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ORIGINAL ARTICLE

Retrospective Study

Management and prevention of iatrogenic ipsilateral femoral neck fracture during intramedullary nailing of femoral shaft

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Abstract

BACKGROUND

Iatrogenic ipsilateral femoral neck fractures are rare but significant complications associated with intramedullary nailing of femoral shaft fractures. These injuries may occur intraoperatively due to technical errors or be diagnosed postopera-

tively, often with delayed recognition.

AIM
To identify etiological factors contributing to iatrogenic femoral neck fractures during femoral shaft nailing and to propose a structured management algorithm for prevention and treatment.

METHODS
A retrospective analysis was conducted on 1342 femoral interlocking nail procedures performed between 2017 and 2021. Eighteen cases (1.3%) of iatrogenic femoral neck fractures were identified. Clinical data, imaging findings, surgical techniques, and fixation methods were reviewed. Fractures were classified based on timing of diagnosis (intraoperative *vs* postoperative) and displacement status.

RESULTS
The most common causes included erroneous entry points (6 cases), inadvertent jig hammering (5 cases), misdirected nail manipulation (3 cases), and hoop stress-related fractures (3 cases). Fourteen fractures were diagnosed intraoperatively, while four were identified postoperatively. Fixation strategies included long proximal femoral nails (10 cases), cannulated cancellous screws (6 cases), and salvage techniques such as hemiarthroplasty (1 case). Delayed diagnosis correlated with increased operative time and poorer outcomes ($P < 0.05$), though union rates at 6 months and 12 months were statistically comparable across fixation methods.

CONCLUSION
Iatrogenic femoral neck fractures during femoral nailing are preventable with meticulous technique, appropriate implant selection, and vigilant intraoperative imaging. A standardized preoperative and intraoperative protocol can reduce incidence and improve outcomes.

Key Words: Femur; Interlock nail; Femoral neck fracture; Femoral shaft fracture; Iatrogenic

Core Tip: Iatrogenic femoral neck fractures, though rare, are a notable complication during or after femoral shaft fixation with interlocking nails. This study highlights key technical errors-erroneous entry points, misdirected nail manipulation, and forceful jig hammering-as primary causes. Early recognition and adherence to surgical precision can prevent such fractures. Timely diagnosis and appropriate fracture management are essential to optimize patient outcomes and reduce postoperative morbidity.

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INTRODUCTION

Intramedullary nailing is the most commonly employed surgical procedure for managing fractures of the femoral shaft in adults[1,2]. Nailing is a technically demanding technique that must be performed appropriately to prevent complications. An iatrogenic femoral neck fracture is a rare preventable complication following a femur interlocking nail procedure[3,4]. It can occur primarily due to improper surgical techniques, such as erroneous entry or hammering the awl while making the entry point, the improper introduction or manipulation of the nail, the inadequate reaming and or inadvertent hammering of the nail[5,6].

The other entity is the presence of a subclinical occult fracture that may get missed preoperatively; hence, it mandates preoperative computed tomography (CT) assessment in high-velocity double impact injuries or highly suspicious cases[7, 8]. It may help us get informed consent to avoid medicolegal issues and effectively plan surgical management. The neck fracture and the avascular necrosis of the femoral head are the preventable devastating complications following the interlock nailing procedure[9-11]. Most of the iatrogenic neck fractures are diagnosed within the intraoperative period of operating femoral shaft fracture[12,13]. However, the inadequate intraoperative screening at the end of the surgery increases the incidence of delayed diagnosis of such fractures.

This study aims to systematically identify and classify the etiological factors contributing to iatrogenic ipsilateral femoral neck fractures during intramedullary nailing of femoral shaft fractures, and to evaluate their impact on surgical outcomes. Importantly, this study proposes a practical algorithm for early detection and tailored intervention, addressing a clinically underreported complication.

MATERIALS AND METHODS

This retrospective study was conducted at a tertiary trauma center between January 2017 and December 2021, following institutional ethical committee approval (No. Dr. MGR-ERI/SLMCH/2025/005 dated March 5, 2025). The study aimed to identify the incidence, etiological factors, and management strategies for iatrogenic ipsilateral femoral neck fractures occurring during or after intramedullary nailing of femoral shaft fractures.

Study population

A total of 1342 adult patients who underwent closed antegrade intramedullary nailing for femoral shaft fractures were included. Inclusion criteria comprised skeletally mature individuals with isolated femoral shaft fractures treated with interlocking nails. Patients with pre-existing femoral neck fractures, pathological fractures, or polytrauma involving the pelvis or acetabulum were excluded. The flow of selection of patients in the study is given in Figure 1.

Data collection

Clinical records, operative notes, and imaging archives were reviewed to identify cases of iatrogenic femoral neck fractures. Fractures were classified based on timing of diagnosis (intraoperative *vs* postoperative), displacement status (displaced *vs* undisplaced), and fixation method. Preoperative imaging included standard anteroposterior and lateral pelvic radiographs. In suspicious cases, additional fluoroscopic views or CT scans were performed to exclude occult neck fractures.

Surgical technique

All procedures were performed on a fracture table under fluoroscopic guidance. The piriformis fossa was used as the standard entry point. Reaming was performed with incremental sizing, maintaining a 1.5 mm clearance over the intended nail diameter. Nail insertion was performed under controlled impaction, avoiding excessive force. Intraoperative imaging was used to confirm reduction and detect any proximal femoral complications.

Fracture identification and classification

Iatrogenic neck fractures were diagnosed either intraoperatively (*via* fluoroscopy) or postoperatively (*via* radiographs within six weeks). Etiological factors were categorized as: (1) Erroneous entry point; (2) Misdirected nail manipulation; (3) Inadvertent jig hammering; (4) Hoop stress-related fractures; and (5) Unexplained causes. Each case was reviewed for surgical technique, implant type, and intraoperative events.

Management protocol

Fracture management was individualized based on displacement, timing of diagnosis, and implant status as illustrated in Figure 2. Undisplaced fractures diagnosed intraoperatively were managed with long proximal femoral nails. Displaced fractures diagnosed after nail insertion were treated using cannulated cancellous screws *via* the "miss-the-nail" technique. In select cases with poor bone quality or delayed diagnosis, salvage procedures such as hemiarthroplasty were employed. Postoperative follow-up included radiographic assessment at 6 weeks, 3 months, 6 months, and 12 months.

Statistical analysis

Descriptive statistics were used to summarize demographic and clinical variables. Statistical analysis was performed using descriptive and inferential methods to evaluate associations between fracture characteristics, timing of diagnosis, fixation strategies, and clinical outcomes. Categorical variables such as fracture etiology, displacement status, and fixation method were analyzed using the χ^2 test, while Fisher's exact test was applied when expected cell counts were below five to ensure validity in small sample comparisons. Continuous variables, including surgical duration, were assessed using independent samples *t*-tests to determine their impact on fracture union and complication rates. A P value of less than 0.05 was considered statistically significant.

RESULTS

Out of 1342 patients who underwent closed antegrade intramedullary nailing for femoral shaft fractures, 18 cases (1.3%) of iatrogenic ipsilateral femoral neck fractures were identified. The cohort included 14 males and 4 females, with a mean age of 41.6 years (range: 19-63 years). All patients had preoperative pelvic radiographs of acceptable diagnostic quality; however, none revealed a pre-existing femoral neck fracture. In six cases with high clinical suspicion, additional fluoroscopic views or preoperative CT scans were performed to exclude occult fractures.

Timing and mechanism of injury

Fractures were diagnosed intraoperatively in 14 cases, immediately postoperatively in 1 case, and during follow-up (within 4 weeks) in 3 cases. The etiological breakdown included erroneous entry point (6 cases) as shown in Figure 3, inadvertent jig hammering (5 cases) as shown in Figure 4, misdirected nail manipulation (3 cases), hoop stress-related fractures (3 cases) as shown in Figure 5, and one case of unexplained origin. Intraoperative fractures were typically identified during final fluoroscopic checks, while postoperative fractures were detected on follow-up radiographs without intervening trauma Figure 6. The list of eitiologies contributing to iatrogenic fractures during femoral nailing is

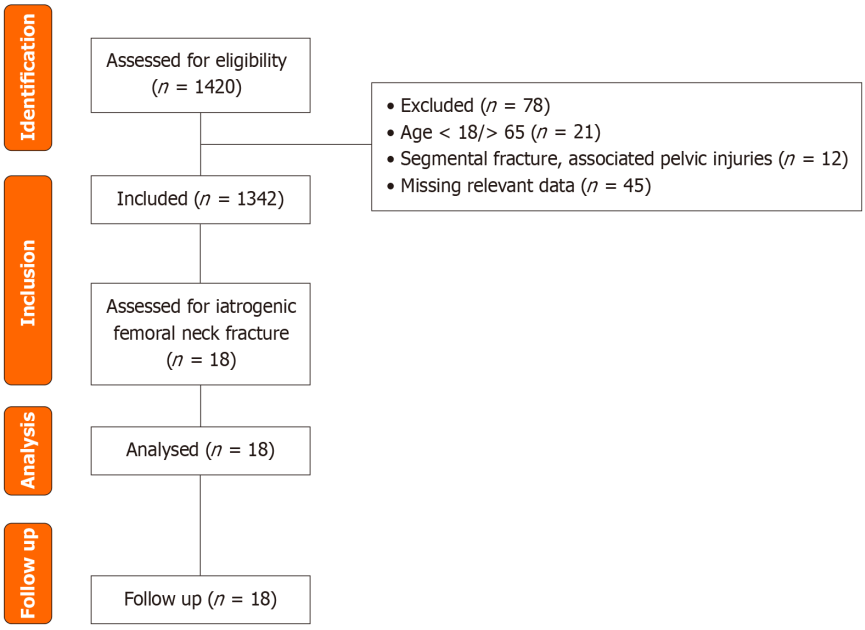


Figure 1 Flow diagram of patient inclusion and classification. Flowchart illustrating the selection process of 1342 patients undergoing femoral shaft nailing, with identification of 18 cases of iatrogenic ipsilateral femoral neck fractures. Cases are stratified by timing of diagnosis and fracture etiology.

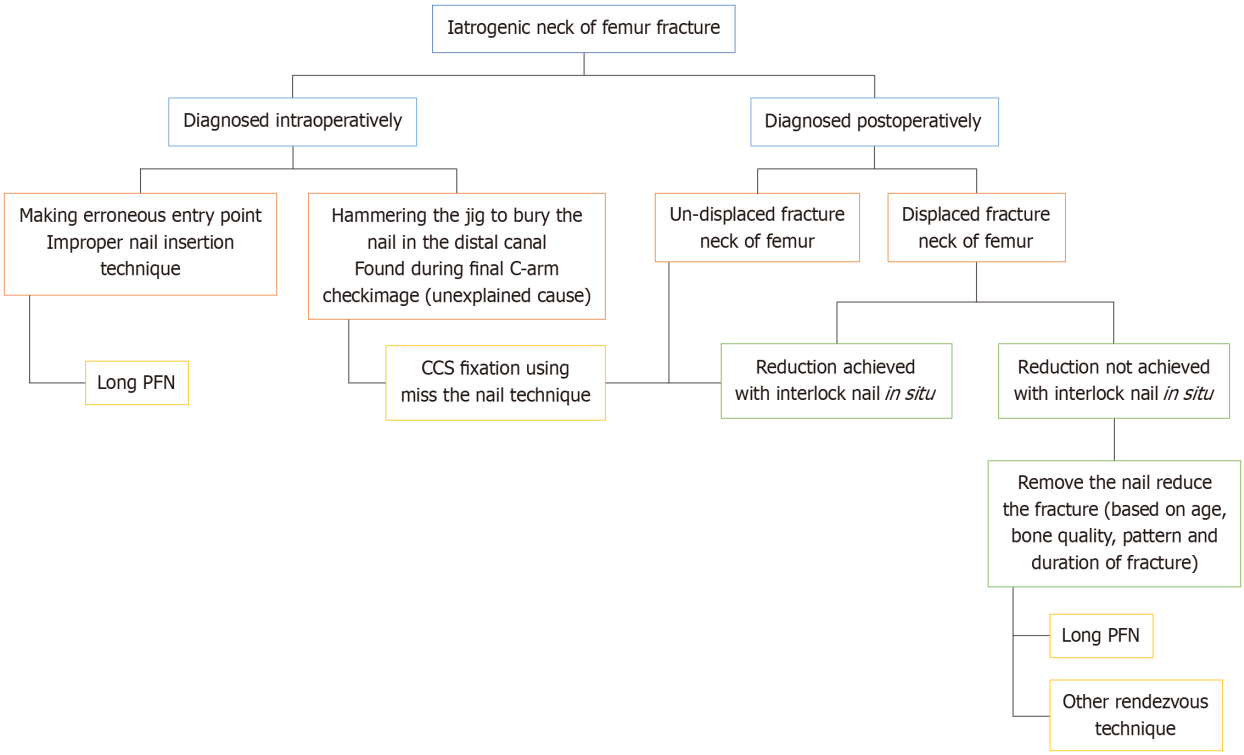


Figure 2 Algorithm for management of iatrogenic femoral neck fractures. Decision-making flowchart outlining management strategies based on fracture displacement, timing of diagnosis, and implant status. Includes options for long proximal femoral nail, cannulated cancellous screw fixation, and salvage techniques. PFN: Proximal femoral nail; CCS: Cannulated cancellous screw.

listed in Table 1.

Fracture classification and fixation strategy

Among the 18 cases, 11 were undisplaced and 7 were displaced. Fixation methods included long proximal femoral nails (10 cases), cannulated cancellous screws (6 cases) as shown in Figure 6, bipolar hemiarthroplasty (1 case) as shown in Figure 7, and dual implant technique with limited contact dynamic compression plate (1 case) as shown in Figure 7. The "miss-the-nail" technique was employed in cases where the interlock nail remained *in situ* and removal was deemed risky

Table 1 Etiological classification of iatrogenic femoral neck fractures (*n* = 18)

Etiology	Number of cases	Timing of diagnosis	Displacement status	Fixation method used
Erroneous entry point	6	Intraoperative	4 undisplaced, 2 displaced	Long PFN (5), CCS (1)
Inadvertent jig hammering	5	Intraoperative	3 undisplaced, 2 displaced	Long PFN (3), CCS (2)
Misdirected nail manipulation	3	Intraoperative	2 undisplaced, 1 displaced	Long PFN (2), CCS (1)
Hoop stress-related fracture	3	Postoperative (≤ 4 weeks)	1 undisplaced, 2 displaced	CCS (2), hemiarthroplasty (1)
Unexplained origin	1	Immediate postoperative	Displaced	CCS (1)

PFN: Proximal femoral nail; CCS: Cannulated cancellous screw.

due to potential displacement as shown in Figure 5 and Table 2.

Radiographic and functional outcomes

Immediate postoperative imaging confirmed stable fixation in 15 cases and unstable fixation in 3 cases. Radiographic union of both shaft and neck fractures was achieved in 14 cases by 12 months. Four cases showed delayed union or incomplete healing at the neck site, including one requiring salvage hemiarthroplasty due to poor bone quality and late diagnosis. The average neck-shaft angle was 125° ± 10°, with no significant difference between fixation groups ($P = 0.342$) as shown in Table 3.

Statistical associations

Union rates at 6 months and 12 months were not significantly associated with fracture etiology, timing of diagnosis, or fixation method ($P > 0.05$). However, delayed diagnosis and inappropriate implant selection were significantly associated with increased operative time and poorer functional outcomes ($P < 0.05$). The mean surgical duration was notably higher in cases requiring implant exchange or salvage procedures as shown in Table 4.

Complications and observations

No cases of avascular necrosis were documented during the follow-up period, although longer-term surveillance is warranted. One patient developed superficial wound infection, managed conservatively. The study highlighted that technical errors, particularly medialized entry points and forceful jig hammering, were preventable contributors to iatrogenic neck fractures. The use of intraoperative fluoroscopy and adherence to reaming protocols were critical in early detection and prevention.

DISCUSSION

The standard treatment for femoral shaft fractures is intramedullary interlocking nailing of the femur. The prevalence of ipsilateral shaft and neck fracture is about 2.5%-6% out of all femoral shaft fractures[14]. According to researchers, delayed diagnosis of this association ranges from 19% to 31%[15,16]. On the initial survey, these fractures are diagnosed using X-rays, but occult or undisplaced fractures may not be evident on X-rays. Hence, CT scan is needed to detect such fractures when there is strong suspicion. A femoral neck fracture while doing or after intramedullary nailing has been considered an iatrogenic complication, and it is rarely reported in the literature[3,17-19]. In our series, all cases had preop X-rays of good quality in both views and a new anteroposterior and axial view under fluoroscopy to rule out the presence of a femoral neck fracture.

The pioneer of femoral nailing, Gerhard Küntscher, warned about iatrogenic femoral neck fractures and recommended a lateral-based greater trochanter entry point[20]. Later, Winquist *et al*[21] described the piriformis fossa entry point for antegrade femoral nails. Subsequently, multiple authors have reported the potential for iatrogenic femoral neck fractures associated with a piriformis starting point, with a 1% incidence[4,22].

Harper and Henstorf[23] stated that iatrogenic neck fracture could be produced due to a misdirected introduction of the nail into the proximal canal, resulting in violation of the medial cortex of the femoral neck. Christie and Court-Brown [24] insist on the importance of avoiding an oblique insertion of the nail. The Kuntscher, Grosse-Kempf, and Russell-Taylor nails were of straight-line nail designs, so the optimal entry in these cases was the piriformis fossa. Also, the rigidity of these nails could be a contributing factor to this unusual complication. However, the nails with lateral bend should be inserted laterally or over the tip of the trochanter[25].

Tornetta *et al*[26] suggest a preoperative protocol that includes an anteroposterior internal rotation X-ray of the hip, a fine cut (2-mm) CT scan through the femoral neck, and an intraoperative fluoroscopic lateral view of the hip before the procedure. Further, an anteroposterior and lateral X-ray of the hip should be obtained after proximal interlocking screw fixation before shifting from the fracture table. At follow-up, anteroposterior and lateral radiographs should be done, and the patient should be clinically assessed about hip pain with any concerning findings or suspicious in X-ray; the patient is subjected to repeat computed tomography. The results of the study appear to be promising, with improved sensitivity

Table 2 Association between timing of diagnosis and fixation strategy, *n* (%)

Timing of diagnosis	Number of cases	Common fixation method(s)	Mean surgical duration (minute)	Union achieved at 12 months
Intraoperative	14	Long PFN, CCS	110 ± 15	12/14 (85.7)
Immediate post-operation	1	CCS	125	1/1 (100)
Delayed post-operation (≤ 4 weeks)	3	CCS, hemiarthroplasty	145 ± 20	1/3 (33.3)

PFN: Proximal femoral nail; CCS: Cannulated cancellous screw.

Table 3 Outcome analysis based on fixation method

Fixation method	Number of cases	Displacement status	Union at 6 months	Union at 12 months	Complications observed
Long proximal femoral nail	10	6 undisplaced, 4 displaced	9/10	9/10	1 delayed union
Cannulated cancellous screws	6	4 undisplaced, 2 displaced	5/6	5/6	1 superficial infection
Hemiarthroplasty + plate	1	Displaced	NA	NA	No AVN, satisfactory function

NA: Not available; AVN: Avascular necrosis.

Table 4 Statistical correlation of surgical variables with outcome

Variable	*P* value	Interpretation
Timing of diagnosis *vs* union	> 0.05	Not statistically significant
Fixation method *vs* union	> 0.05	No significant difference in union rates
Surgical duration *vs* outcome	< 0.05	Longer duration is associated with poorer outcomes
Displacement status *vs* AVN	NA	No AVN observed during follow-up

NA: Not available; AVN: Avascular necrosis.

and a significant reduction in delay of diagnosis by more than 90%.

The iatrogenic neck fracture diagnosed before the complete insertion of interlock nail should be managed with long proximal femoral nail[4]. However, once the interlock nail has been fully inserted, the diagnosed neck fracture should be fixed as early as possible using the cannulated cancellous screw since removing the nail may displace the neck fracture and increase the risk of avascular necrosis of the head. Also, the use of the long proximal femoral nail in this scenario may results in significant malreduction of the neck fracture[27]. It has been found that postoperatively diagnosed iatrogenic neck femur fracture can be managed effectively with cannulated cancellous screws but delay in such diagnosis adversely affect the outcome[6,27]. Doing proximal femur nailing in such cases increases the operative time, blood loss, infection rate and may also disturb the primary shaft fracture union while removing the interlocking nail. We must consider the various options of rendezvous dual implanting techniques based upon the fracture pattern, the time elapsed since fracture, and patient risk factors[22].

The preventive measures include making an appropriate entry point with the bone awl under C-arm guidance, which should be confirmed in both views. The internal rotation of the proximal fragment using Steinmann pin visualizes the entire neck morphology and the entry site clearly. The awl should be advanced with rotatory movement, trajected towards the medullary canal without hammering it. The reamer size should be increased consecutively with an increasing trend of 0.5 mm size, and it should start with a minimal size of 8 mm. The entire medullary canal should be reamed with a size of 1.5 mm, more incredible than that of the desired nail size. The nail should be inserted only after adequate reduction and appropriate reaming; the manipulation with the nail to achieve the reduction should be avoided. If hammering is needed, the nail must be advanced 1-1.5 cm into the canal on each impaction with the hammer. During hammering, the degree of the nail advancing should be monitored. If it is not advancing, one should check the reamer size or decrease the nail diameter of the next lesser size, and it should be alternating with rotating the jig 180°, thereby reducing the stress at the nail-bone interface at the entry site. Proximal part of the femur should be reamed with the

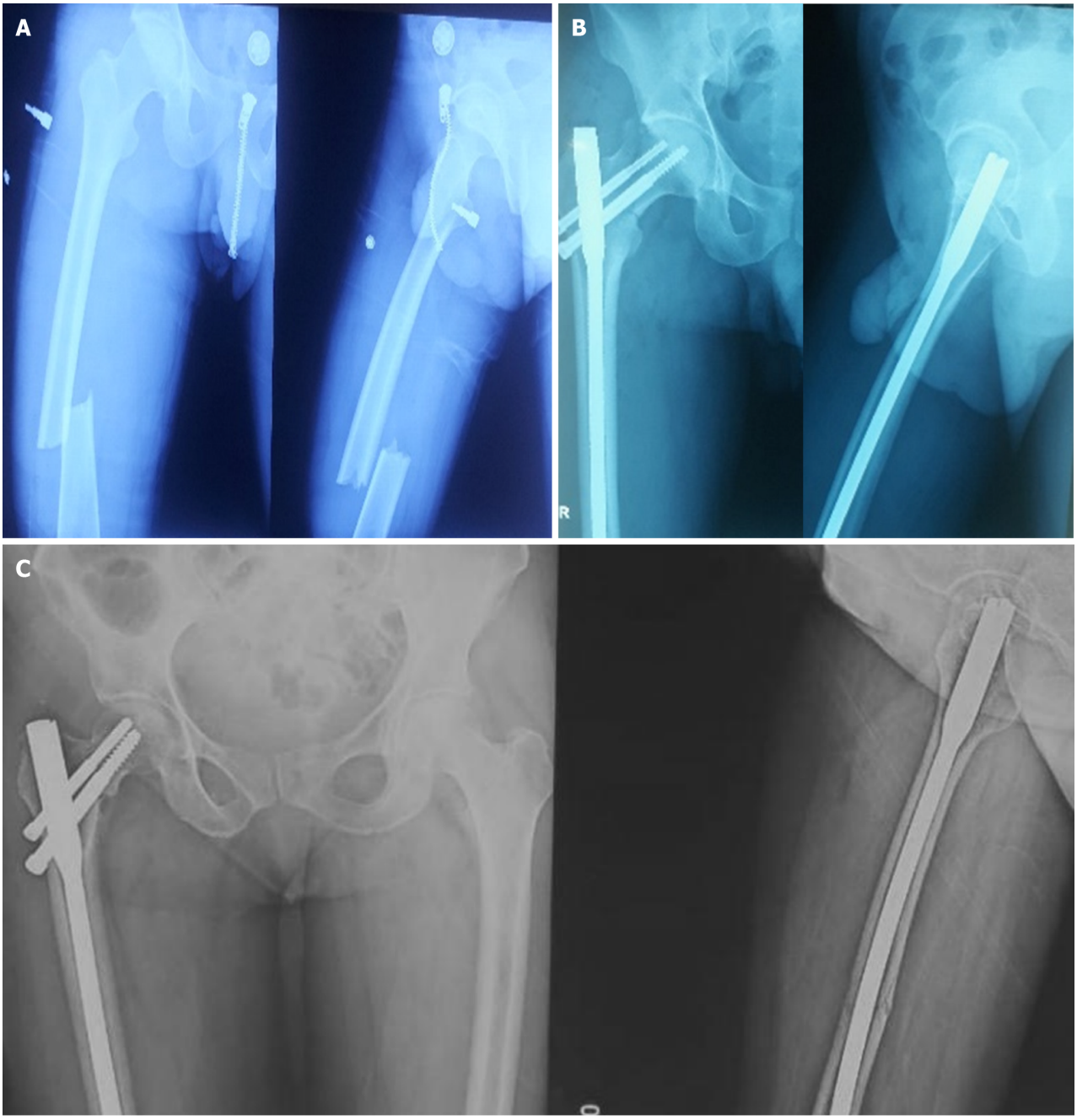


Figure 3 Case of iatrogenic neck fracture due to erroneous entry point. A: Preoperative radiograph showing femoral shaft fracture (Arbeitsgemeinschaft für Osteosynthesefrage 32-A3); B: Intraoperative detection of neck fracture caused by medialized entry point; managed with long proximal femoral nail; C: One-year follow-up showing union at both shaft and neck fracture sites.

appropriate size reamer, which depends on the thickness of the proximal part of the nail. This appropriate reaming will avoid the hammering process and prevent nail hoop stress.

This study has several limitations inherent to its retrospective and descriptive design. First, the relatively small number of iatrogenic femoral neck fracture cases (n = 18) limits the statistical power to detect significant associations between specific etiological factors and clinical outcomes. Second, the absence of a control group precludes comparative analysis with patients who underwent uneventful femoral nailing, thereby restricting causal inference. Third, the classification of fracture mechanisms was based on intraoperative documentation and postoperative imaging, which may be subject to reporting bias or interobserver variability. Additionally, the study did not employ a standardized radiological protocol across all cases, and the use of preoperative CT was selective rather than routine, potentially underestimating the incidence of occult pre-existing neck fractures. Finally, the follow-up duration was insufficient to assess long-term complications such as avascular necrosis of the femoral head. Future prospective studies with larger cohorts, uniform imaging protocols, and extended follow-up are warranted to validate these findings and refine preventive strategies.

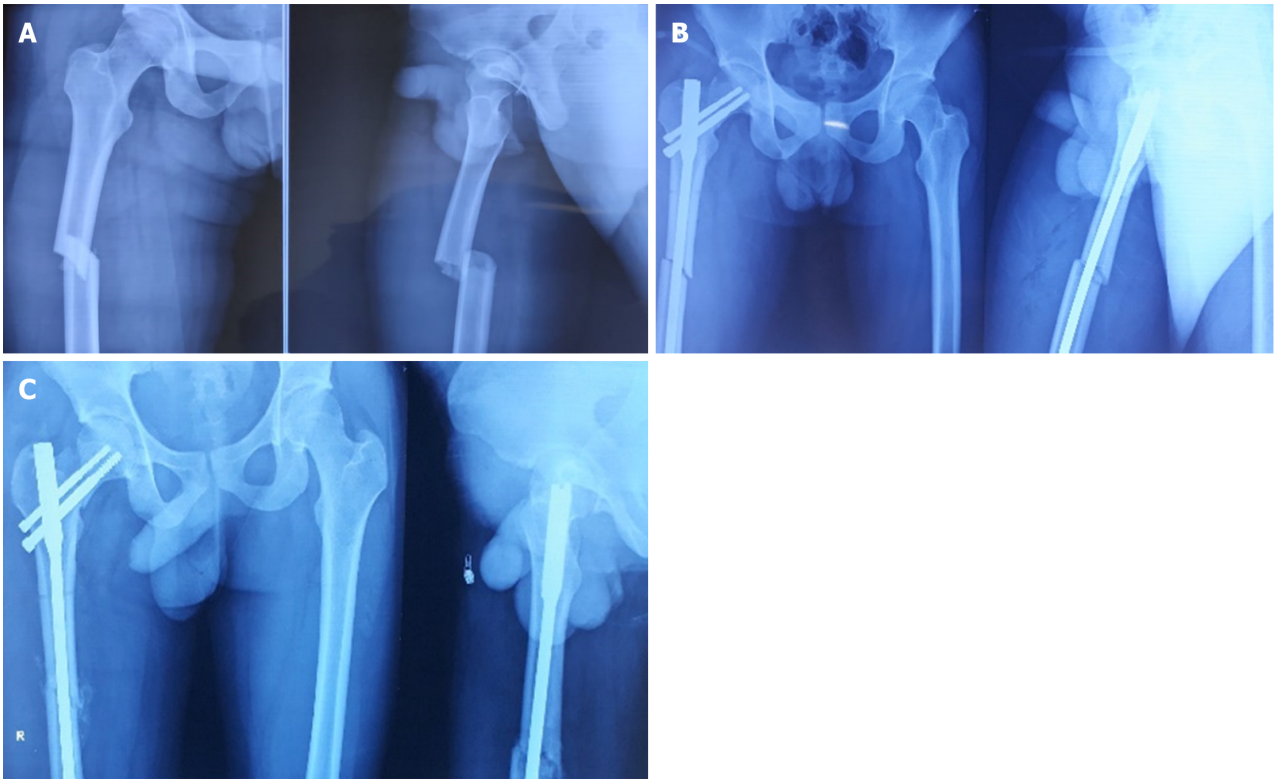


Figure 4 Neck fracture induced by inadvertent jig hammering. A: Preoperative radiograph of femoral shaft fracture (Arbeitsgemeinschaft für Osteosynthesefrage 32-A2); B: Iatrogenic neck fracture resulting from forceful jig impaction; nail removed and long proximal femoral nail inserted; C: One-year follow-up showing shaft union with incomplete neck healing.

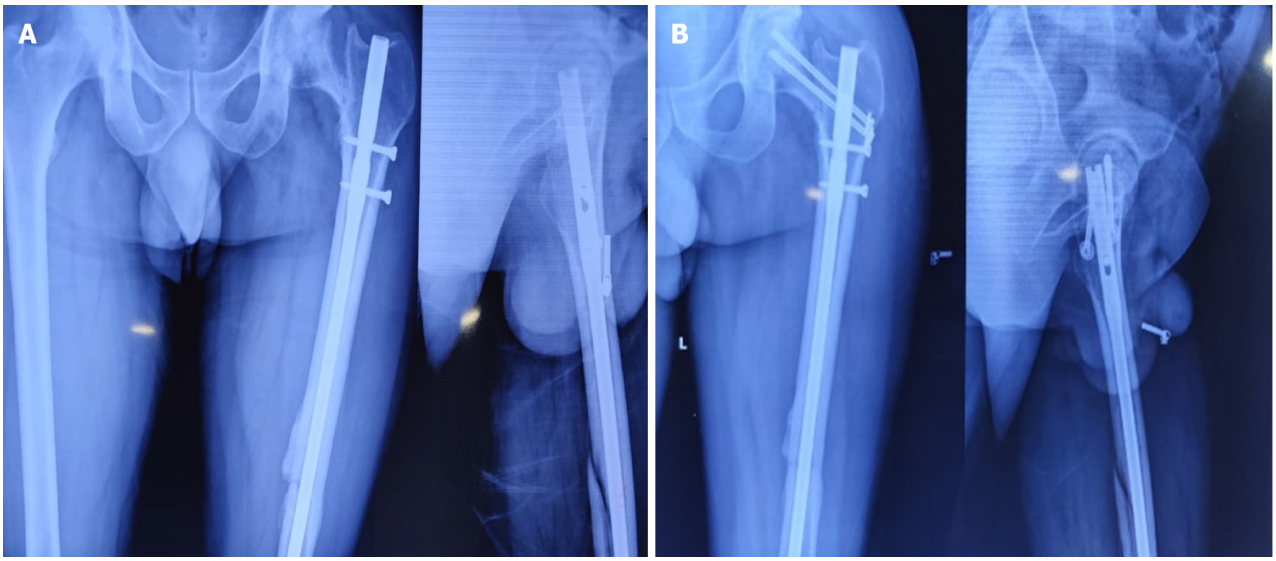


Figure 5 Missed neck fracture diagnosed postoperatively. A: Two-week postoperative radiograph revealing displaced femoral neck fracture missed during initial evaluation; B: Fixation using two cannulated cancellous screws *via* "miss-the-nail" technique.

CONCLUSION

Iatrogenic ipsilateral femoral neck fractures during intramedullary nailing of femoral shaft fractures, though uncommon, represent a preventable surgical complication with significant implications for patient outcomes. This study highlights key technical errors, medialized entry points, misdirected nail manipulation, and forceful jig hammering, as primary contributors. Early intraoperative recognition, adherence to precise surgical technique, and appropriate implant selection are critical to minimizing risk. The proposed management algorithm offers a structured approach to timely diagnosis and tailored fixation strategies, including the use of long proximal femoral nails and "miss-the-nail" screw techniques. While union rates were not significantly affected by fracture etiology or timing of diagnosis, delayed recognition was associated

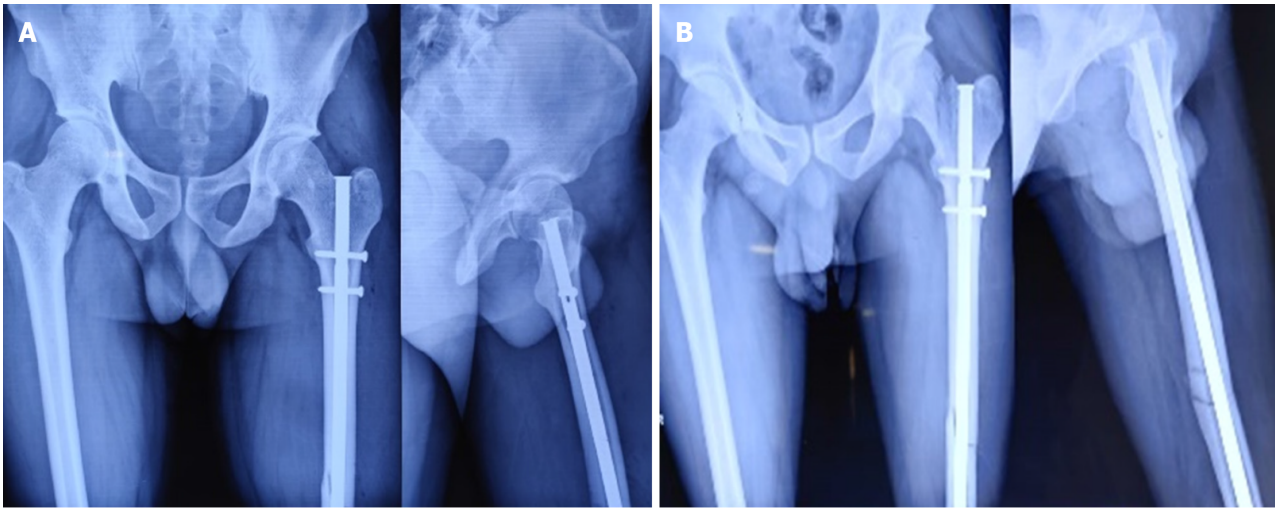


Figure 6 Delayed hoop stress fracture presentation. A: Immediate postoperative radiograph showing no neck fracture; B: Four-week follow-up revealing fracture at femoral neck due to hoop stress, without intervening trauma.

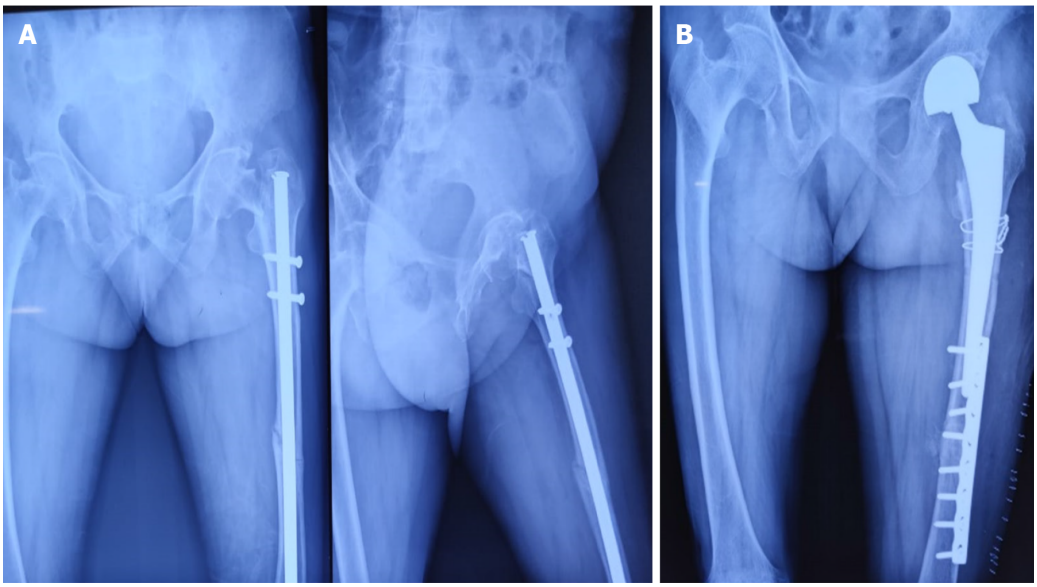


Figure 7 Salvage management with hemiarthroplasty and plate fixation. A: Displaced neck fracture diagnosed at four weeks in an osteoporotic patient; B: Managed with bipolar hemiarthroplasty for the neck and limited contact dynamic compression plate for the shaft.

with increased operative time and complexity. Preoperative imaging protocols, intraoperative fluoroscopic vigilance, and postoperative radiographic scrutiny should be integral to femoral nailing workflows. Ultimately, heightened awareness and surgical discipline, especially among early-career surgeons, can reduce iatrogenic morbidity and improve the safety profile of femoral shaft fracture fixation.

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