fractures with minimal comminution will have good cortical read of the reduction along the inferior margin of the femoral neck. If additional reduction maneuvers need to be employed, a small incision over the lateral aspect of the greater trochanter will allow a ball-spiked pusher to be introduced in a percutaneous fashion against the lateral cortex of the proximal femur (Fig. 8). This tool can hold the reduction, while additional K-wires are placed for provisional stabilization. Additionally, a bone hook or similar instrument may be placed over the anterior portion of the femoral neck to provide a laterally directed counter force against the ball-spiked pusher. A more direct reduction technique may be utilized which involves the use of two 3.5-mm cortex screws and the Farabeuf reduction clamp. The two screws are placed bi-cortically on either side of the fracture and measured long to allow ~5 mm of the screw head to sit prominently such that it can be grasped by the Farabeuf clamp (Fig. 9). Securing the clamp to both screw heads allows varying degrees of compression as well as rotation to be applied across the fracture. Once an anatomic reduction has been achieved and confirmed under direct vision and fluoroscopically, the fracture can be provisionally held in the reduced position with multiple K-wires.

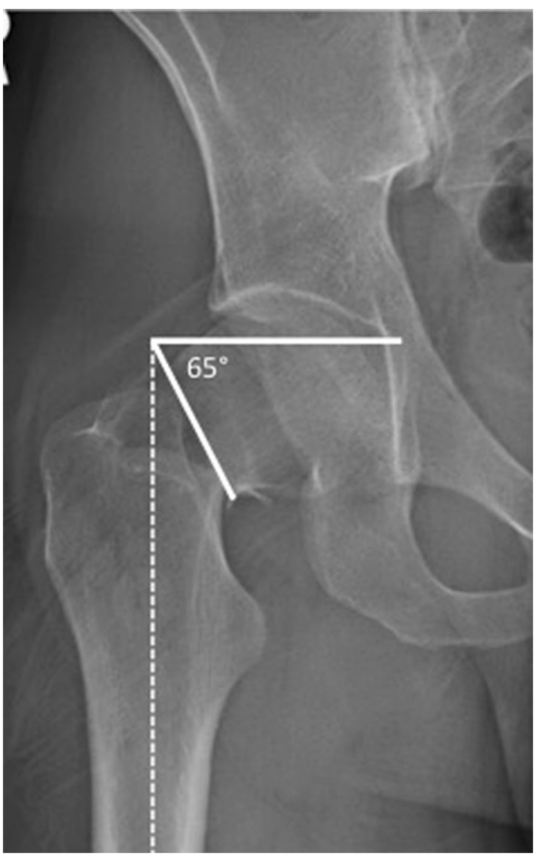

Fig. 7 Determination of the Pauwels angle. The long axis of the femur is marked, and a perpendicular line to this is drawn. The angle formed by the fracture and this perpendicular line is the Pauwels angle

Fixation strategies

The choice of internal fixation will determine the next steps in the case. If cannulated lag screw fixation is chosen, the guide wires can be placed through a small incision over the lateral aspect of the proximal femur without a formal approach. To minimize stress riser formation, care should be taken to avoid placing the starting point of these screws below the level of the lesser trochanter [34]. Partially threaded 6.5- or 7.3-mm cannulated screws are typically placed in an inverted triangle configuration, with the screws abutting the endosteal cortex to provide the most stable fixation possible [35–37]. A divergent or parallel pattern has been shown to be biomechanically superior to a convergent pattern [37]. Inverted triangle pattern may also reduce the risk of subtrochanteric fracture after fixation [38]. Other biomechanical studies have suggested that the addition of a fourth screw may improve fixation strength in cases with posterior comminution [39]. Similarly, in high-risk patterns (i.e., Pauwels type III), utilizing a trochanteric lag screw (Fig. 10) has been shown to be biomechanically superior when compared to an inverted triangle pattern [40]. The use of washers in the setting of cancellous screws improves compression forces [41].

If a sliding hip screw construct is chosen, a direct lateral approach to the proximal femur is performed for hardware placement. A separate screw placed above the sliding hip screw can serve as an anti-rotation device and confer additional fracture stability from improved biomechanical strength [20]. Increased torsional stress may contribute to higher rates of avascular necrosis after SHS fixation in some studies, highlighting the importance of de-rotation pin and/or screw use [42]. From a technical standpoint, the surgeon should strive for a tip–apex distance of less than 25 mm to prevent screw cutout and placement of the lag

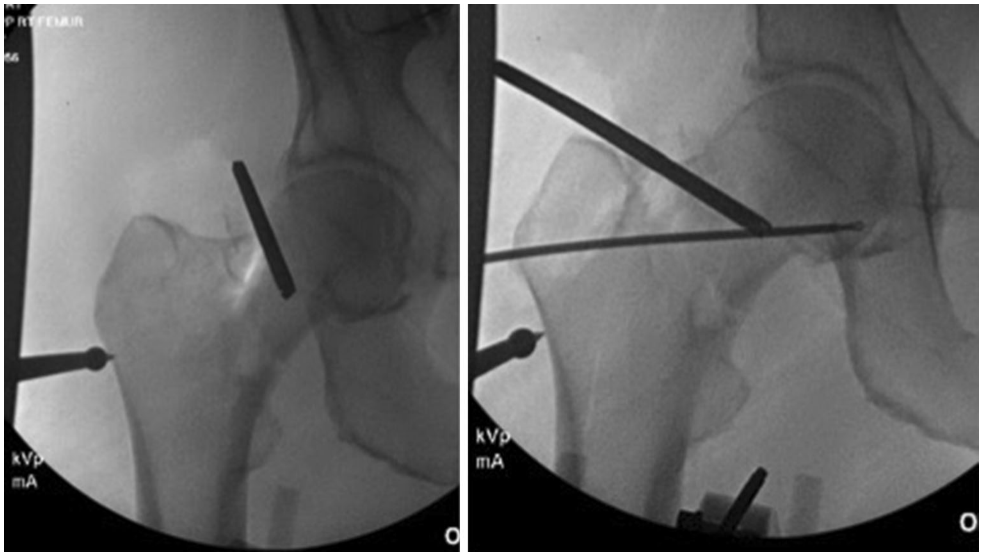

Fig. 8 Intraoperative fluoroscopic view demonstrating a Schanz pin in the proximal fragment and a ball-spiked pusher placed in a percutaneous fashion to affect a reduction in the femoral neck. A K-wire can be placed for provisional stabilization

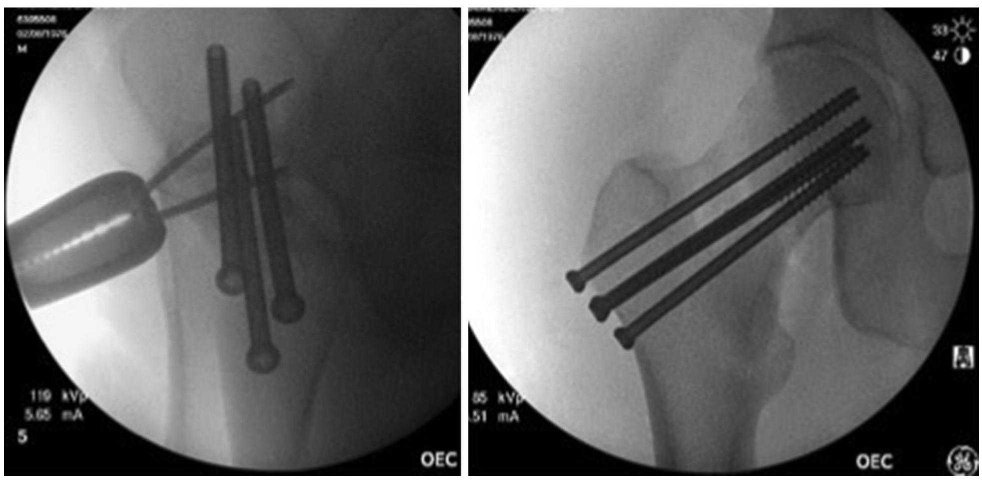

Fig. 9 Lateral view showing a Farabeuf reduction clamp placed over two 3.5-mm screws for a direct reduction in the femoral neck fracture. AP view demonstrates final fixation with partially threaded lag screws

screw in the inferior portion of the neck to abut the cortex [43].

When considering the implant selection, the specific fracture pattern must be considered. Biomechanical studies have suggested that for highly unstable fracture patterns (Pauwels type III, basi-cervical and highly comminuted fractures), a SHS construct may confer greater stability to resist shear forces than cancellous screws [19, 44–46]. However, recently Stockton et al. [47] noted an increase in femoral neck shortening after fixation with SHS when compared to cancellous screw fixation. The functional impact in that study was unclear, though shortening has been shown in older patients to decrease functional outcomes and alter biomechanics [48]. Supplementary fixation such as an infero-medial buttress plate may be placed after primary fixation. External rotation of the hip will allow dissection along the inferior femoral neck toward the lesser trochanter. A 1/3 tubular plate is then contoured to fit and secured with 3.5-mm cortical screws (Figs. 10, 11). The addition of an infero-medial plate has been shown to result in a biomechanically stiffer and stronger construct than either cannulated screws or a SHS alone [49, 50].

Discussion

Femoral neck fractures in the young adult represent a high-risk injury with the potential for significant complications. There remains a paucity of high-level prospective literature guiding the management of these injuries. Specifically,

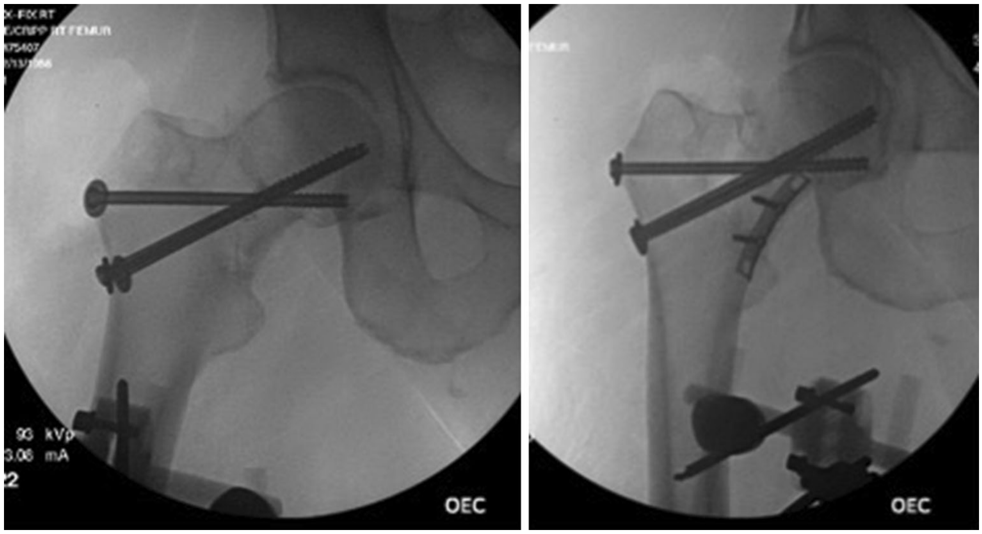

Fig. 10 Intraoperative fluoroscopic views demonstrating placement of a trochanteric lag screw placed perpendicular to the fracture plane. An infero-medial buttress plate was placed as supplementary fixation

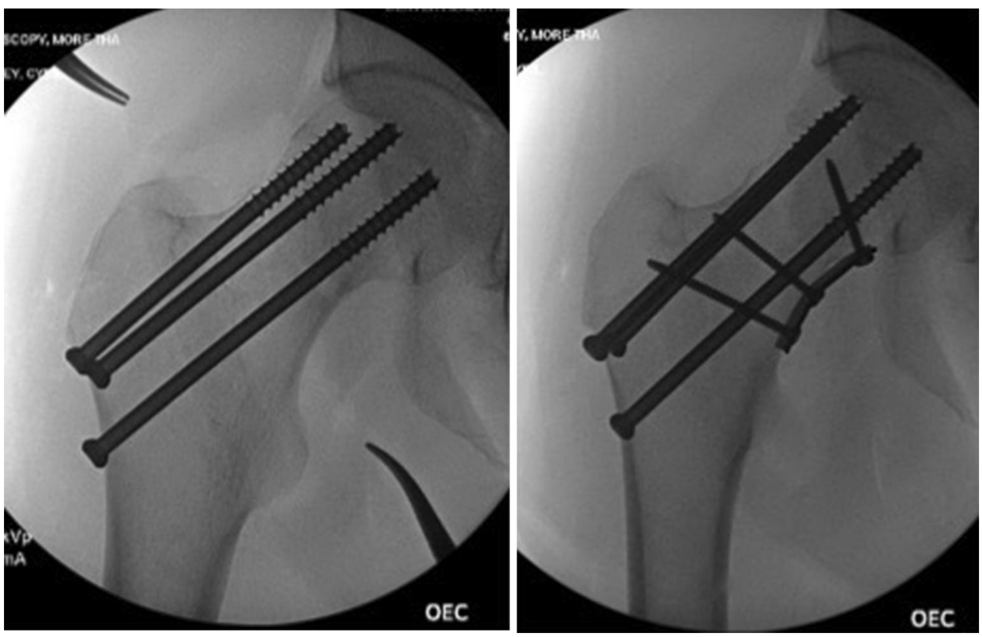

Fig. 11 Once the fracture has been reduced and stabilized, external rotation of the hip can be performed for placement of an infero-medial buttress plate

prospective comparative literature is lacking regarding (1) open versus closed reduction, (2) SHS versus cannulated screws, (3) the timing of operative intervention, and (4) the role of capsulotomy. The Fixation using Alternative Implants for the Treatment of Hip Fractures (FAITH) trial is currently ongoing as a multicenter prospective, randomized study comparing cancellous screw fixation to SHS fixation, adding to the body of literature on this topic.

Despite these limitations, several patterns emerge from the available literature. To reduce the risk of both nonunion and avascular necrosis while maximizing functional outcome, an anatomic reduction must be obtained with stable fixation [9, 26–29]. High-risk fractures (i.e., vertical shear or comminuted) carry a higher risk of complication, and supplemental fixation should be considered in these patterns [16, 18, 20, 21, 40, 49].

Patients should be counseled on the nature of these injuries. Meta-analyses and multiple studies have demonstrated consistent complication rates: an avascular necrosis rate of ~15–25 %, nonunion rate just under 10 %, and a re-operation rate approaching 20 % [5, 8–11, 22]. From the available literature, the key to a successful clinical outcome is the maintenance of the native femoral head free of avascular necrosis. Haidukewych et al., Krischak et al. and Broos et al. demonstrate that the majority of patients who meet these criteria maintain good to excellent functional outcomes.

Summary

- Expedient ORIF is the treatment of choice for the young adult patients with a displaced femoral neck fracture.
- Anatomic reduction and stable fixation reduce the risk of AVN, nonunion, and other complications.
- Surgical approach dictated by surgeon preference and implant selection.
- Fixation strategy dictated by fracture pattern and degree of instability.
- Supplemental fixation has biomechanical benefit.
- Outcome is driven by union without avascular necrosis.
- Further prospective studies needed.

Compliance with ethical standards

Ethical statement Dr. Hak reports personal fees from Globus, personal fees from Merck, personal fees from Invibio, outside the submitted work. Dr. Mauffrey reports personal fees from Springer, personal fees from Slack, personal fees from Elsevier, and institutional support from Striker, institutional support from Synthes, institutional support from Abbott, institutional support from AO organization, and institutional grant support from Hebei province and CoI, all outside the submitted work.

Conflict of interest Dr. Renninger and Dr. Stacey have nothing to disclose.

Human and animal rights This article does not contain any studies with human participants performed by any of the authors.

References

1. Johnell O, Kanis JA (2006) An estimate of the worldwide prevalence and disability associated with osteoporotic fractures. Osteoporos Int 17(12):1726–1733. doi:10.1007/s00198-006-0172-4
2. Mauffrey C (2009) The management of subcapital fractures in the elderly population. Eur J Orthop Surg Traumatol 20(5):359–364. doi:10.1007/s00590-009-0570-3
3. Robinson CM, Court-Brown CM, McQueen MM, Christie J (1995) Hip fractures in adults younger than 50 years of age. Clin Orthop Relat Res 312:9
4. Protzman RR, Burkhalter WE (1976) Femoral-neck fractures in young adults. J Bone Joint Surg Am 58-A(5):7
5. Swiontkowski MF, Winquist RA, Hansen ST (1984) Fractures of the femoral neck in patients between the ages of twelve and forty-nine years. J Bone Joint Surg Am 66-A(6):10
6. Gerber C, Strehle J, Ganz R (1993) The treatment of fractures of the femoral neck. Clin Orthop Relat Res 292:10
7. Pihlajamaki H, Ruohola J-P, Kiuru MJ, Visuri TI (2006) Displaced femoral neck fatigue fractures in military recruits. J Bone Joint Surg Am 88-A(9):10
8. Slobogean GP, Sprague SA, Scott T, Bhandari M (2015) Complications following young femoral neck fractures. Injury 46(3):484–491. doi:10.1016/j.injury.2014.10.010
9. Haidukewych GJ, Rothwell WS, Jacofsky DJ, Torchia ME, Berry DJ (2004) Operative treatment of femoral neck fractures in patients between the ages of fifteen and fifty years. J Bone Joint Surg Am 86-A(8):7
10. Haidukewych GJ (2009) Salvage of failed treatment of femoral neck fractures. AAOS Instr Course Lect 59:8
11. Dedrick DK, Mackenzie JR, Burney RE (1986) Complications of femoral neck fracture in young adults. J Trauma 26(10):6
12. Peljovich AE, Patterson BM (1998) Ipsilateral femoral neck and shaft fractures. J Am Acad Orthop Surg 6:8
13. Ly TV, Swiontkowski MF (2008) Treatment of femoral neck fractures in young adults. J Bone Joint Surg Am 90-A(10):13. doi:10.1016/S0021-9355(08)72690-0
14. Bedford MR, Brewster MBS, Grimstvedt LO, O'Dwyer K (2011) Re-evaluating the lateral hip view in the management of femoral neck fractures. Eur J Orthop Surg Traumatol 21(3):165–169. doi:10.1007/s00590-010-0680-y
15. Garden RS (1961) Low-angle fixation in fractures of the femoral neck. J Bone Joint Surg Am 43-B(4):17
16. Bartonicek J (2001) Pauwels' classification of femoral neck fractures: correct interpretation of the original. J Orthop Trauma 15:3
17. Gaspar D, Crnkovic T, Durovic D et al (2012) AO group, AO subgroup, Garden and Pauwels classification systems of femoral neck fractures: are they reliable and reproducible? Med Glas (Zenica) 9:5
18. Collinge C, Mir H, Reddix R (2014) Fracture morphology of high shear angle "vertical" femoral neck fractures in young adult patients. J Orthop Trauma 28(5):6
19. Baitner AC, Maurer SG, Hickey DG, Jazrawi LM, Kummer FJ, Jamal J, Goldman S, Koval KJ (1999) Vertical shear fractures of the femoral neck: a biomechanical study. Clin Orth Rel Res 367:6
20. Bonnaire FA, Weber AT (2002) Analysis of fracture gap changes, dynamic and static stability of different osteosynthetic procedures in the femoral neck. Injury 33(Suppl 3):9
21. Stankewich CJ, Chapman J, Muthusamy R, Quaid G, Schemitsch E, Tencer AF, Ching RP (1996) Relationship of mechanical factors to the strength of proximal femur fractures fixed with cancellous screws. J Orthop Trauma 10:10
22. Damany DS, Parker MJ, Chojnowski A (2005) Complications after intracapsular hip fractures in young adults: a meta-analysis of 18 published studies involving 564 fractures. Injury 36(1):11
23. Schweitzer D, Melero P, Zylberberg A, Salabarrieta J, Urrutia J (2013) Factors associated with avascular necrosis of the femoral head and nonunion in patients younger than 65 years with displaced femoral neck fractures treated with reduction and internal fixation. Eur J Orthop Surg Traumatol 23(1):61–65. doi:10.1007/s00590-011-0936-1
24. Gao YS, Ai ZS, Zhu ZH, Yu XW, Zhang CQ (2013) Injury-to-surgery interval does not affect postfracture osteonecrosis of the femoral head in young adults: a systematic review. Eur J Orthop Surg Traumatol 23(2):203–209. doi:10.1007/s00590-012-0948-5
25. Jain R, Koo M, Kreder HJ, Schemitsch EH, Davey JR, Mahomed NN (2002) Comparison of early and delayed fixation of subcapital hip fractures in patients sixty years of age or less. J Bone Joint Surg Am 84-A(9):8
26. Bedi A, Karunakar MA, Caron T, Sanders RW, Haidukewych GJ (2009) Accuracy of reduction of ipsilateral femoral neck and

shaft fractures–an analysis of various internal fixation strategies. J Orthop Trauma 23(4):5
27. Krischak G, Beck A, Wachter N, Jakob R, Kinzl L, Suger G (2003) Relevance of primary reduction for the clinical outcome of femoral neck fractures treated with cancellous screws. Arch Orthop Trauma Surg 123(8):404–409. doi:10.1007/s00402-003-0571-3
28. Lowell JD (1980) Results and complications of femoral neck fractures. Clin Orthop Relat Res 152:11
29. Weinrobe M, Stankewich CJ, Mueller B, Tencer AF (1998) Predicting the mechanical outcome of femoral neck fractures fixed with cancellous screws: an in vivo study. J Orthop Trauma 12(1):10
30. Florschutz AV, Langford JR, Haidukewych GJ, Koval KJ (2015) Femoral neck fractures: current management. J Orthop Trauma 29(3):9
31. Harper WM, Barnes MR, Gregg PJ (1991) Femoral head blood flow in femoral neck fractures. An analysis using intra-osseous pressure measurement. J Bone Joint Surg Br 73:3
32. Bonnaire FA, Schaefer DJ, Kuner EH (1998) Hemarthrosis and hip joint pressure in femoral neck fractures. Clin Orthop Relat Res 353:8
33. Stromqvist B, Nilsson LT, Egund N, Thorngren KG, Wingstrand H (1988) Intracapsular pressures in undisplaced fractures of the femoral neck. J Bone Joint Surg Br 70:3
34. Robinson CM, Adams CI, Craig M, Doward W, Clarke MCC, Auld J (2002) Implant-related fractures of the femur following hip fracture surgery. J Bone Joint Surg Am 84-A(7):7
35. Selvan VT, Oakley MJ, Rangan A, Al-Lami MK (2004) Optimum configuration of cannulated hip screws for the fixation of intracapsular hip fractures: a biomechanical study. Injury 35(2):136–141. doi:10.1016/s0020-1383(03)00059-7
36. Zdero R, Keast-Butler O, Schemitsch EH (2010) A biomechanical comparison of two triple-screw methods for femoral neck fracture fixation in a synthetic bone model. J Trauma 69(6):1537–1544. doi:10.1097/TA.0b013e3181efb1d1
37. Papanastassiou ID, Mavrogenis AF, Kokkalis ZT, Nikolopoulos K, Skourtas K, Papagelopoulos PJ (2011) Fixation of femoral neck fractures using divergent versus parallel cannulated screws. J Long Term Eff Med Implants 21(1):7
38. Oakey JW, Stover MD, Summers HD, Satori M, Robert M, Patwardhan AG (2006) Does screw configuration affect subtrochanteric fracture after femoral neck fixation? Clin Orthop Relat Res 443:5
39. Kauffman JI, Simona JA, Kummer FJ, Pearlman CJ, Zuckerman JD, Koval KJ (1999) Internal fixation of femoral neck fractures with posterior comminution: a biomechanical study. Clin Orthop Relat Res 13(3):5
40. Hawks MA, Kim H, Strauss JE, Oliphant BW, Golden RD, Hsieh AH, Nascone JW, O'Toole RV (2013) Does a trochanteric lag screw improve fixation of vertically oriented femoral neck fractures? A biomechanical analysis in cadaveric bone. Clin Biomech (Bristol, Avon) 28(8):886–891. doi:10.1016/j.clinbiomech.2013.08.007
41. Zlowodzki MP, Wijdicks CA, Armitage BM, Cole PA (2015) Value of washers in internal fixation of femoral neck fractures with cancellous screws: a biomechanical evaluation. J Orthop Trauma 29:4
42. Bray TJ (1997) Femoral neck fracture fixation. Clinical decision making. Clin Orthop Relat Res 339:12
43. Baumgaertner MR, Curtin SL, Lindskog DM, Keggi JM (1995) The value of the tip-apex distance in predicting failure of fixation of peritrochanteric fracture of the hip. J of Bone Joint Surg Am 77-A(7):8
44. Liporace F, Gaines R, Collinge C, Haidukewych GJ (2008) Results of internal fixation of Pauwels type-3 vertical femoral neck fractures. J Bone Joint Surg Am 90(8):1654–1659. doi:10.2106/JBJS.G.01353
45. Blair B, Koval KJ, Kummer F, Zuckerman JD (1994) Basicervical fractures of the proximal femur: a biomechanical study of 3 internal fixation techniques. Clin Orthop Relat Res 306:8
46. Deneka DA, Simonian PT, Stankewich CJ, Eckert D, Chapman JR, Tencer AF (1997) Biomechanical comparison of internal fixation techniques for the treatment of unstable basicervical femoral neck fractures. J Orthop Trauma 11(5):7
47. Stockton DJ, Lefaivre KA, Deakin DE, Osterhoff G, Yamada A, Broekhuyse HM, O'Brien PJ, Slobogean GP (2015) Incidence, magnitude, and predictors of shortening in young femoral neck fractures. J Orthop Trauma 29(9):6
48. Zlowodzki M, Brink O, Switzer J, Wingerter S, Woodall J, Petrisor BA, Kregor PJ, Bruinsma DR, Bhandari M (2008) The effect of shortening and varus collapse of the femoral neck on function after fixation of intracapsular fracture of the hip: a multicentre cohort study. J Bone Joint Surg Br 90-B:8. doi:10.1302/0301-620X.90B11
49. Kunapuli SC, Schramski MJ, Lee AS, Popovich JMJ, Cholewicki J, Reeves NP, Crichlow RJ (2015) Biomechanical analysis of augmented plate fixation for the treatment of vertical shear femoral neck fractures. J Orthop Trauma 29(3):7
50. Ye Y, Hao J, Mauffrey C, Hammerberg EM, Stahel PF, Hak DJ (2015) Optimizing stability in femoral neck fracture fixation. Orthopedics 38(10):625–630. doi:10.3928/01477447-20151002-05