

Vertical femoral neck fractures in young adults: a closed fixation strategy using a transverse cancellous lag screw

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KEYWORDS

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ABSTRACT

Vertical femoral neck fractures (Pauwels type III classification) in young adults generally occur as a consequence of high-energy trauma and are frequently seen in association with multiple injuries. Considering the controversies regarding the optimal fixation for this fracture, our aim was to evaluate the clinical outcome of a closed fixation strategy for vertical femoral neck fractures in young adults using two parallel and one transverse cancellous lag screws. This was a single-surgeon, prospective study including 20 young adults with average age of 38.75 years (range 18–59 years) with a high-energy Pauwels III femoral neck fracture. Closed reduction and internal fixation with three cancellous lag screws were performed. The first screw was inserted crosswise to avoid further shear forces. Second and third parallel screws were placed above the lesser trochanter and centrally on the greater trochanter, respectively. Clinical outcomes were assessed by comparing postoperative and final follow-up radiographs 24 months post-injury. Eleven patients had an isolated vertical femoral neck fracture. Of these, five had further femoral neck comminution. Nine patients had an associated ipsilateral femoral shaft fracture. All fractures were displaced at the time of the first radiological evaluation. Closed reduction quality was considered excellent or good in 15 patients. After 24 months, bone union was achieved in 16 cases. Osteonecrosis of the femoral head developed in association with two fractures, and a nonunion developed in association with two fractures. We conclude that vertical high-energy femoral neck fractures can be treated successfully with internal fixation with two parallel cancellous lag screws positioned above the lesser trochanter and a third screw inserted centrally on the greater trochanter at an angle perpendicular to the fracture line.

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Introduction

Vertical femoral neck fractures (Pauwels type III classification) in young adults generally occur as a consequence of high-energy trauma and are frequently seen in association with multiple injuries, including ipsilateral femoral shaft fracture [1]. As these fractures are submitted to greater shearing forces, their treatment is challenging and has increased risks of complications, such as fixation failure, malunion, nonunion, and avascular necrosis of the femoral head [2,3]. Many factors, including associated lesions, presence of comminution, and general medical status, affect the choice of treatment; however, there is a broad consensus that the intervention should include precise reduction and rigid internal fixation [4,5]. The most commonly used devices for fixation of vertical femoral neck fractures are multiple parallel screws or a sliding hip screw

with or without an anti-rotation screw [6–9]. The rationale of both techniques is fracture healing by sliding and compressing fragments when subjected to loading forces during weight-bearing. However, shortening of the femoral neck is often reported, both in displaced and undisplaced fractures, causing adverse effects on the physical function of the patients [3,10]. Therefore, different assemblies of screws, with varying insertion angles and/or association with locking plates, have been tested in both patients and biomechanical models [9,11–13]. Although some reports indicate good clinical outcome after reduction with a fixed-angle plate, this strategy requires an open reduction procedure, which is often highly invasive, and the initial clinical results using a locked plate were not encouraging [11,12,14].

Considering the controversies regarding the optimal fixation for Pauwels III femoral neck fracture in young adults, we propose a fixation strategy using two parallel 7.0-mm lag cancellous screws inserted towards the neck at a 125° angle from the femoral shaft and a third transverse screw, inserted perpendicularly to the fracture line between the first two screws. The main goal of this construct

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was to achieve a stable fracture fixation to promote bone union and avoid telescoping of fragments and, consequently, femur shortening.

Patients and methods

Between 1 October 2002 and 31 December 2012, all adult patients with a high-energy vertical femoral neck fracture, categorised as type III according to Pauwels original classification [1], were selected, evaluated, and operated on by one of the authors at the Trauma Centre of an Orthopaedics Institution. Exclusion criteria included fractures secondary to a low-energy mechanism of injury, gunshot, Pauwels type I and II femoral neck fractures, age over 60 years, and any known metabolic bone disease, including osteoporosis. Twenty patients (17 male and 3 female), with an average age of 38.4 years (range, 18–59 years), met the inclusion criteria and consented to participate in the study, which was approved by the Institutional Research Ethics Committee. All patients in this series were submitted to the same surgical procedure.

Fracture assessment on plain radiographs

Plain radiographs of the pelvis at the anteroposterior position (AP) were used to determine the vertical angle of the fracture by measuring the angle of the fracture line with a line perpendicular to the femoral shaft. When this angulation was greater than 50°, fractures were categorised as type III, in accordance with Pauwels original classification [1] (Figure 1), with the typical apical fracture spike on the head-neck segment. All fractures were classified as type 31B2.3 according to the system of the AO-OTA [15]. The presence of comminution and association with an ipsilateral shaft fracture were also determined. When the rotation of the lower limb precluded accurate measurement of the fracture angle on the preoperative radiographs, the angle was confirmed by radioscopy in surgery during the reduction of the neck fracture.

Surgical procedure

All patients were submitted to fluoroscopy-guided closed reduction in a regular radiolucent table. With the patient in the supine position, initial anatomic or nearly anatomic reduction was achieved through movements of internal and external rotation, abduction and adduction of the limb. The drainage of articular haematoma through capsulotomy was not used in any of the cases. Reduction was secured with 2.0-mm guide wires, followed by definitive fixation with three 7.0-mm lag cancellous screws. The guide wires were inserted according to the following sequence: the first guide wire was placed posteriorly to the femoral neck and the second was placed parallel to the first and anteriorly to the femoral neck. Both guides were inserted at a 125° angle from the femoral shaft, with an entry point slightly above the lesser trochanter from the lateral aspect of the femur. The third guide wire was placed centrally, inserted from the lateral aspect of the greater trochanter towards the central and lower part of the femoral head at a 90° angle from the fracture line, between the previously placed guide wires. The transverse screw with washers was placed first, followed by the posterior and anterior screws without washers (Figure 2).

Postoperative interventions and outcome evaluation

Antibiotic prophylaxis with cefazolin for 24 hours and thromboembolic prophylaxis with low molecular weight heparin was given to all patients. Partial weight-bearing using crutches was allowed 6 weeks postoperatively.

Plain radiographs were performed monthly after surgery until the sixth month, when the clinical and radiographic evaluation defined bone healing. The quality of fracture reduction was

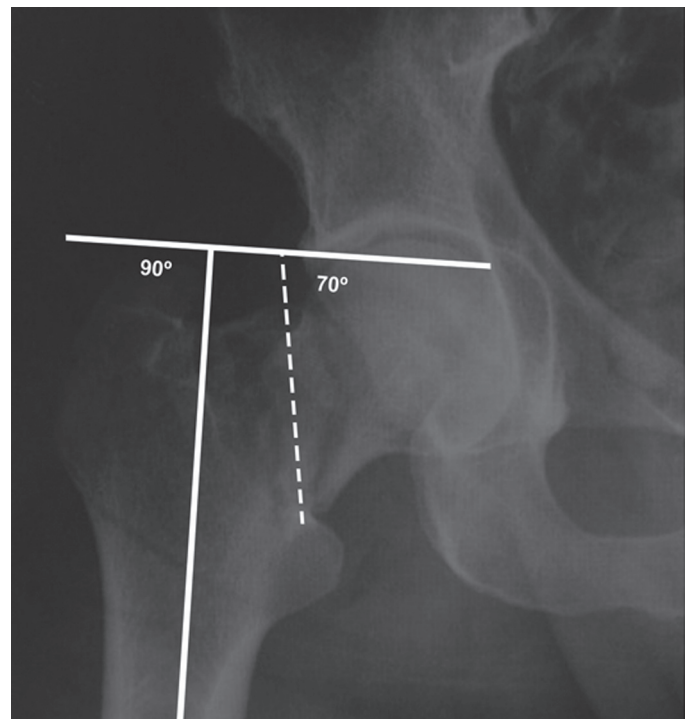


Fig. 1. Anteroposterior injury plain radiograph of a 53-year-old man with a typical vertical femoral neck fracture measuring 70°.

graded according to Haidukewych and co-workers based on the degree of residual angulation and the amount of displacement, and categorised as excellent (<2 mm of displacement and <5° of angulation in any plane), good (2 to 5 mm of displacement and/or 5° to 10° of angulation), fair (>5 to 10 mm of displacement and/or >10° to 20° of angulation), or poor (>10 mm of displacement and/or >20° of angulation) [5]. All patients received postoperative follow-up for a minimum period of 2 years after the surgical procedure. Union of the fracture was defined by the presence of bridging trabeculation on orthogonal radiographic views and by clinical examination. Nonunion was defined by persistence of the fracture line 6 months after the surgical procedure.

Statistical analysis

Demographic and local fracture data were strictly descriptive. Fisher exact test was used for analysis of categorical data regarding outcome. The level of statistical significance was set at $P < 0.05$. The statistical analysis was performed with GraphPad Prism version 5.00 software for Windows.

Results

A total of 20 patients, 3 female and 17 male, with an average age of 38.75 years (range 18–59 years), were enrolled in the study (Table 1). All fractures were classified as Pauwels III according to the original classification and were the result of high-energy trauma [1]. The average time from injury to operative treatment was 11.5 days (range 1–21 days). Eleven patients had an isolated intracapsular fracture of the proximal femur. Of these, five had posteroinferior comminution of the femur neck. In nine patients, the femoral neck fracture was associated with an ipsilateral femoral shaft fracture. All fractures showed some degree of displacement at the first radiographic evaluation. Closed fracture reduction was considered excellent/good in 15 patients and poor/fair in five.

After 24 months of follow-up, bone union (Figure 3) was achieved in 16 patients. Nonunion was observed in two patients and avascular

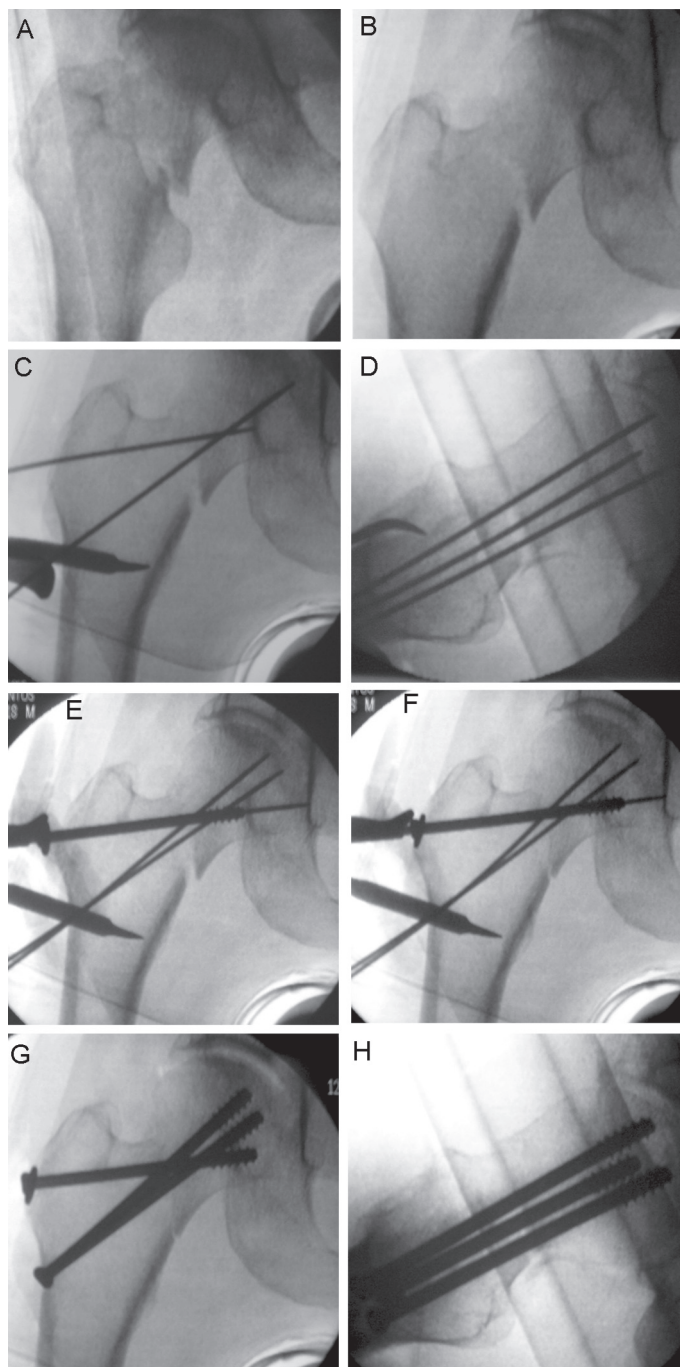


Fig. 2. Intraoperative c-arm images of a closed reduction and the sequence of guide wire insertion in a high shear angle femoral neck fracture in a 59-year-old man. (A) Typical Pauwels Type III displaced fracture of the femoral neck. The fracture line has an angle $>50^\circ$ from the horizontal plane. (B) After reduction, Garden's angle was aligned to 160° on the anteroposterior view. A small diastasis is seen in the calcar. (C) With use of fluoroscopic control, two parallel guide wires are placed, followed by a third wire inserted through the lateral aspect of the greater trochanter, between the other two guide wires. (D) Lateral hip fluoroscopic image after placement of three parallel guide wires. The first wire was placed close to where there is posterior cortical comminution. (E) The first screw is then inserted crosswise to avoid further shear forces. (F) Reduction is confirmed by calcar alignment. (G) Anteroposterior radiograph after placement of the second and third parallel screws. (H) In a lateral view of the hip, note the importance of the position of the most posterior screw in relation to the comminuted fragments.

necrosis of the femoral head was diagnosed in two patients. All but one patient who failed fracture healing had a comminuted fracture (Table 2). Furthermore, there was a relationship between lack of consolidation and quality of fracture reduction (Table 3). The two cases of nonunion were treated with an intertrochanteric valgus

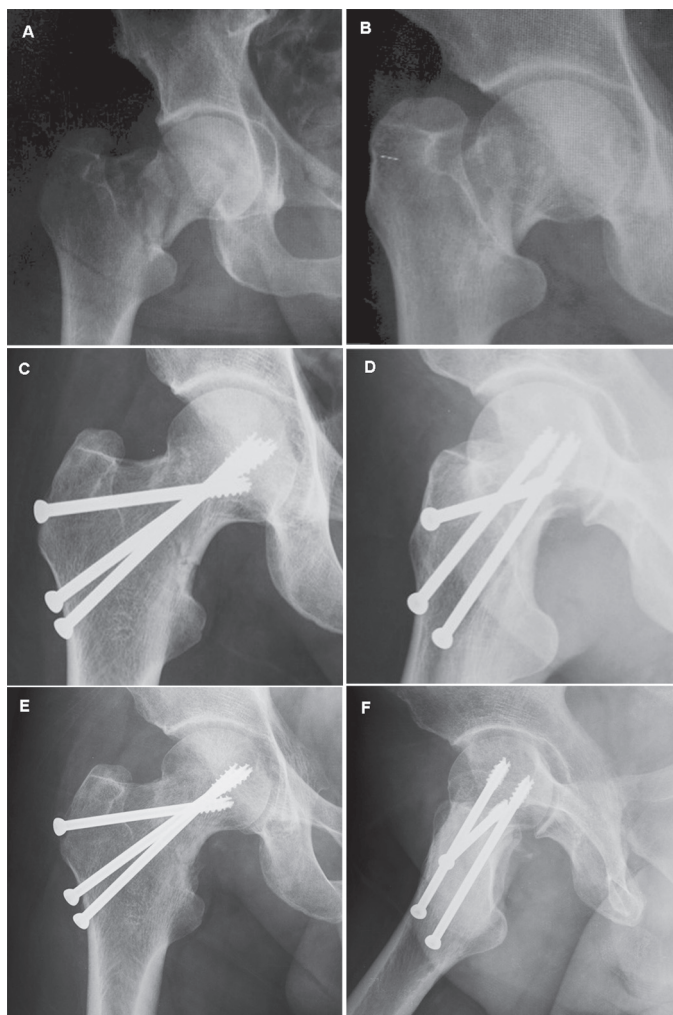


Fig. 3. A favourable outcome case of a 53-year-old man with a displaced vertical right femoral neck fracture sustained in a motorcycle accident. Preoperative anteroposterior (A) and oblique (B) radiographs. (C and D) Closed reduction and internal fixation with three cannulated cancellous screws with the first screw inserted transversally to the fracture line. (E and F) Complete fracture healing 6 months postoperatively. The patient had no pain and was fully weight-bearing.

osteotomy fixed with an angled blade-plate after the removal of the screws (Figure 4). The two cases of avascular necrosis underwent total hip arthroplasty (Figure 5).

Discussion

Despite advances in surgical techniques and implants for vertical femoral neck fractures, treatment failure rates for these fractures are still of concern. Even for a physiologically young and active adult, these fractures are problematic and challenging. The goal is to preserve the femoral head, avoiding osteonecrosis, nonunion, and femur shortening.

Among trauma surgeons, it is generally agreed that proper anatomic reduction and stable internal fixation are paramount for a good outcome [2,4,5]. Due to the inherent instability of vertical femoral neck fractures, multiple treatment algorithms have been utilised to define the best osteosynthesis option, but there is still no gold standard protocol.

The use of crossed screws for fixation of femoral neck fracture was discouraged in a systematic review of studies analysing the results of such surgical treatments [8]. The review compared this technique with the use of parallel cannulated screws without taking into account the type of fracture, patient age, and bone quality. The

Table 1
Patient information and injury characteristics.

Patient	Sex/age	Injury mechanism	Time until surgery (days)	Ipsilateral shaft fracture	Femoral neck comminution	Quality of reduction	Negative outcomes
1	M/36	Car Accident	02	Yes	No	Good	None
2	M/40	Motorcycle Accident	20	Yes	No	Good	None
3	M/31	Motorcycle Accident	10	Yes	No	Excellent	None
4	M/44	Motorcycle Accident	20	No	No	Good	None
5	M/42	Fall from height	15	No	Yes	Poor	AVN
6	M/58	Car Accident	08	Yes	No	Good	None
7	M/50	Motorcycle Accident	05	Yes	No	Good	None
8	M/26	Motorcycle Accident	07	Yes	No	Excellent	None
9	M/20	Motorcycle Accident	13	Yes	No	Fair	None
10	M/32	Motorcycle Accident	13	Yes	No	Good	None
11	F/51	Fall from height	06	No	Yes	Fair	AVN
12	M/59	Fall from height	01	No	Yes	Good	None
13	M/47	Fall from height	17	No	No	Fair	None
14	M/37	Run over by Car	13	Yes	No	Good	None
15	F/18	Motorcycle Accident	16	No	Yes	Excellent	None
16	M/28	Fall from height	10	No	No	Fair	Nonunion
17	M/18	Motorcycle Accident	17	No	No	Good	None
18	F/33	Motorcycle Accident	03	No	Yes	Good	Nonunion
19	M/53	Motorcycle Accident	21	No	No	Good	None
20	M/52	Fall from height	14	No	No	Good	None

F: female; M: Male; AVN: avascular necrosis

Table 2
Clinical outcome according to comminution of the fracture.

Comminution	Nonunion or avascular necrosis		Uneventful union	
Total	P value			
Yes	3	2	5	0.03
No	1	14	15	

Number of patients. Fisher's exact test.

transverse screw fixation should be reserved for younger patients who have good bone mass so that stable fixation can be obtained after anatomical reduction. This reduces impaction of the fracture and the consequent shortening of the femoral neck [10].

In this prospective series, we evaluated the clinical outcome of 20 patients with high-energy vertical femoral neck fractures treated with a novel assembly strategy, based on the old concept of Garden crossed screws [16]. In this protocol, besides two 7.0-mm parallel cancellous lag screws inserted with a 125° angulation from the femoral shaft, another screw is inserted towards the central and lower part of the femoral head, perpendicularly to the fracture line (Figure 6).

The use of perpendicular, transverse screws in different types of assemblies has been tested previously in biomechanical models using cadaveric or synthetic femurs [17,18]. Sirkin and colleagues compared the results of the technique based on two 7.0-mm cannulated lag screws inserted along the axis of the femoral neck and a transverse 4.5-mm cortical lag screw directed into the calcar (XCS) with three other strategies: 7.0-mm multiple parallel screws (CS), a 135° sliding hip screw with a two-hole side plate (DHS), and a 95° sliding condylar screw with a five-hole side plate (DCS). These authors found that the XCS construct was stiffer and stronger than the others. The transverse screw placed through the side plate into the calcar creates an inferior buttress that resists displacement and, by being 90° to the fracture, achieves optimum compression and a better control of shear forces [18].

Using synthetic bones, Nowotarski et al. compared the CS and XCS methods to a femoral neck locking plate (FNLP) with two 5.7-mm locking screws, one lag screw into the calcar, and two screws into the shaft. Their results showed that the FNLP method had a superior rotational stiffness and attributed the enhanced stability of the FNLP to both the multiple locking screw configurations and the

Table 3
Quality of femoral neck reduction and related outcome.

Quality of reduction	Nonunion or avascular necrosis		Uneventful union	
Total	P value			
Excellent or Good	1	14	15	0.03
Fair or Poor	3	2	5	

Number of patients. Fisher's exact test.

compression afforded by the transverse calcar lag screw [13]. Thus, the rationale of our strategy was to achieve a good anatomic closed reduction, but also to avoid telescoping of bone fragments and, therefore, neck shortening, through the use of the perpendicular screw to improve the fracture compression and to help control the shear forces.

Of the 20 selected patients, the quality of fracture reduction was considered excellent or good in 15 and poor or fair in five. Among those four patients who failed in fracture healing, two (a 28-year-old man and a 33-year-old woman) were due to nonunion and two (a 42-year-old man and a 51-year-old woman) were due to avascular necrosis of the femoral head. Three of these four patients had femoral neck comminution and/or poor/fair quality of fracture reduction, which might have contributed to the impaired outcome.

Therefore, our results agree with previous studies reporting fragment comminution as an important risk factor for failure [19–21]. Analysing clinical and radiographic data of 149 patients treated for neck fractures, Alho et al. found that a small head fragment, comminution of the calcar, and varus angulation of the femoral head were predictive of an unfavourable outcome [21]. Later, in a randomised study of 102 patients treated for femoral neck fractures with internal fixation with cannulated screws, Upadhyay and colleagues showed that comminution, poor reduction, and improper screw placement were the most important factors contributing to non-union [22].

Another important finding from our study was that all patients with an associated ipsilateral shaft fracture (n=9) had uneventful bone healing. None of them had comminution, which leads us to hypothesise that the trauma energy must have been mainly absorbed in the femur shaft, minimising the degree of neck injury [23,24].

Several factors, such as fracture displacement, poor fixation quality, and time of surgery, have been suggested to be associated

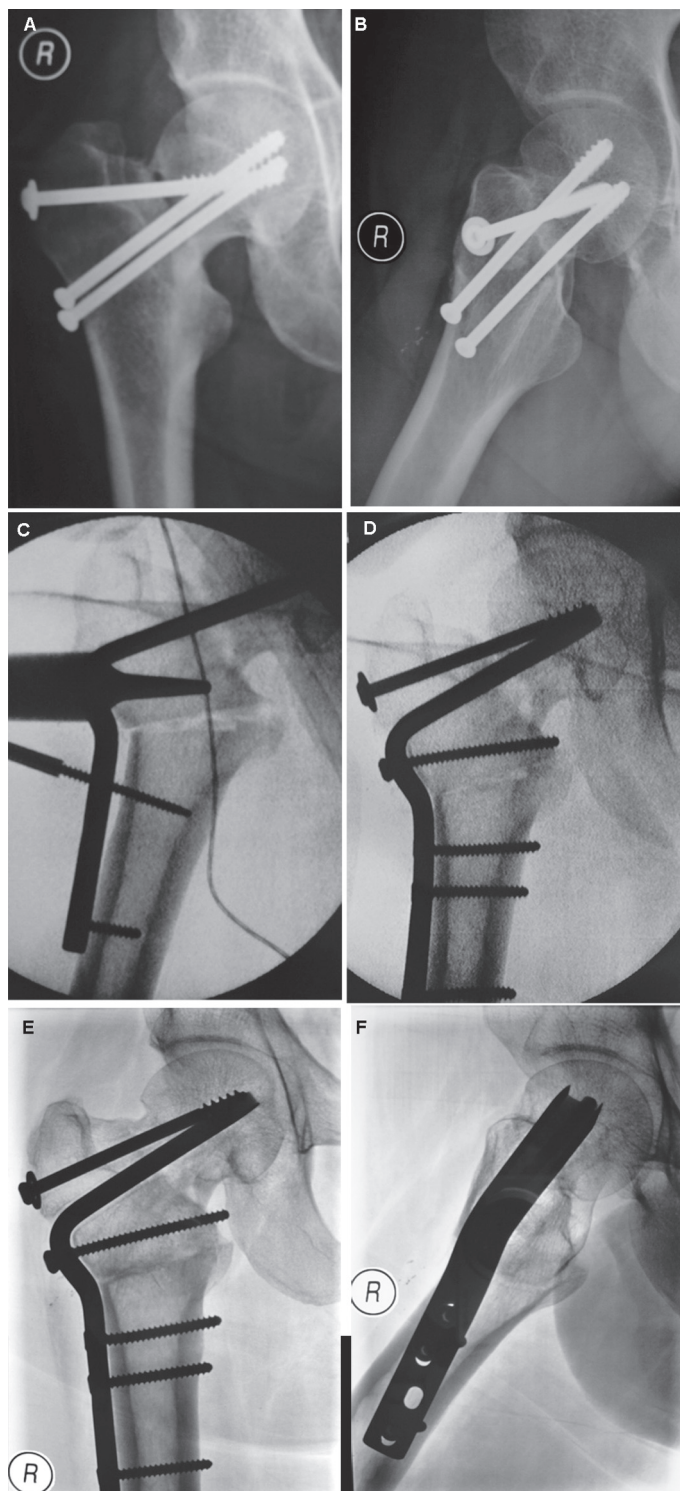


Fig. 4. An unfavourable case of vertical femoral neck fracture complicated by nonunion in a 28-year-old man. (A) Anteroposterior radiograph taken 6 months postoperatively displaying femoral neck shortening and varus collapse. (B) Oblique radiograph showing retroversion deviation of the femoral head. (C) The patient was treated with a valgus intertrochanteric osteotomy as shown on the anteroposterior intraoperative fluoroscopic image. (D) Internal fixation with a fixed-angle device associated with a cannulated screw system. Nonunion and osteotomy healed 4 months after the secondary procedure as seen on the anteroposterior (E) and lateral (F) radiographs.

with the development of avascular necrosis [5]. However, the exact cause of avascular necrosis of the femoral neck after fracture healing is still not well understood. In this series, the delay between fracture and fixation was 11.5 days (range 1–21 days). In the literature, it is

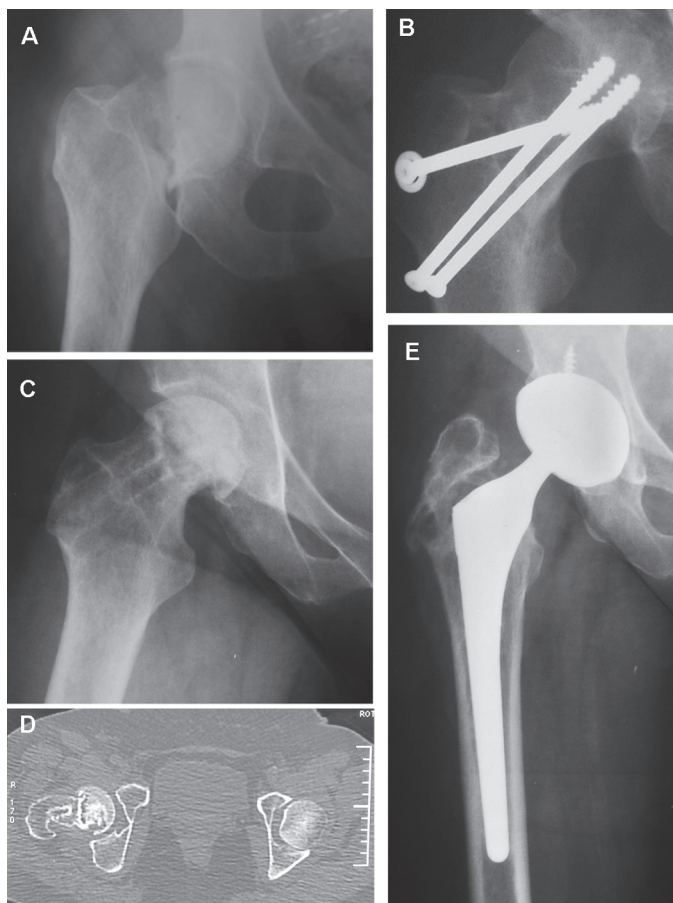


Fig. 5. Vertical femoral neck fracture associated with the development of osteonecrosis of the femoral head in a 51-year-old female. (A) Anteroposterior radiograph of a typical high-energy, high-shear angle fracture with postero-medial comminution of the femoral neck. (B) Three months postoperatively, the radiographic image shows the progress of the healing process. (C) Twenty months after the primary high-energy injury and after removal of the lag screws, the patient was diagnosed with avascular necrosis of the femoral head, as demonstrated in anteroposterior radiograph. (D) Axial CT image shows typical findings of avascular necrosis of the femoral head. (E) Conversion to total hip arthroplasty 22 months after the primary injury.

stated that the gold standard procedure for femoral neck fractures in young patients is immediate fixation. It is believed that early surgical reduction and fracture stabilisation may improve femoral head blood flow, thereby leading to a decrease in avascular necrosis and union complications [4]. However, in a multicentre study of 1503 subcapital fractures of the femur, Barnes and collaborators examined many factors affecting union and late segmental collapse, and reported that there was no evidence to suggest that delay up to 7 days before reduction and fixation adversely affected the fate of the femoral head [25]. Similarly, Holmberg et al. reported no common trend for redisplacement, nonunion, or for segmental collapse when the delay was greater than one week [26]. Despite the small size of our sample, we believe that the delay before surgery was not related to the occurrence of avascular necrosis and nonunion as most of the patients – with similar or even longer delay intervals – reached uneventful healing. The findings from this series confirm previous results that demonstrated that the quality of fracture reduction and femoral neck comminution play an important role in the outcome of the consolidation of vertical femoral neck fractures in young individuals.

The limitations of this study were the small sample size and the lack of comparison with current standard methods. Thus, larger, multicentre, prospective, randomised series are necessary to determine the effectiveness of the presented technique. On the other

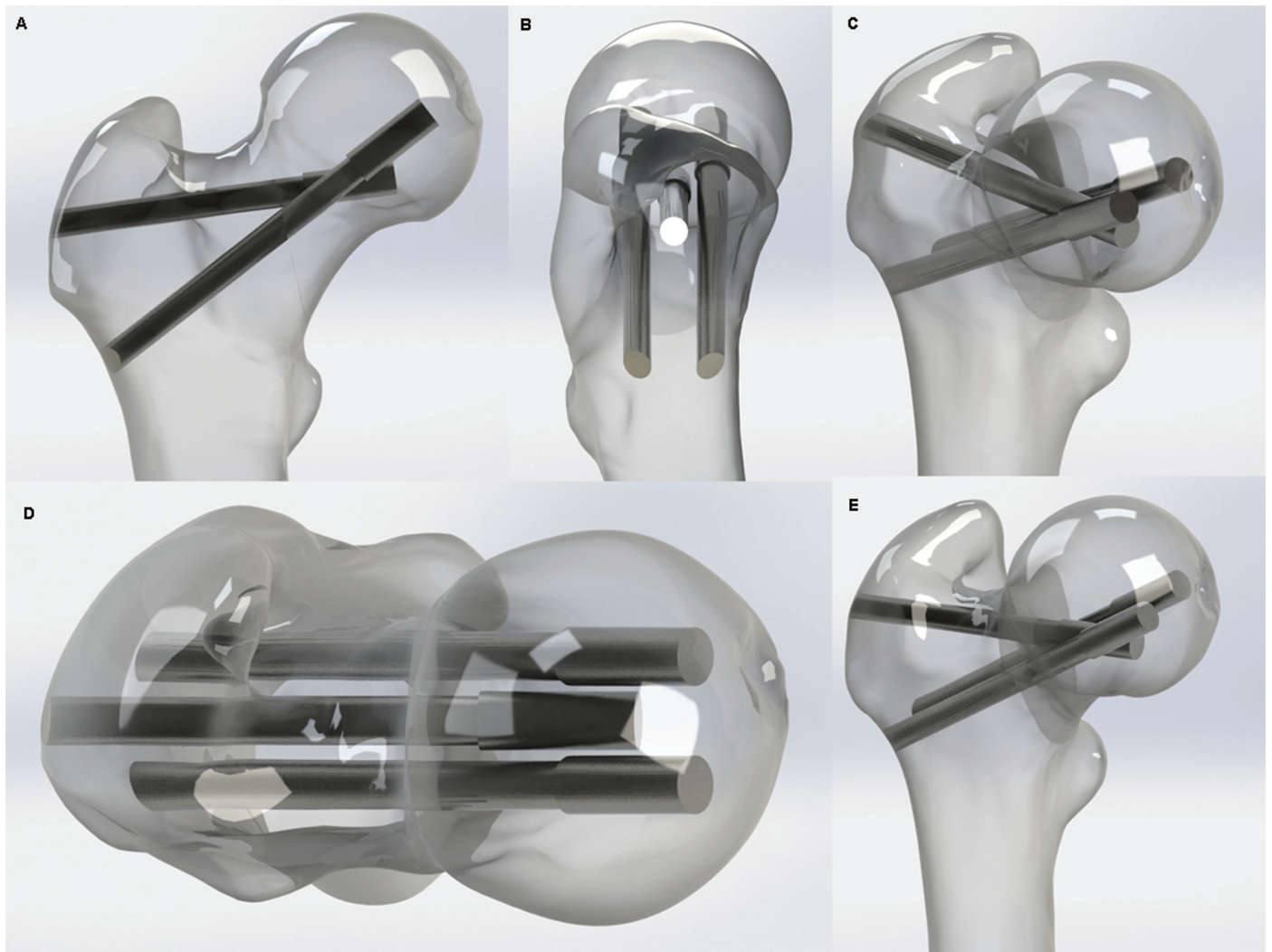


Fig. 6. Schematic transverse cancellous lag screw in vertical femoral neck fractures. (A) Anteroposterior view with a transverse lag screw perpendicularly to the fracture line; (B) Lateral view showing the transverse screw between other two lag screws; (C) Oblique view of lag screws fixation in the femoral head; (D) Axial view noting the parallel screws; (E) Posterior view showing two parallel cancellous lag screws inserted with a 125° angulation from the femoral shaft, another screw is inserted towards the central and lower part of the femoral head.

hand, the strengths of this study include the involvement of a single surgeon, the accurate reduction obtained in the majority of patients with a healing rate of 80%, and a good clinical and radiographic follow-up. In addition, this technique enables easy conversion for total hip arthroplasty or osteotomy, when necessary. It is also worth mentioning that despite the results reported in the literature with the use of transverse screws for fixation of vertical fracture of the femoral neck, our study is the first clinical series to investigate this novel type of screw mounting [14,27,28].

Conclusion

The use of two parallel and one transverse cancellous lag screws to treat vertical fractures of the femoral neck has been shown to be an efficient approach to achieve bone healing in young adults. Our findings might give potentially important contributions towards the improvement of surgical treatments for high-energy femoral neck fractures in young patients through a less invasive and less time-consuming surgical approach.

Conflict of interest

The authors declare no conflicts of interest.

References

- [1] Bartonicek J. Pauwels' classification of femoral neck fractures: correct interpretation of the original. *J Orthop Trauma* 2001;15:358–60.
- [2] Protzman RR, Burkhalter WE. Femoral-neck fractures in young adults. *J Bone Joint Surg Am* 1976;58:689–95.
- [3] Zlowodzki M, Ayieni O, Petrisor BA, Bhandari M. Femoral neck shortening after fracture fixation with multiple cancellous screws: incidence and effect on function. *J Trauma* 2008;64:163–9.
- [4] Szita J, Cserhati P, Bosch U, Manninger J, Bodzay T, Fekete K. Intracapsular femoral neck fractures: the importance of early reduction and stable osteosynthesis. *Injury* 2002;33 Suppl 3:C41–6.
- [5] Haidukewych GJ, Rothwell WS, Jacofsky DJ, Torchia ME, Berry DJ. Operative treatment of femoral neck fractures in patients between the ages of fifteen and fifty years. *J Bone Joint Surg Am* 2004;86-A:1711–6.
- [6] Bonnaire FA, Weber AT. Analysis of fracture gap changes, dynamic and static stability of different osteosynthetic procedures in the femoral neck. *Injury* 2002;33(Suppl 3):C24–32.
- [7] Enocson A, Lapidus LJ. The vertical hip fracture - a treatment challenge. A cohort study with an up to 9 year follow-up of 137 consecutive hips treated with sliding hip screw and antirotation screw. *BMC Musculoskelet Disord* 2012;13:171.
- [8] Parker MJ, Porter KM, Eastwood DM, Schembi Wismayer M, Bernard AA. Intracapsular fractures of the neck of femur. Parallel or crossed garden screws? *J Bone Joint Surg Br* 1991;73:826–7.
- [9] Selvan VT, Oakley MJ, Rangan A, Al-Lami MK. Optimum configuration of cannulated hip screws for the fixation of intracapsular hip fractures: a biomechanical study. *Injury* 2004;35:136–41.
- [10] Zlowodzki M, Brink O, Switzer J, Wingerter S, Woodall J Jr, Petrisor BA, et al. The

- effect of shortening and varus collapse of the femoral neck on function after fixation of intracapsular fracture of the hip: a multi-centre cohort study. *J Bone Joint Surg Br* 2008;90:1487–94.
- [11] Berkes MB, Little MT, Lazaro LE, Cymerman RM, Helfet DL, Lorch DG. Catastrophic failure after open reduction internal fixation of femoral neck fractures with a novel locking plate implant. *J Orthop Trauma* 2012;26:e170–6.
 - [12] Glassner PJ, Tejwani NC. Failure of proximal femoral locking compression plate: a case series. *J Orthop Trauma* 2011;25:76–83.
 - [13] Nowotarski PJ, Ervin B, Weatherby B, Pettit J, Goulet R, Norris B. Biomechanical analysis of a novel femoral neck locking plate for treatment of vertical shear Pauwel's type C femoral neck fractures. *Injury* 2012;43:802–6.
 - [14] Liporace F, Gaines R, Collinge C, Haidukewych GJ. Results of internal fixation of Pauwels type-3 vertical femoral neck fractures. *J Bone Joint Surg Am* 2008;90:1654–9.
 - [15] Fracture and dislocation compendium. Orthopaedic Trauma Association Committee for Coding and Classification. *J Orthop Trauma* 1996;10(Suppl 1):v-ix, 1–154.
 - [16] Garden RS. Stability and union in subcapital fractures of the femur. *J Bone Joint Surg Br* 1964;46:630–47.
 - [17] Aminian A, Gao F, Fedoriv WW, Zhang LQ, Kalainov DM, Merk BR. Vertically oriented femoral neck fractures: mechanical analysis of four fixation techniques. *J Orthop Trauma* 2007;21:544–8.
 - [18] Sirkin M, Sanders R, DiPasquale T, Herscovici D Jr. A staged protocol for soft tissue management in the treatment of complex pilon fractures. *J Orthop Trauma* 1999;13:78–84.
 - [19] Alves T, Neal JW, Weinhold PS, Dahners LE. Biomechanical comparison of 3 possible fixation strategies to resist femoral neck shortening after fracture. *Orthopedics* 2010;33(4).
 - [20] Scheck M. Intracapsular fractures of the femoral neck. Comminution of the posterior neck cortex as a cause of unstable fixation. *J Bone Joint Surg Am* 1959;41-a:1187–200.
 - [21] Alho A, Benterud JG, Rønningen H, Høiseth A. Prediction of disturbed healing in femoral neck fracture. Radiographic analysis of 149 cases. *Acta Orthop Scand* 1992;63:639–44.
 - [22] Upadhyay A, Jain P, Mishra P, Maini L, Gautum VK, Dhaon BK. Delayed internal fixation of fractures of the neck of the femur in young adults. A prospective, randomised study comparing closed and open reduction. *J Bone Joint Surg Br* 2004;86:1035–40.
 - [23] Barei DP, Schildhauer TA, Nork SE. Noncontiguous fractures of the femoral neck, femoral shaft, and distal femur. *J Trauma* 2003;55:80–6.
 - [24] Bedi A, Karunakar MA, Caron T, Sanders RW, Haidukewych GJ. Accuracy of reduction of ipsilateral femoral neck and shaft fractures—an analysis of various internal fixation strategies. *J Orthop Trauma* 2009;23:249–53.
 - [25] Barnes R, Brown JT, Garden RS, Nicoll EA. Subcapital fractures of the femur. A prospective review. *J Bone Joint Surg Br* 1976;58:2–24.
 - [26] Holmberg S, Kalen R, Thorngren KG. Treatment and outcome of femoral neck fractures. An analysis of 2418 patients admitted from their own homes. *Clin Orthop Relat Res* 1987;(218):42–52.
 - [27] Collinge CA, Mir H, Reddix R. Fracture morphology of high shear angle “vertical” femoral neck fractures in young adult patients. *J Orthop Trauma* 2014;28:270–5.
 - [28] Probe R, Ward R. Internal fixation of femoral neck fractures. *J Am Acad Orthop Surg* 2006;14:565–71.